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Diagnostic accuracy of haemoglobin colour strip (HCS-HLL), a digital haemoglobinometer (TrueHb) and a non-invasive device (TouchHb) for screening patients with anaemia

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ABSTRACT

Aim Estimation of haemoglobin (Hb) remains a challenge, particularly in outreach settings. There is a need to have a simple and cost-effective device to detect anaemia. Three devices (haemoglobin colour scale (HCS)-HLL (Hindustan Lifecare Limited), TrueHb V.1.1, TouchHb Alpha 1.1- non-invasive) have been developed in India recently. This study aimed to determine the diagnostic accuracy of these tests (index) for the screening of anaemia against haematological autoanalyzer (reference).

Methods The study was conducted in four medical colleges of India. All consenting adult patients (>18 years of age) undergoing routine investigations were included. Each patient underwent the reference test and at least one index test. Outcome assessors for the index tests were blinded to the results of the reference test. Diagnostic accuracy was calculated using cut-offs proposed by WHO.

Results A total of 5244 patients underwent the reference test while HCS-HLL, TrueHb and TouchHb tests were conducted on 2745, 2331 and 2874 patients respectively. The positive likelihood ratio of HCS-HLL using capillary blood (1.2), venous blood (1.7) and TouchHb (1.5) was lower than TrueHb capillary (3.7; 95% CI 3.3 to 4.2) and venous blood (5.7; 95% CI 4.9 to 6.6). TrueHb had a sensitivity of 74.4% (95% CI 71.9% to 76.8%) for venous and 82.0% (95% CI 79.8% to 89.2%) for capillary samples. The specificity was high (>75.0%). The area under receiver operating characteristic was close to 80.0%. Consistent results were seen for detection of severe anaemia.

Conclusions The digital method (TrueHb) emerged as a better diagnostic method for screening anaemia. Its effectiveness should be established in outreach settings before further recommendation.

INTRODUCTION

Anaemia continues to be a major public health problem globally. Iron-deficiency anaemia is among the top three major causes of disability in the world leading to an estimated loss of 42.2 million disability-adjusted life years in 2011.[1] South-east Asia is the worst affected region and estimates suggest that in India, 74.3% preschool children, 49.7% pregnant women, 52% non-pregnant women and 24% of men are anaemic.[2] The primary cause of anaemia is iron deficiency although malaria, parasitic infections and other nutritional deficiencies, and haemoglobinopathies are also contributing factors.[2] Anaemia leads to poor pregnancy outcomes, impaired physical and cognitive development in children, increased risk of morbidity in children and reduced work productivity, posing a threat to health and the economy.[3]

Haemoglobin (Hb) estimation is used to diagnose anaemia. Any intervention to treat anaemia is largely based on the level of Hb.[4] Assessment of palmar, nail bed and tongue pallor is a traditional method for the detection of anaemia. In national programmes that have a focus on pregnant women and children, detection of anaemia by Sahli's haemoglobinometer or by standard haemoglobin colour scale (HCS) are established methods.[4] However, the accuracy of these methods is questionable.[5–7] Despite this limitation, these devices are still in use since an efficient and cost-effective method for detection of anaemia is yet to be incorporated in national programmes.[5 8]

Most reliable methods for Hb estimation require the presence of an equipped laboratory. Moreover, these methods are not always cost effective and have operational challenges.[5 8] It is important to have a simple, cost-effective, user-friendly and portable diagnostic aid to detect anaemia in set-ups with no or minimal laboratory facilities.[8]

Three different devices for detection of anaemia have been developed recently. *HCS* was originally developed by the WHO. This has been improved by Hindustan Lifecare Limited (HLL), India, and named the HCS-HLL device. Colour shades on the card were developed for Indian population (P. Gupta, personal communication. India: Hindustan Lifecare Limited (HLL), 2015).[5] *TrueHb* 'Hemometer System' *V.1.1* (manufactured by Wrig Nanosystems, New Delhi, India), is another method which works like a conventional glucometer based on the principle of reflectance photometry. It can be charged like a mobile phone and allows up to 300 tests after which it has to be recharged.[9] *ToucHb Version Alpha 1.1* (manufactured by Biosense Technologies, Thane West, India), a non-invasive device, captures the picture of conjunctiva with the help of a mobile camera and uses the method of reflectance photometry to estimate the Hb content in blood.[10]

These methods have been evaluated in limited controlled settings and the results were found to be

satisfactory (P. Gupta, personal communication, 2015).[5] However, none of them could be recommended for use at the national level in the absence of evidence from large studies. Hence, a study was conceptualised to determine the diagnostic accuracy of HCS-HLL, digital haemoglobinometer (TrueHb) and a non-invasive device (TouchHb) for screening of anaemia.

METHODS

This study was a prospective diagnostic accuracy study conducted between August 2014 and January 2015 at four tertiary care hospitals across India—Pandit Bhagwat Dayal Sharma Medical College & Hospital (PGIMS), Rohtak, Haryana; Jawaharlal Institute of Postgraduate Medical Education and Research (JIPMER), Puducherry; Calcutta Medical College, Kolkata, West Bengal; Post Graduate Institute of Medical Research (PGIMER), Chandigarh. The four hospitals were chosen purposively based on case load, facilities for performing the reference test (autoanalyzer in this case) and willingness to be a part of the study.

Recruitment of study subjects

The study population included all adult patients attending the haematology laboratory for routine investigations. Consecutive patients who underwent any investigation using automated autoanalyzer (reference test) as advised by the on-duty medical officer (who was independent of the study) were considered. Patients (>18 years) who met the eligibility criteria and gave written informed consent were recruited for the study. Pregnant women, children, seriously ill patients and those with known bleeding diathesis were excluded. Age above 60 years and known cases of jaundice were additional exclusion criteria for the non-invasive (TouchHb) device only.

For the purpose of the study, each patient underwent either one or two index tests apart from the reference test. When two index tests were performed, one was always invasive and the other non-invasive. To choose between the invasive tests (HCS-HLL and TrueHb), alternate days were earmarked to avoid any bias. The non-invasive test was done every day. The index tests were always performed before the reference test. The blood samples for the index tests and the reference test were collected in the same sitting and there was no treatment administered between the index and the reference test.

Diagnostic tests

Reference test (gold standard)

Haematological autoanalyzer was selected as the reference test. This system is an automated blood cell counter which measures Hb using a non-cyanide method. To perform this test 2 mL of venous blood was collected under all aseptic condition in an EDTA vial. The samples were analysed within 24 h of sample collection as per the standard operational guidelines for the machine using the reagents/kits provided with the instrument as recommended by manufacturers. The procedural manual for the testing process was followed. It was ensured that a sufficient sample quantity was obtained and the apparatus were washed and cleaned rigorously between tests and reagents were stored under the stated conditions and used within the recommended time frame. The calibration and quality control programmes were run as recommended and a calibration guide was used to generate the reference values. The autoanalyzers used in the study were manufactured by Beckman Coulter LH 780 (Chandigarh), Sysmex XS 1000i (Kolkata), Mindray BC-5800 (Rohtak) and Sysmex XT 20001 (Puducherry).

Index tests

A standard protocol was followed for performing the three index tests.

- Invasive tests—Hb concentration was measured using capillary and venous blood samples for the invasive index tests. Venous sample was used for the reference test (autoanalyzer).

To collect capillary blood, the tip of the middle finger was cleaned using an isopropyl alcohol-dipped cotton swab. After air drying, it was pricked with a 23 gauge lancet placed in a lancing device prefixed at 4 mm depth. Precautions were taken to avoid pressure on the fingertip so as to avoid haemodilution. The first two to three drops of blood were wiped away to remove tissue fluid and debris. The next two drops of free-flowing blood obtained by skin puncture were used for the tests.

  - *HCS-HLL test:* This device comprises a small card with six shades of red that represent Hb levels at 4.0, 6.0, 8.0, 10.0, 12.0 and 14.0 g/dL respectively. Two drops of capillary blood were placed on the test strip paper to make a stain 1 cm in diameter. After 30 s the colour of blood was matched against the shades on the scale starting from the lightest shade and sliding the blood stain up and down the apertures in the scale until the best colour match was found. The appropriate reading on the scale which matched the drop of the blood was recorded as the Hb value. If the colour lay between two shades on the scale, the lower value was recorded. It was ensured that the readings were taken in a well-lit room by daylight and/or artificial light and direct sunlight was avoided. A clean, dry and fresh strip and lancet were used every time (P. Gupta, personal communication, 2015).
  - *True Hb test:* A drop of blood was placed on the disposable strip. The blood dispersed within the hydrophilic mesh, Hb was extracted out from the red blood cell and with the help of reagents present in the strip, was converted into a complex. The optical reflectance, which is inversely proportional to the concentration of Hb in the sample, was measured and Hb levels read within a minute.[9]

- Non-invasive test

It quantifies the pallor in the eye to estimate Hb in grams (g)/decilitre (dL) of blood. It can estimate Hb ranging from 4 to 15 g/dL with a resolution of 0.5 g/dL. Anything beyond the specified values was shown up as one of the boundary values.[10]

To perform the TouchHb test, participants were asked to retract the lower eyelid of the right eye. The rubber cup surrounding the mobile camera was placed around eye enclosing it to prevent external light from coming inside. Then an image of the exposed conjunctiva was taken with steady hands. The area of the image was selected manually to obtain the digitalised Hb reading.

Sample size

Sample size was estimated assuming the prevalence of anaemia to be 30.0% (as the study included both men and women), sensitivity=80.0%, specificity=80.0% and precision=0.03. A sample size of 2500 was considered adequate for the study to assess the diagnostic accuracy of each method.

Data collection

Data collection was done by eight research staff, who were qualified medical laboratory technicians (two technicians at each site) trained in the study protocol. They recruited the eligible patients after taking written informed consent.

The data collection for reference and index tests was done separately. The research staff performed the index test, entered

Table 1 Classification of anaemia according to WHO and ICMR (haemoglobin values in g/dL)

WHO	No anaemia	Mild anaemia	Moderate anaemia	Severe anaemia
Men	≥130	110–129	80–109	<80
Women	≥120	110–119	80–109	<80
ICMR	≥110	100–109	70–99	<70

ICMR, Indian Council of Medical Research.

the data concurrently in a tablet device (details of tablet device in section on data management and analysis) and electronically transferred to the central team. The data collectors were blinded to the results of the reference test. The reference test was performed by the laboratory technician of the haematology laboratory who was independent of the study team. Data on the reference test were collected by site investigators on paper forms and transferred electronically to the central team. Data from both the sources were then matched based on the unique identification number given to each study participant.

Quality assurance

The study team was oriented to the study and trained in a common workshop at the All India Institute of Medical Sciences (AIIMS), New Delhi, in August 2014. The facilitators for the training included the investigators as well as the technical experts from companies who had supplied the devices. On-site monitoring and trainings were conducted by these facilitators as well as the site investigators. The two sets of data (reference test and index tests) were kept separate and blinded.

A single autoanalyzer in each site was earmarked for the reference test. Internal quality checks of the autoanalyzers were done every day as per their institutional protocol. External quality assurance mechanisms were in place in all the sites. The reports were assessed by the investigators to ensure quality. Data analysis was performed by two researchers independently.

Data management and analysis

The data regarding particulars of the patients and results of the index tests were entered in a tablet uploaded with an android-based mobile application tool Census and Survey Processing System (CSPro). Data pertaining to the reference test were merged with the main data after matching with the unique identification number. Data were exported to STATA SE V.11 and SPSS V.19.0 for analysis.

A descriptive analysis was done for the key variables; continuous variables were presented as means and categorical variables as proportions. Each of the index tests (categorised by venous and capillary blood for invasive tests) was compared against the reference.

Anaemia was classified according to WHO cut-offs. The WHO cut-offs are described in table 1. The first set of analysis focused on screening for anaemia. For this, *mild, moderate* and *severe anaemia* were combined into a single category and compared with *no anaemia*. In the second set of analysis that focused on treatment of anaemia, *mild* and *no anaemia* were clubbed as one category and *moderate* and *severe anaemia* categorised as another.

Diagnostic accuracy for each test was examined based on the sensitivity, specificity, positive and negative predictive values, likelihood ratios (LRs), and receiver operating characteristic curve and 95% CIs. This calculation was done for each site to look for the site-specific variation in the diagnostic test results. We did not do any estimates for test reproducibility.

Reporting of results is based on Standards for Reporting of Diagnostic Accuracy guidelines.

Ethical considerations

Ethics clearance was obtained from IECs of Indian Institute of Public Health-Delhi (IIPHD), AIIMS and the four recruiting sites.

RESULTS

A total of 5316 participants were recruited from four sites over a period of 6 months (figure 1). The site-wise distribution of

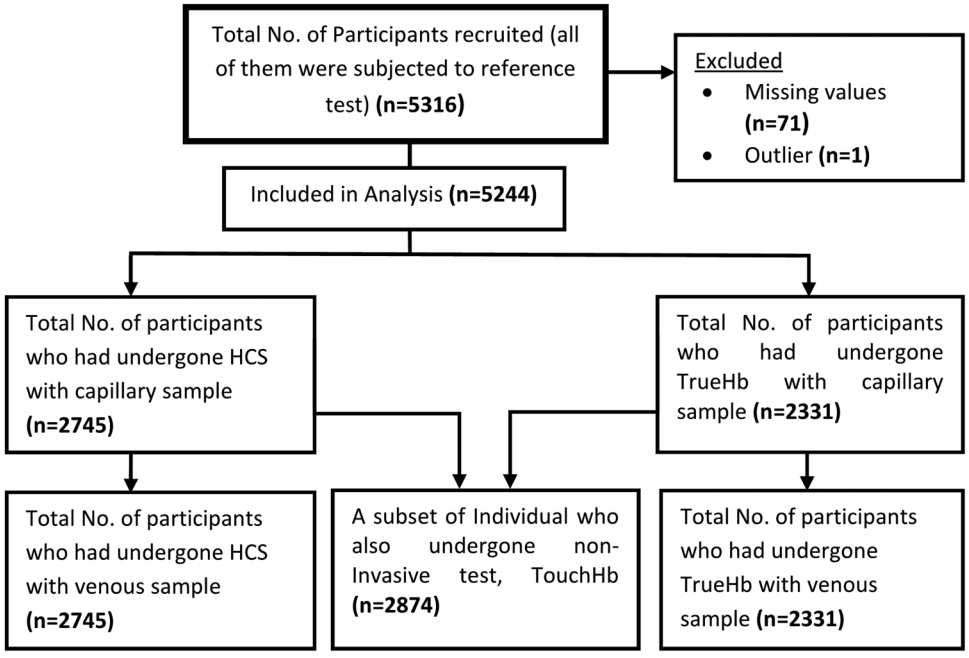

Figure 1 Flowchart depicting recruitment of participants in the study for various tests. HCS, haemoglobin colour scale.

Table 2 Profile of study participants (n=5316)

Variables	Total	Puducherry	Kolkata	Rohtak	Chandigarh
Recruitment of participants	5316	1313 (24.7%)	1307 (24.6%)	1403 (26.4%)	1293 (24.3%)
Age (in years)					
Mean (SD)	39.3 (13.7)	39.8 (12.6)	36.5 (13.0)	41.7 (14.5)	39.1 (13.8)
Range	18–88	18–85	18–78	18–88	18–85
Gender					
Male	2826 (53.2%)	715 (54.5%)	701 (53.6%)	708 (50.5%)	702 (54.3%)
Female	2490 (46.8%)	598 (45.5%)	606 (46.4%)	695 (49.5%)	591 (45.7%)
Provisional diagnosis* (n=3349)					
Any haematological disorder (non-malignant)	620 (18.5%)	47 (7.5%)	491 (8.0%)	23 (15.4)	59 (4.6%)
Infectious conditions	427 (12.7%)	165 (26.4%)	42 (3.2%)	55 (37%)	165 (12.9%)
Malignant conditions	435 (13.0%)	29 (4.6%)	350 (27.0%)	19 (7.5%)	37 (2.9%)
Immunological disorder	149 (4.4%)	43 (6.9%)	44 (3.4%)	0	62 (4.8%)
Cardiovascular disorder	133 (4.0%)	23 (3.7%)	23 (1.8%)	3 (2.0%)	84 (6.6%)
Endocrinal disorder	105 (3.1%)	31 (5.0%)	13 (1.0%)	3 (2.0%)	58 (4.5%)
Respiratory disorders	113 (3.4%)	60 (9.6%)	8 (1.0%)	2 (1.3%)	43 (3.4%)
Skeletal and muscular disorders	103 (3.1%)	34 (5.4)	14 (1.1%)	5 (3.4%)	50 (3.9%)
Gastrointestinal tract disorders	96 (2.9%)	10 (1.6%)	10 (1.0%)	3 (2.0%)	73 (5.7%)
Surgical conditions	90 (2.7%)	22 (3.5%)	9 (1.0%)	0	59 (4.6%)
Gynaecological	71 (2.1%)	6 (1.0%)	19 (1.5%)	0	46 (3.6%)
Others	1007 (30.1%)	155 (24.8%)	272 (21.0%)	36 (24.2%)	544 (42.5%)

*Column %.

patients was equitable. The mean age of the participants was 39.3 years (SD 13.7 years). More than half (53.0%) of the participants were men. From among the 3349 participants whose presenting complaints were recorded, haematological disorders (18.5%), malignant conditions (13.0%) and infectious conditions (12.7%) were the most common provisional diagnoses (table 2).

A total of 72 participants were excluded from analysis (1 outlier and 71 missing values for reference test) (figure 1). Missing values were of those patients in whom blood sample was inadequate, or it coagulated before the test or there were data entry errors. There were no adverse events reported from the conduction of these tests.

The diagnosis of anaemia for all three methods was done using age-specific cut-offs as recommended by WHO classification.[11] The Hb cut-offs used for classification of anaemia according to WHO and Indian Council of Medical Research (ICMR) are given in table 1.[11 12]

As per the WHO classification, prevalence of anaemia in the study population was 53.0% (range 38.0%–86.0%). Around 12.0% of patients were severely anaemic. The distribution of anaemia among the participants is included in table 3.

Diagnostic accuracy of index tests

In our study, the sensitivity of the HCS-HLL test was high (92.0%) with capillary sample but its specificity was 21.9%. Venous blood had a lower sensitivity (70.0%) but a higher specificity (60.0%). A variation was noted between the sites. The positive LRs were 1.2 and 1.7 respectively for capillary and venous blood (table 4).

The TrueHb device with capillary sample had a sensitivity of 82.1% (lower than HCS-HLL) but a much higher specificity (77.9%). Venous sample fared better in terms of specificity (86.9% vs 77.9%). The positive and negative predictive values were good (close to 80.0%). This device had the highest LR positive ratio (5.7) for the venous sample and the lowest LR negative ratio (0.2) for the capillary sample among all the index tests. Parameters varied across the sites but the LRs remained consistently high (see web table 1).

We also found a strong correlation (r=0.77) between TrueHb with capillary sample against autoanalyzer readings (figure 2). The mean difference of 0.1 (95% CI 0.02 to 0.17) between the paired observation with limits of agreement ranging from −3.5 to 3.7 was noted. The correlation coefficient was even stronger

Table 3 Distribution of participants as per WHO classification for anaemia across four sites

Hb (g/dL) based on reference test (n=5244)*					
Hb (g/dL)	**Total**	**Puducherry**	**Kolkata**	**Rohtak**	**Chandigarh**
Mean (SD)	118 (28)	128 (25)	101 (30)	121 (24)	121 (25)
Range	13–220	20–220	31–216	13–199	34–200
Classification of anaemia					
No anaemia	2459 (46.9%)	814 (62.1%)	311 (24.1%)	688 (49.8%)	646 (51.1%)
Mild anaemia	1044 (19.9%)	256 (19.5%)	216 (16.8%)	329 (23.8%)	243 (19.2%)
Moderate anaemia	1149 (21.9%)	184 (14.0%)	387 (30%)	285 (20.6%)	293 (23.2%)
Severe anaemia	592 (11.9%)	57 (4.3%)	375 (29%)	79 (5.7%)	81 (6.4%)

*Column %.
Hb, haemoglobin.

Table 4 Parameters to assess diagnostic accuracy for various tests to screen patients with anaemia (using WHO classification)

Test	Sensitivity (95% CI)	Specificity (95% CI)	PPV (95% CI)	NPV (95% CI)	LR+ (95% CI)	LR− (95% CI)	Area under ROC (95% CI)
HCS-HLL (capillary sample)	92.0% (90.4% to 93.3%)	21.9% (19.6% to 24.2%)	57% (55% to 59%)	70.7% (65.9% to 75.1%)	1.2 (1.1 to 1.2)	0.4 (0.3 to 0.4)	0.57 (0.56 to 0.58)
HCS-HLL (venous sample)	69.6% (67.1% to 71.9%)	59.5% (56.8% to 62.2%)	66% (63.5% to 68.3%)	63.4% (60.6% to 66.1%)	1.7 (1.6 to 1.9)	0.5 (0.5 to 0.6)	0.64 (0.63 to 0.66)
TrueHb (capillary sample)	82.1% (79.8% to 84.2%)	77.9% (75.3% to 0.3%)	80.6% (78.3% to 82.8%)	79.5% (76.9% to 81.9%)	3.7 (3.3 to 4.2)	0.2 (0.20 to 0.3)	0.80 (0.78 to 0.82)
TrueHb (venous sample)	74.4% (71.9% to 76.8%)	86.9% (84.8% to 88.8%)	86.4% (84.2% to 88.4%)	75.2% (72.7% to 77.6%)	5.7 (4.9 to 6.6)	0.3 (0.3 to 0.3)	0.81 (0.79 to 0.82)
TouchHb	73.1% (70.7% to 75.4%)	51.5% (48.7% to 54.3%)	62.8% (60.4% to 65.2%)	63.1% (60% to 66.1%)	1.5 (1.4 to 1.6)	0.5 (0.5 to 0.6)	0.62 (0.61 to 0.64)

Hb, haemoglobin; HCS-HLL, haemoglobin colour scale-Hindustan Lifecare Limited; LR, likelihood ratio; NPV, negative predictive value; PPV, positive predictive value; ROC, receiver operating characteristic.

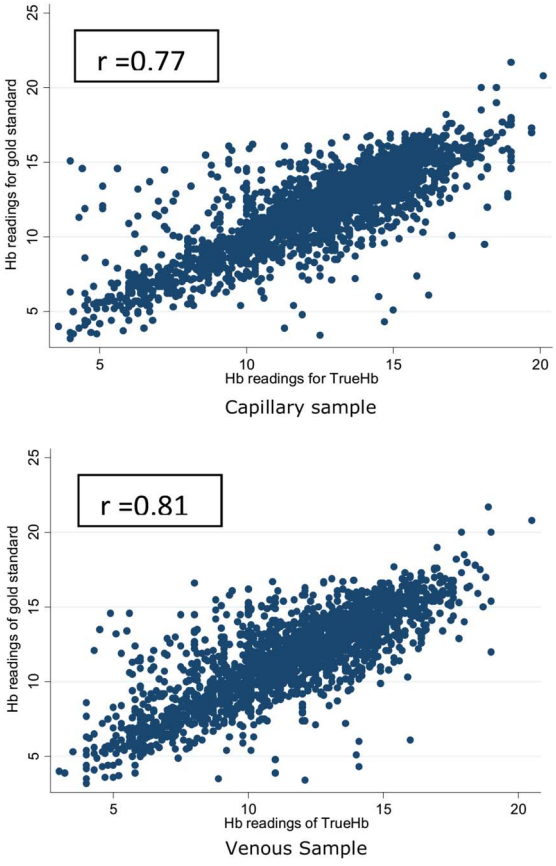

Figure 2 Scatter plot showing correlation between haemoglobin (Hb) values of TrueHb device against gold standard.

for the same device with venous sample r=0.8 and mean difference of 0.5 (95% CI −0.58 to 0.4) between the paired observations. TouchHb device had given a sensitivity of 73.1% and specificity of 51.5% but it had a lower positive LR of 1.5 and negative LR of 0.5 (table 4).

In the second set of analysis, *no* and *mild anaemia* were combined as one category and *moderate* and *severe anaemia* as another category. The purpose of this analysis was to examine the performance of the index tests when used as a tool for detecting treatable anaemia (table 5). Diagnostic accuracy parameters were calculated at a cut-off that defines no anaemia as Hb≥11 for both men and women (obtained by clubbing no anaemia and mild anaemia of WHO's classification). This is the cut-off used for providing iron supplementation for treating anaemia in India as per ICMR's guidelines. Sensitivity of each device dropped and specificity increased as was expected at a lower cut-off (table 5).

The diagnostic accuracy of the devices was also assessed in detecting severe anaemia (Hb<8.0 g%) (see web table 2). LRs improved for every diagnostic test.

DISCUSSION

An assessment of the diagnostic accuracy of the three devices showed that TrueHb gave better results on all the parameters, with venous values faring better then capillary results.

These test results are comparable with other devices used for screening of anaemia in surveys such as WHO-HCS and Hemocue. Clinical diagnosis has a sensitivity of 29.0%–44.0% and a specificity of 81.0%–89.0%, limiting its usefulness in diagnosing anaemia.[13] A systematic review of 14 studies has

Table 5 Parameters to assess diagnostic accuracy of various tests to screen patients for treating anaemia (Hb<110 and Hb≥110) (using WHO classification)

	Sensitivity (95% CI)	Specificity (95% CI)	PPV (95% CI)	NPV (95% CI)	LR+ (95% CI)	LR− (95% CI)	Area under ROC (95% CI)
HCS-HLL (capillary sample)	90.3% (88.2% to 92.2%)	42.2% (39.9% to 44.5%)	56.6% (51.6% to 57.6%)	81.9% (80% to 83.8%)	1.6 (1.5 to 1.6)	0.2 (0.2 to 0.3)	0.66 (0.65 to 0.68)
HCS-HLL (venous sample)	67.1% (63.9% to 70.2%)	72.8% (70.7% to 74.8%)	43.2% (41% to 45.5%)	89.9% (87.7% to 91.9%)	2.5 (2.3 to 2.7)	0.5 (0.4 to 0.5)	0.70 (0.68 to 0.72)
TrueHb (capillary sample)	79.4% (76.4% to 82.1%)	87.1% (85.3% to 88.7%)	75.7% (72.6% to 78.6%)	89.3% (87.6% to 90.8%)	6.1 (5.4 to 7.0)	0.2 (0.2 to 0.3)	0.83 (0.82 to 0.85)
TrueHb (venous sample)	70.7% (67.4% to 73.9%)	93.8% (92.5% to 94.9%)	85.3% (82.3% to 87.9%)	86.3% (84.6% to 87.9%)	11.4 (9.3 to 13.9)	0.3 (0.3 to 0.4)	0.82 (0.80 to 0.84)
TouchHb	44.3% (41.7% to 47%)	80.5% (78.2% to 82.70%)	71.9% (68.7% to 74.9%)	56.3% (54% to 58.7%)	2.3 (2.0 to 2.6)	0.7 (0.6 to 0.7)	0.62 (0.61 to 0.64)

Hb, haemoglobin; HCS-HLL, haemoglobin colour scale-Hindustan Lifecare Limited; LR, likelihood ratio; NPV, negative predictive value; PPV, positive predictive value; ROC, receiver operating characteristic.

shown that the sensitivity of HCS for detecting anaemia was high (75.0%–97.0%) while its specificity was lower (41.0%–98.0%).[14 15] These findings were quite similar to an assessment conducted in field settings.[16] Our findings also reiterate this fact. Hemocue, widely used in health surveys, had a sensitivity of 79.0% and specificity of 97.0% when compared with Cell Dyn automated autoanalyzers.[17] It showed a sensitivity of 70.6% and specificity of 95.2% with capillary blood.[18] A review of Hemocue suggested a sensitivity ranging from 75.0% to 91.0% and a specificity of 88.0% to 100%; however, they also found a positive reporting bias.[19] Although found optimal, the readings are likely to get affected by humidity[18 19] and this is one of the most expensive methods with an estimated cost of around US$0.75/test (the cost of Hemocue B instrument is about 35 000 Indian Rupees and each disposable microcuvette costs approximately 30 Indian Rupees).[20 21] Procurement of the device sometimes poses a challenge, particularly in low-income and middle-income countries.[20 22]

A device for use in communities or primary healthcare facilities in resource-poor settings should be inexpensive, rapid and simple to use with reasonably accuracy.[8] Operational issues while using a device are important in deciding about the feasibility of use in field settings. We explored aspects such as ease of use, portability, cost of device, recurring cost, efficiency in daylight, average time taken to perform each test and skills for operating the devices. These were gathered from specifications mentioned in product inserts, from the manufacturers and from experiences of research staff involved in the study (see web table 3).

All the three devices were portable, easy to use and could give results in <10 min time. However, exposure to direct sunlight emerged as a limiting factor across all of them. Nevertheless, each one had certain distinct advantages over others. For instance, HCS-HLL is not battery driven and hence a cheaper option but is prone to subjective errors. The errors are reported to occur because of inadequate or excessive blood, reading the results too soon or too late, poor lighting or holding the scale at the wrong angle.[23] In our study, timeliness of the readings and method of holding the scale properly were some of the operational challenges. TrueHb and TouchHb could overcome the limitations related to subjectivity since the readings are generated automatically. These two devices store data digitally within the device itself. TouchHb is suitable for adults <60 years of age but cannot be used among patients suffering from jaundice, eye infections, cyanosis, myxoedema and vasovagal syncope, thus restricting its use.

Research staff was trained in data collection and test procedures before commencement of data collection in a common training session centrally and also on-site by the device manufacturers. Two trained researchers at each site collected and managed the study data. We believe that standardised training contributed towards a valid assessment of the index tests at each site. The research staff was blinded to the results of the reference standard. The hospital laboratories where the study was conducted had mechanisms for internal and external quality assurance for the reference test. The study population was drawn from a pool of patients visiting the general outpatient department from four geographically different sites across India, thereby supporting the external validity of the results.

The findings suggest higher sensitivity for capillary sample as compared with venous samples, which is not in concordance with documented literature.[17] This could possibly be due to the rigorous training that the staff had undergone before initiating data collection. Moreover, they worked under the direct supervision of site investigators. A study on simulation models on the use of capillary blood to estimate Hb has shown that estimates

of the prevalence of low Hb are unbiased when the true prevalence is 50% (which is the case in our study).[24]

One of the limitations of this study was related to selection of participants. We excluded pregnant women and participants below 18 years of age from recruitment due to ethical reasons. National programmes focus more on these age groups. The study primarily examined the validity of diagnostic methods, and hence cannot comment on the reliability of the methods.

The sample size was based on a 30% prevalence of anaemia drawn from a general population. In our study, the prevalence was found to be higher (53%) since the sites were tertiary hospitals with a huge case load.

Apart from accuracy, the recurrent cost, simplicity of device for use, feasibility of using the device in outdoor settings, available manpower and technical skills of laboratory workforce are major considerations for implementation of any test in a community with high anaemia burden. Previous studies have shown that the process of choosing an appropriate laboratory method is complex and very little guidance is available for health managers.[20] Diagnostic accuracy is reported to be higher in laboratory-based studies compared with more pragmatic 'real-life' studies.[15 25] Feasibility and acceptability of the devices also needs to be worked out to resolve the complexities around the recommendation of a device for using it in the public health system. Therefore, it is advisable to test the effectiveness of any device before recommending for use in public health settings.

Take home messages

- Estimation of haemoglobin is a challenge in resource-poor settings.
- Several invasive and non-invasive techniques are available that require systematic assessment of their diagnostic accuracy.
- An efficacy study showed that TrueHb has better accuracy as compared with haemoglobin colour scale (HLL, Hindustan Lifecare Limited) and non-invasive TouchHb device in their current forms/versions.
- Effectiveness of the TrueHb device has to be established in field/community settings before recommending it for use in public health facilities.

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Contributors SBN conceptualised the study, provided overall coordination, analysed the data and drafted the final manuscript. HN designed the study, coordinated with the sites and contributed towards final analysis and writing the manuscript. RK, MB, RS, NV were site coordinators who contributed in the design phase of the study and finalised the manuscript. PB managed the project, did the analysis and drafted the manuscript. JS contributed towards managing the study and finalised the manuscript. HB and SZ provided support in the design phase and data analysis. RS led the study and gave inputs in the study design and analysis. All the authors approved the final version of the manuscript.

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Diagnostic accuracy of haemoglobin colour strip (HCS-HLL), a digital haemoglobinometer (TrueHb) and a non-invasive device (TouchHb) for screening patients with anaemia

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