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Introducing pulse oximetry for outpatient management of childhood pneumonia:

Citation for published version:
Rahman, AE, Ameen, S, Hossain, AT, Perkins, J, Jabeen, S, Majid, T, Uddin, AA, Shaikh, MZH, Islam, MS, Islam, MJ, Ashrafee, S, Md. Shah Alam, H, Saberin, A, Ahmed, S, Banik, G, Kabir, AE, Ahmed, A, Chisti, MJ, Cunningham, S, Dockrell, DH, Nair, H, Arifeen, SE & Campbell, H 2022, 'Introducing pulse oximetry for outpatient management of childhood pneumonia: An implementation research adopting a district implementation model in selected rural facilities in Bangladesh', *EClinicalMedicine*, vol. 50, 101511. https://doi.org/10.1016/j.eclinm.2022.101511

Digital Object Identifier (DOI):
10.1016/j.eclinm.2022.101511

Link:
Link to publication record in Edinburgh Research Explorer

Document Version:
Publisher's PDF, also known as Version of record

Published In:
EClinicalMedicine

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Download date: 24. Sep. 2022

Introducing pulse oximetry for outpatient management of childhood pneumonia: An implementation research adopting a district implementation model in selected rural facilities in Bangladesh

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Introducing pulse oximetry for outpatient management of childhood pneumonia: An implementation research adopting a district implementation model in selected rural facilities in Bangladesh

SUMMARY

Background: Pulse oximetry has enormous potential for identifying hypoxaemic pneumonia and substantially reducing under-five deaths in low- and middle-income country (LMIC) settings. However, there are few examples of introducing pulse oximetry in resource-constrained paediatric outpatient settings, i.e., Integrated Management of Childhood Illness (IMCI) services.

Methods: The National IMCI-programme of Bangladesh designed and developed a district implementation model for introducing pulse oximetry in routine IMCI services through stakeholder engagement and demonstrated the model in Kushtia district adopting a health system strengthening approach. Between December 2020 and June 2021, two rounds of assessment were conducted based on WHO's implementation research framework and outcome variables, involving 22 IMCI service-providers and 1680 children presenting with cough/difficulty-in-breathing in 12 health facilities. The data collection procedures included structured-observations, re-assessments, interviews, and data-extraction by trained study personnel.

Findings: We observed that IMCI service-providers conducted pulse oximetry assessments on all eligible children in routine outpatient settings, of which 99% of assessments were successful; 85% (95% CI 83,87) in one attempt, and 69% (95% CI 67,71) within one minute. The adherence to standard operating procedure related to pulse oximetry was 92% (95% CI 91,93), and agreement regarding identifying hypoxaemia was 97% (95% CI 96,98). The median performance-time was 36 seconds (IQR 20,75), which was longer among younger children (2-11 months: 44s, IQR 22,78; 12-59 months: 30s, IQR 18,53, $p<0.01$) and among those classified as pneumonia/severe-pneumonia than as no-pneumonia (41s, IQR 22,70; 32s, IQR 20,62, $p<0.01$). We observed improvements in almost all indicators in round-2. IMCI service-providers and caregivers showed positive attitudes towards using this novel technology for assessing their children.

Interpretation: This implementation research study demonstrated the adoption, feasibility, fidelity, appropriateness, acceptability, and sustainability of pulse oximetry introduction in routine IMCI services in resource-poor settings. The learning may inform the evidence-based scale-up of pulse oximetry linked with an oxygen delivery system in Bangladesh and other LMICs.

Funding:

This research was funded by the UK National Institute for Health Research (NIHR) (Global Health Research Unit on Respiratory Health (RESPIRE); 16/136/109) using UK aid from the UK Government to support global health research. The views expressed in this publication are those of the author(s) and not necessarily those of the NIHR or the UK Government.

The RESPIRE collaboration comprises the UK Grant holders, Partners and research teams as listed on the RESPIRE website (www.ed.ac.uk/usher/respire).

Keywords: Pulse oximetry, IMCI, pneumonia, feasibility, implementation research, Bangladesh

1 INTRODUCTION

Pneumonia is the leading cause of childhood mortality, accounting for approximately 16% of under-five deaths globally.[1] The majority of these deaths occur in low- and middle-income countries (LMICs) and most are preventable.[1-3] It takes more lives than any other causes in post-neonatal periods, specially in low-resource settings.[4] In Bangladesh, it causes approximately one million episodes of severe-illness and 24,000 under-five deaths every year.[5,6] Around 30% children with pneumonia suffer from hypoxaemia, defined by low oxygen saturation in arterial blood (SpO_2), and is a strong predictor of hospitalisations and deaths.[7,8] Pulse oximetry is an accurate and non-invasive procedure to measure SpO_2 at point of care.[9] It can significantly improve childhood pneumonia classification through hypoxaemia identification and substantially reduce deaths in low- and middle-income country (LMIC) settings.[9]

In 2014, the World Health Organization (WHO) updated its outpatient-based child-curative care guidelines, i.e., Integrated Management of Childhood Illness (IMCI) and recommended introducing pulse oximetry for pneumonia assessment.[10] Several health system challenges are associated with integrating a new technology/device like pulse oximetry in LMIC settings.[11] Although there is some published experience of introducing pulse oximetry in low-resource settings, most predates the 2014-WHO recommendations.[12-14]

Successful introduction of a generic recommendation, technology or device in routine services demands context-specific adaptations, demonstration and feasibility assessments.[15-17] In 2019, the national IMCI-programme of the Government of Bangladesh (GoB) decided to introduce pulse oximetry in routine IMCI services.[18] A national technical committee was formed, which updated the National IMCI Implementation Package by incorporating recommendations to conduct pulse oximetry assessments on all children presenting with cough/difficulty-in-breathing for pneumonia assessments.[18,19] The IMCI-programme also decided to demonstrate the updated package in a district setting to inform evidence-based scale-up. Here, we present the experience and learning synthesised during the demonstration phase.

2 METHODS

2.1 STUDY DESIGN

An implementation research study was conducted, where the IMCI-programme designed, developed, and demonstrated a district implementation model to introduce pulse oximetry in routine IMCI services. icddr,b, an international health research organisation based in Bangladesh, provided implementation facilitation support and assessments.

2.2 STUDY SETTINGS

This study was conducted in Kushtia district (zila), approximately 200 kilometres from Dhaka, which was selected as the demonstration site as its under-five mortality rate was close to the national average and the IMCI services were functioning relatively well.[17] The IMCI-programme, in consultation with the district manager (Civil Surgeon) and sub-district managers (Upazila Health and Family Planning Officers), selected one district hospital (secondary-referral), all five sub-district hospitals (primary-referral) and six union-based facilities (health centres) as demonstration facilities (additional details in SM1&SM2).

2.3 DISTRICT IMPLEMENTATION MODEL

The IMCI-programme designed and developed a district implementation model through stakeholder engagement and adopted a health systems approach to strengthening the overall IMCI services, including the introduction of pulse oximetry in demonstration facilities (additional details in SM3). It had four components, which are as follows:

i) Sensitisation of district- and sub-district managers and IMCI service-providers through workshops and involve them in planning and implementation

ii) Capacity development of IMCI service-providers, supervisors, data officers and district- and sub-district managers

iii) Health system strengthening to improve IMCI service readiness and distribution of pulse oximetry devices through the routine distribution channel

iv) Follow-up support to IMCI service-providers through routine monitoring, supportive supervision and performance appraisal workshops

The demonstration study started in October-2019, was suspended in March-2020 due to COVID-19, resumed in October-2020, and ended in October-2021.

i. SENSITISATION AND PLANNING

The National IMCI Programme organised a district-level workshop with the district- and sub-district managers of Kushtia to sensitise them regarding the importance of introducing pulse oximetry in routine IMCI services and develop a high-level plan for implementing the updated IMCI implementation package in the selected health facilities. Following that, a workshop was organised in each sub-district with the respective sub-district health managers, IMCI services-providers and their clinical supervisors for further sensitisation and developing facility-specific micro-plans. Then, a workshop was also organised in each of the selected health facilities with IMCI services-providers and their supervisors to introduce pulse oximetry officially. These workshops were organised between October and December 2019. Unfortunately, the implementation was suspended in March 2020 due to the COVID-19 pandemic. The IMCI-programme decided to resume the activities in September 2020. Between October and November 2020, another round of district- and sub-district-level workshops were organised to update the high-level as well as the facility-specific micro plans.

ii. CAPACITY BUILDING

Between December 2019 and February 2020, the IMCI Programme organised a series of training for IMCI service-providers from across the country based on the updated IMCI implementation package as a part of their routine programme activities. The National IMCI master trainers facilitated the sessions, and all IMCI service-providers from the selected health facilities of Kushtia received the training. The updated IMCI training manual had a module on pneumonia assessment and pulse oximetry adapted from the pulse oximetry training manual of WHO. The module had information and instructions on the pathophysiology of hypoxaemia; function, types and parts of a pulse oximetry device; steps of conducting pulse oximetry assessments; and maintenance of the device. Half a day was dedicated to pulse oximetry which included both theoretical ad practical sessions. In addition, an orientation session was organised in Kushtia for the district- and sub-district managers, IMCI clinical supervisors, and data officers to discuss the basics of pulse oximetry and inclusion of SpO_2 status and hypoxaemia reporting in the IMCI service register and monthly reporting form

iii. DISTRIBUTION OF PULSE OXIMETERS

icddr,b surveyed the selected health facilities in December 2019 and identified the gaps in the availability of equipment, drugs, and logistics required for managing pneumonia based on the updated IMCI guidelines. The IMCI-programme addressed these gaps through the existing procurement and distribution channel. In addition, icddr,b supported the IMCI-programme to procure and distribute Masimo Rad-5v handheld pulse oximeters to the selected health facilities. The specific model was chosen by the national technical committee (mentioned earlier) based on the superiority in technical specifications and expert consultations. The distribution of pulse oximeters and other logistics were done between January and February 2020. In addition, batteries of the pulse oximetry devices were replaced through the existing procurement and distribution channel throughout the implementation period. In general, batteries were replaced after 15-25 days in the district hospitals, 30-40 days in sub-district hospitals and 60-70 days in health centres.

iv. MONITORING, SUPERVISION AND PERFORMANCE REVIEW WORKSHOPS

National, district and sub-district managers were responsible for monitoring and supervising the pulse oximetry related implementation in Kushtia. Representatives from the IMCI-programme conducted several field visits during the implementation period. They also conducted online meetings with the district- and sub-district managers to review the progress and discuss implementation quality and challenges. In addition, the district and sub-district managers conducted at least one supervisory visit to each selected facility during the implementation period. The observations from these supervisory visits were discussed in the routine monthly meetings. Moreover, a review workshop was organised in March 2021 with all IMCI service-providers in the presence of national-, district- and sub-district managers and clinical supervisors to discuss the achievements and gaps identified through the first round of assessments. A similar review workshop was also organised in October 2021 after completing the second round of assessments.

2.4 STUDY OBJECTIVES

We adapted WHO's implementation research framework and implementation outcome variables for this study.[20] The IMCI-programme and icddr,b jointly conducted a series of workshops with district- and sub-district managers to

finalise the research questions based on WHO's framework and set a benchmark for successful demonstration for each outcome variable (additional details in SM4).[18] The primary research questions are outlined in table-1.

2.5 STUDY PARTICIPANTS

Children aged 2-59 months presenting with cough/difficulty-in-breathing and receiving IMCI services at selected health facilities and government-employed IMCI service-providers (doctors, nurses, and paramedics) providing those services were the study population.

2.6 SAMPLING

We calculated the sample size for each of the primary research questions based on the benchmark set for successful demonstration (table-1). The maximum variance (67%) was expected for the usability-time indicator. The adjusted sample size was 639 children presenting with cough/difficulty-in-breathing per round. There were 22 IMCI service-providers in the selected facilities. We aimed to assess the pulse oximetry performance of all IMCI service-providers by observing and re-assessing at least 30 children presenting with cough/difficulty-in-breathing per provider, per round. We approached all children presenting with cough/difficulty-in-breathing on the day of assessment, and it required 3-7 days per provider per round to achieve the required sample size. On the day the required sample size (30 children) was reached for each IMCI service-provider, we continued enrolment and data collection until the end of business hours.

2.7 DATA COLLECTION

We conducted two rounds of assessment: round-1 in December 2020-February 2021; round-2 in March-May 2021. The data collection procedures included structured-observation of IMCI service-providers conducting pulse oximetry assessments during routine consultations by study nurses, re-assessment (history taking, clinical assessment and pulse oximetry) of children (after IMCI consultation) by study nurses, exit-interviews of the caregivers by study paramedics, data-extraction from IMCI-registers by data collectors, and structured-interviews with IMCI service-providers by study paramedics (additional details in SM5). All respondents gave written informed consent prior to participating. We assessed the pulse oximetry performance of the same IMCI service-providers in both rounds. All forms/questionnaires were pretested separately on at least five participants. The construct/framing of some of the questions and skip logics were updated based on the pretests. Data collection was conducted by means of a specially designed android-app, which had the provision to capture each pulse oximetry step with time stamping.[21] The data collection team received extensive training and refresher training on IMCI guidelines, pulse oximetry principles and process, data collection forms/questionnaires and the data-collection app. All tools were developed based on the extensive literature review and the structured interview and exit interview tool for the IMCI service providers on barriers and operational challenges were developed based on qualitative exploration. All tools were field-tested and pretested before finalisation.

i. Enrolment

A non-medical study staff approached all children in the waiting room/area of selected health facilities and enrolled children aged 2-59 presenting with cough/difficulty-in-breathing before receiving consultation from the IMCI service-providers.

ii. Structured-observation

Trained study nurses conducted structured-observations of IMCI service-providers conducting pulse oximetry assessments on children presenting with cough/ difficulty-in-breathing. The observers collected information on the following outcomes: use, success, usability by attempts, usability by time and performance time. The observers received ten days of training before data collection (five days on IMCI, one day on pulse oximetry, two days on using the data collection app based on the structured observation tool, and two days of field practice). Three days of refresher training was organised before the second round of data collection.

iii. Re-assessment

A separate group of trained study nurses conducted re-assessments of the enrolled children in a separate room after the structured-observation. The assessors collected data on the history of illness, conducted clinical assessments based on the IMCI guideline, and conducted pulse oximetry assessments using a device of the same model. The assessors

received ten days of training before data collection (five days on IMCI, one day on pulse oximetry, two days on the re-assessment tool, and two days for field practice). Three days of refresher training was organised before the second round of data collection.

iv. Exit-interview

A separate group of trained paramedics conducted exit-interviews of the caregivers of the enrolled children after re-assessment. The interviewers used an interviewer-administered structured-questionnaire (translated in Bangla) to collect data on the acceptability and perceived importance of pulse oximetry. The interviewers received five days of training before data collection (one day on pulse oximetry, two days on the exit-interview questionnaire and two days of field practice). One day of refresher training was organised before the second round of data collection.

v. Data-extraction

Trained data collectors extracted data from the IMCI services register of those children who were enrolled in this study. The data collectors took snapshots of the IMCI registers after service hours on the day of assessment (additional details in SM6). We obtained administrative approval from national IMCI-programme of Directorate General of Health Services of Bangladesh for conducting this study including the approval for taking snapshots of register. We also received approval from district-level health manager at Kushtia district. Furthermore, we have conducted facility level sensitisation, preparatory and planning meeting in presence of the IMCI-service providers, respective supervisors and facility managers. A dedicated team of data operators used a desktop-based application that was specially developed for this study and entered all available information, including SpO_2 and hypoxaemia status reported in the IMCI registers. The data operators received two days of training on IMCI registers and the desktop-based application. A data entry supervisor checked the data extraction process and conducted re-extraction and re-entry of 5% observations. There were very few cases where we identified minor issues, which we rectified by checking the source documents (snapshopts).

vi. Structured-interviews

The interviewers who conducted the exit-interviews of the caregivers also conducted structured-interviews with IMCI services-providers at the end of round two. The interviewers used a structured-questionnaire with a five-point Likert scale and collected data on the perceived utility of introducing pulse oximetry in routine IMCI services and barriers and challenges faced while conducting pulse oximetry in routine practice.

vii. Monitoring and supervision

A medical graduate directly supervised the data collection team. During the data collection period, the supervisor conducted regular monitoring visits meetings and organised weekly meetings with the data collection team to discuss data quality issues and specific gaps.

2.8 ANALYSIS PLAN

The following indicators were selected as primary outcomes of interest: adoption-use, feasibility-success, feasibility-usability by attempt, feasibility-usability by time, fidelity-SoP adherence, fidelity-agreement, appropriateness-experience, acceptability-usefulness, acceptability-importance, and acceptability-satisfaction (table-1).

Adoption was operationally defined as conducting pulse oximetry assessments on children presenting with cough/difficulty in breathing. A pulse oximetry assessment was considered successful if a stable (±1%) SpO_2 reading was observed for at least 10 seconds with adequate signal strength. Performance time was defined by the time taken (in seconds) from placing the probe to obtaining a stable reading. Adherence to standard operating procedures (SoP-adherence) was defined as putting the probe in the appropriate position and direction, and taking measures to keep the baby calm before conducting pulse oximetry assessments. The agreement was reported on identifying hypoxaemia through pulse oximetry by IMCI service-providers and re-assessment study nurses. We used a SpO_2 cut-off of <94% to operationally define hypoxaemia.[22] Regarding experience, IMCI service-providers reported barriers and challenges on a five-point Likert scale for 12 device-, patient-, environment-, and user-related factors.

Relationships between patient- (age, sex, weight-for-height, clinical features, and pneumonia status), provider- (age, sex, and designation), facility-related (types) factors and assessment rounds, and primary outcomes of interest (table-1) were considered as the secondary outcomes of interest (additional details in SM4). We also reported median performance time and infection prevention and control (IPC) practice, defined as cleaning the probe or attachment site of the child before conducting pulse oximetry assessments, as secondary outcomes of interest.

For categorical variables as outcomes of interest, we presented point estimates with 95% confidence intervals (CI). We used prevalence-adjusted and bias-adjusted kappa (PABAK) to report the agreement between IMCI service-providers and re-assessment study nurses.[23] We used Generalised Estimating Equation (GEE) models and reported crude and adjusted odds ratios (with 95% CI and p-value) to assess the adjusted effect of various factors and assessment rounds on these indicators. Wald statistics were used for checking the adequacy of the models. We used radar-plots to present the variations by each IMCI service-provider and reported the heterogeneity with I^2 and Tau^2 statistics. The statistical significance of the estimates have been reported at 5% level of significance.

For performance time, we checked the normality distribution using Shapiro-Wilk test (SM7). As they were non-normally distributed, we presented medians with interquartile ranges (IQRs) and used Mood's non-parametric equality of medians test to check for significant differences in various factors and assessment rounds. Barrier and challenge experiences were presented as means with standard deviations (SDs).

We used Stata version 15.0 for data analysis. More details regarding the analysis plan are available in the supplementary material (SM4).

Ethical approval of the study was obtained from the Institutional Review Board of icddr,b (Protocol Number: PR-18054). Research Governance of The University of Edinburgh declared the study does not need any UK based ethical opinion as it was categorised as minimal risk.

Role of the funding source

The funders had no role in study design, data collection, data analysis, data interpretation, or writing the report.

AER, SA and ATH had access to all data and take full responsibility for its integrity and the accuracy of the analyses. The corresponding author had final responsibility for the decision to submit for publication.

3 RESULTS

Sample size by each round of assessments

We assessed the pulse oximetry performance of five doctors, five nurses and twelve paramedics as IMCI service-providers in both rounds (additional details in SM8). During the two rounds of assessment, 3563 children received IMCI services from the selected facilities, of which 3195 (90%) were aged 2-59 months, 1765 (49%) had cough/difficulty-in-breathing, and 1680 (47%) were enrolled for assessments (fig-1). Around one percent (0.9%) enrolled children were not re-assessed and 1.4% caregivers could not be interviewed.

Of the enrolled children, 729 (43%) were aged 2-11 months, 164 (10%) were wasted/severely-wasted, and 220 (13%) were classified as pneumonia/severe-pneumonia (additional details in SM9, SM10, &SM11).

Performance of conducting pulse oximetry assessments by IMCI-service providers

During our assessment, the IMCI service-providers conducted pulse oximetry assessments (adoption-use) on all children presenting with cough/difficulty-in-breathing, of which 99% of assessments were successful (feasibility-success); 85% (95% CI 83,87) in one attempt (feasibility-usability by attempt) and 69% (95% CI 67,71) within one minute (feasibility-usability by time) (fig 2). The adherence to SoPs was 92% (95% CI 91,93) (fidelity-SoP-adherence), and the agreement was 97% (95% CI 96,98) (fidelity-agreement). All IMCI service-providers reported that pulse oximetry was useful for identifying hypoxaemia and pneumonia classification (acceptability-usefulness). Almost all (98%) caregivers felt that it was an important diagnostic for assessing their children (acceptability-importance) and all of them would allow conducting it on their children during future visits (acceptability-satisfaction). The indicators representing adoption, feasibility, fidelity, appropriateness, and acceptance demonstrated equal or better performance in round-2 (sustainability).

Influence of patient-,provider- and facility-related factors on the performance of conducting pulse oximetry assessments

Table-2 summarises the effect of various factors and assessment rounds on feasibility- and fidelity-related indicators. The highlighted cells indicate the statistically significant odds ratio. The odds of successfully conducting pulse oximetry assessments in one attempt was significantly higher among older (aged 12-59 months) (AOR 2.19, 95% CI 1.65, 2.92) and male (AOR 1.54, 95% CI 1.16, 2.04) children (Wald statistics 44.71, p<0.01). They were also more likely to successfully conduct pulse oximetry assessments within one minute on older children (AOR 2.05, 95% CI 1.65, 2.55) (Wald statistics 59.98, p<0.01). Older, female, and sub-district hospital- and health centre-based providers were less likely to adhere to pulse oximetry SoPs (Wald statistics 100.14, p<0.01). Substantial improvement was observed in round-2 regarding most of these indicators. More details about the models are available in SM12, SM13, SM14 & SM15.

Variability in performance of conducting pulse oximetry assessments

Regarding performance by individual IMCI service-providers, we observed minimum variability in successfully conducting pulse oximetry assessment in one attempt (I^2=55%; Tau^2=0.02), within one minute (I^2=36%; Tau^2=0.01), SoP-adherence (I^2=91%; Tau^2=0.12) and agreement (I^2=76%, Tau^2=0.04) (fig-3).

Performance time for conducting pulse oximetry assessment

The median performance time was 36 seconds (IQR 20,75) (fig-4). The performance time was significantly (p<0.01) longer among younger children (aged 2-11 months; 44s, IQR 22,78) than older children (30s, IQR 18,53). Similarly, it took significantly (p<0.01) more time among children classified as pneumonia/severe-pneumonia (41s, IQR 22,70) than those who were classified as no-pneumonia (32s, IQR 20,62). There was wide variability among IMCI service-providers regarding the timing (Pearson chi^2= 38.0240; p<0.01).

Device-, patient-, environment- and user-related barriers and challenges faced by the IMCI service-providers

Figure 5 presents the barriers and challenges (appropriateness-experience) reported by the IMCI service-providers while conducting pulse oximetry assessments based on a five-point Likert scale. Regarding patient-related factors, the highest (mean 4.1, 95% CI 3.6, 4.5) challenge was faced in making the child calm before conducting pulse oximetry assessments, which was closely followed by cleaning the area of attachment before placing the probe (mean 4.0, 95% CI 3.6, 4.4). Regarding environment-related factors, providers reported a high level of challenge in allocating adequate time for pulse oximetry during the period of peak service use (mean 4.3, 95% CI 3.9, 4.8) and performing pulse oximetry alone (mean 4.0, 95% CI 3.4, 4.6).

Agreement between IMCI service-providers and study appointed nurses using prevalence-adjusted and bias-adjusted kappa (PABAK)

The IMCI service-providers maintained optimum IPC practice during 72% (95% CI 70-74) of assessments (details-SM16). This was significantly better among paramedics (AOR 2.6, 95% CI 1.8, 3.8) and nurses (AOR 1.8, 95% CI 1.2, 2.7) compared to doctors providing IMCI services, and in sub-district hospitals (AOR 20.3, 95% CI 13.1, 31.6) and health centres (AOR 7.0, 95% CI 4.1, 11.7) compared to the district hospital. It was also substantially improved in round-2 (AOR 4.8, 95% CI 3.7, 6.3).

Figure 6 presents the agreement between IMCI service-providers and study appointed nurses using prevalence-adjusted and bias-adjusted kappa (PABAK). The overall PABAK was 0.94; a very high level of agreement. We did not observe significant variation by patient-, provider-, and facility-related factors and by individual IMCI service-providers.

4 DISCUSSION

Pulse oximetry has enormous potential for maximising the impact of IMCI in LMIC settings with high burdens of childhood pneumonia and hypoxaemia.[8,13] This is one of the novel studies which adopted a health system strengthening approach and district model of implementation. To the best of our knowledge, this is the first study to report most of the WHO implementation outcome variables which include adoption, feasibility, fidelity, appropriateness, acceptability and sustainability. We observed that IMCI service-providers almost universally conducted pulse oximetry assessments on almost all eligible children, and can successfully measure SpO_2 with minimum attempts, within a relatively short time and without major challenges. Their assessments were accurate, and performance was sustained or generally improved between two rounds. Also, caregivers were very positive towards introducing this technology for assessing their children.

Understanding the adoption and feasibility of introducing a new technology/device into routine systems is crucial to inform policy and programme.[20] We observed high-level of use, success and usability in conducting pulse oximetry assessment by IMCI service-providers. Although there are some differences in the context, case-mix and assessor characteristics, our findings are comparable to studies conducted in Ethiopia, Malawi, UK, Bangladesh and Pakistan.[12,13,24,25] These findings from diverse contexts reinforce the likelihood of adoption and feasibility of introducing pulse oximetry in resource-constrained outpatient settings. We have undertaken an inclusive approach of involving stakeholders, including IMCI service-providers, in various stages of planning and implementation. We have also ensured their continuous engagement through training, support supervision and performance appraisal workshops. This stakeholder engagement process may have contributed to the sense of ownership and acquisition of necessary skills, potentially explaining the encouraging findings related to adoption and feasibility.[18] The first wave of the COVID-19 pandemic started a few months before the round-1 assessments. Although the pandemic created barriers in delivering many essential health services, it positively influenced the awareness of health care providers regarding hypoxaemia and attitude towards pulse oximetry, and may have contributed as an unexpected enabler in this study.[26,27]

Fidelity of implementation is integrally linked to achieving the intended benefit of an intervention.[20] In our study, we observed a high-level of SoP-adherence by IMCI service-providers, similar to a study in rural Ethiopia.[24] A systematic review reported that communicating through multiple approaches can significantly improve SoP-adherence among healthcare providers.[28] We also adopted multiple approaches, such as emphasising the importance of calming the child and correct probe placement, along with ensuring availability of job-aids/visual aids in IMCI consultation rooms, which may have promoted such practice. However, we observed some issues related to IPC practices. Although probe cleaning procedures were not associated with successfully conducting pulse oximetry assessments, they represent an indispensable element of infection control, particularly in the COVID-19 context.[29]

Regarding identifying hypoxaemia through pulse oximetry, we observed a high-level of agreement between IMCI service-providers and study nurses. According to the WHO, fast breathing/chest-in-drawing as the only sign of pneumonia can be treated through outpatient management.[10] However, around one in 10 such cases experience treatment failure, suggesting the presence of some 'severe cases' among apparently 'non-severe' cases of pneumonia.[30] Hypoxemia is one of the strongest predictors of adverse clinical outcomes, and its accurate identification can help reduce the misclassification of non-severe pneumonia.[7,31,32] The high-level of agreement should give confidence to policymakers and families regarding the accuracy of SpO_2 measurement by minimally trained providers and thus their ability to identify the severe cases, even in routine settings.

We did not find any significant effect of provider- or facility-related factors on adoption and feasibility, suggesting that, with health systems inputs, such as training and post-training follow-up support through supervision and performance appraisal, different types of IMCI service-providers can achieve necessary pulse oximetry skills in all kinds of facilities. Regarding patient-related factors, similar to a multi-country trial, we observed that success and usability were significantly poorer among younger children, with performance time decreasing with increasing age.[25] The providers interviewed in our study and several other studies also reported facing difficulties in conducting pulse oximetry among younger and smaller children.[11,33] Pulse oximetry readings are significantly affected by patient movement (motion artefacts) and the appropriateness of the probe size.[34] Younger children are expected to be more restless during pulse oximetry. Although we used Masimo paediatric probes of same size in this study, the size, design and material used for these probes may need specific adaptations, especially in settings with high burdens of both pneumonia and malnutrition, which is the case for Bangladesh.[25] Around a third of the children are underweight or stunted in Bangladesh.[35] For the undernourished children it requires further adaptation for the best fit of the probes. We also found that success in one attempt was higher among male children, despite there being no notable differences

in the clinical presentation of the children by sex. Although this requires more exploration, some studies have reported the presence of implicit gender bias among healthcare professionals while rendering care in routine settings.[36]

With regard to fidelity, we observed that the male and younger IMCI service-providers adhered to SoPs more than their counterparts. This may be because they have more access to new technology/devices in such contexts.[37] Another reason could be that the average year of experience was higher among male providers. However, it requires further exploration and understanding. On facility-related factors, we observed that IMCI service-providers at higher-level facilities are more likely to adhere to SoPs. Service providers in the district hospital usually receive more monitoring and supervision from the national and district health managers. These variations in programme inputs may explain this difference.

Pulse oximetry performance was better in round-2 assessments across most indicators. This strengthens the notion of sustainability of pulse oximetry practice and highlights the importance of allowing an intervention to mature and reach optimum adoption and efficiency. Post-training follow-up support provided through supportive supervision and performance appraisal workshops (after round-1 assessments) possibly played a catalytic role in sustaining and improving the performance over time. The performance of a few providers was somewhat poorer than others, emphasising the importance of identifying weaker performers during the initial training and providing follow-up support through targeted monitoring and supervision.

There are several barriers and challenges to performing pulse oximetry in real-life settings. In our study, IMCI service-providers reported difficulties during peak hours of attendance at health facilities. In Bangladesh, most IMCI services are provided through union-level health centres (> # 3500) and sub-district hospitals (~# 482), which have a relatively lower patient load than district hospitals (# 62). Hence, the peak-hour related challenges are primarily a concern for district hospitals and some high-volume sub-district hospitals. The IMCI service-providers also reported facing major difficulties in keeping the child calm during pulse oximetry, which is mainly a concern for high volume facilities. Pulse oximetry devices with advanced Signal Extraction Technology (SET) require a shorter performance time, even in challenging conditions such as patient movement and low perfusion.[34,38] Although relatively more expensive ($300-500), it will require less than USD 250,000 to procure SET pulse oximetry devices for all high-volume IMCI consultation rooms in Bangladesh. We believe that this is affordable for a country like Bangladesh, as the overall national IMCI-programme under the Maternal, Neonatal, Child & Adolescent Health (MNC&AH) Operation Plan of Bangladesh has a total of around 50 million USD allocated for its activities. We believe, it is worth the investment to avert preventable pneumonia deaths by 2025.[39] In addition to enhancing the capacity of IMCI service providers through training and distributing toys to divert the attention of the child, active involvement of the caregivers has been shown to be effective in reducing the movement of the child during the procedure.[11]

We conceptualised this study based on the WHO framework and implementation outcome variables.[20] Although we contextualised the research questions by involving national- and local-level stakeholders, our reliance on WHO's implementation outcome variables limited the opportunities of capturing unexpected drivers and unintended consequences of pulse oximetry introduction in these settings.[18] Moreover, we acknowledge that the time interval between the two rounds of assessments were not sufficient to allow for firm conclusions to be made regarding the sustainability. Furthermore, the COVID-19 pandemic may have confounded some of our findings as it significantly impacted Bangladesh's health systems awareness, attitude, readiness, response, and practices related to oxygen security. Similarly, the capacity, experience and positionality of icddr,b as an implementation facilitation partner was a strong enabler and a potential confounder in this demonstration.[17,40]

We acknowledge the fact that we did not randomly select Kushtia as our demonstration site. Therefore, the result may not be applicable for the whole country. In Bangladesh, there are geographical variations which have impact on access to health care as well as service availability and readiness regarding various health services. Kushtia predominantly belongs to the plain land which is not representative of the hard-to-reach areas. Based on our findings of this study, pulse oximetry can be introduced in most parts of Bangladesh except the hard-to-reach areas. We also acknowledge that we have selected a district with reasonably well functioning IMCI services. The results would have been more generalisable if we could have included one low performing district which we could not include due to implementation cost challenges.

We employed the same team in both rounds of assessment and used a specially designed and tested android-app for capturing multiple events with time-stamps through structured observations.[21] These measures, we believe, reduced observation and measurement bias, increasing the validity and reliability of measurements, especially the performance time recording. While the presence of study nurses as independent observers may have introduced a surveillance bias, spending considerable time in building rapport with the IMCI service-providers and observing each of them for 3-7

days are expected to minimise this bias (i.e., Hawthorne effect).[41] Finally, the hospitals had set-up temporary fever-clinics during the pandemic, which screened and redirected all symptomatic patients to dedicated COVID-19 services. It changed the overall case-mix of children receiving IMCI services, which may explain the relatively smaller number of hypoxaemia cases identified during the assessment period. Lastly, we acknowledge that the data collection tools used in this study for structured observation, re-assessment, exit-interview and IMCI service-provider interview were not validated. Since we were conducting a novel study based on the WHO recommended implementation outcome variables, we did not find any validated tools. Therefore, we conducted extensive desk review to construct the data collection tools. We also conducted qualitative explorations for understanding the major issues related to acceptance, barriers and challenges, which helped us preparing the exit-interview and IMCI service-provider interview tools. We conducted field-testing and pretesting of each tool before finalisation. We believe that these measures have contributed in improving the content and construct validity of tools that were used in this study.

This implementation research study demonstrated the feasibility of introducing and integrating pulse oximetry in routine IMCI services in Bangladesh, adopting a district implementation model and using a health system strengthening approach. We are confident in our conclusion as we saw evidence of the programme maturing and improving over time and almost no influence of patient-, provider- and facilities-related factors on SpO_2 measurement, except that it was poorer among younger children, and a few providers performed the procedure less effectively. Introducing SET pulse oximetry devices in high-volume facilities can help overcome the challenges associated with motion artefacts, particularly among younger children. Special emphasis can be given to identifying providers who would benefit from targeted monitoring and follow-up support. Routine programmes will need to emphasise adherence to SoPs and IPC practices in training and routine monitoring. The policymakers can capitalise on these encouraging findings and ratify the integration of pulse oximetry with respiratory rate assessment in routine outpatient settings. Moreover, we also highlight the importance of connecting pulse oximetry to a functioning oxygen delivery system and ensuring timely, adequate and appropriate oxygenation. We recommend future studies to assess the feasibility of pulse oximetry at community settings of Bangladesh. We also recommend further study on post-implementation follow-up to assess the sustainability and research looking at feasibility, effectiveness and impact over wider interval. The experience gained through this demonstration and the learning synthesised in this implementation research can help inform evidence-based decisions relating to the introduction and scale-up of pulse oximetry in Bangladesh and other LMICs, as these countries aim to avert all preventable deaths due to childhood pneumonia mortality by 2025.

5 ACKNOWLEDGEMENT

We want to acknowledge all our field level staff who made this arduous work possible through their relentless effort. We also thank all our study participants and their parents, that we have included in our paper.

6 FUNDING

This research was funded by the UK National Institute for Health Research (NIHR) (Global Health Research Unit on Respiratory Health (RESPIRE); 16/136/109) using UK aid from the UK Government to support global health research. The views expressed in this publication are those of the author(s) and not necessarily those of the NIHR or the UK Government.

The RESPIRE collaboration comprises the UK Grant holders, Partners and research teams as listed on the RESPIRE website (www.ed.ac.uk/usher/respire).

7 AUTHOR CONTRIBUTION

AER conceptualised, developed and finalised the manuscript as a first author. SEA and HC provided their guidance and feedback to AER at every stage as joint senior authors. HN and DD also guided AER in conceptualisation of the research idea, finalising the study design, and drafting of the manuscript. SA assisted AER with field management and coordination of data collection. SA and ATH contributed to data analysis and developing the first draft of the manuscript.

AER, SA and ATH had access to all data and take full responsibility for its integrity and the accuracy of the analyses. The corresponding author had final responsibility for the decision to submit for publication. JP and SC helped in conceptualisation of the study and developing the manuscript. SJ, TM, AAU and MZHS supported to implement the field and provided inputs in the manuscript regarding fieldwork. MSI, MJI, SA, HSM and AS from IMCI programme and other development partners SA, GB, AEK and MK contributed in developing the study design and implementation

package, and reviewed the draft manuscript. AA and MJC reviewed the manuscript in detail. All authors reviewed and shared feedback on the manuscript and approved the final draft.

8 DECLARATION OF INTERESTS

SEA and HN from the authors have declared that this research work received grant from NIHR Global Health Research Unit on Respiratory Health (RESPIRE) through the University of Edinburgh, UK, using UK Aid from the UK Government. HN declared receiving grants from innovative Medicine Initiative and WHO in past 36 months; consulting fees from Sanofi Pasteur, WHO and Bill and Melinda Gates Foundation; and payment or honoraria from AbbVie; and Participation on a Data Safety Monitoring Board or Advisory Board in Janseen, Reviral, AbbVie. All the other authors report no conflicts of interest.

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Tables and Figures:

Tables:

Table-1: Research questions and benchmarks for successful demonstration

Caption: Research questions and benchmarks for successful demonstration; adapted from WHO's implementation outcome variables and finalised through stakeholder consultations

Table 2- Influence of patient-, provider- and facility-related factors on the performance of conducting pulse oximetry assessments by IMCI service-providers

Caption: Influence of patient-, provider- and facility-related factors on the performance of conducting pulse oximetry assessments by IMCI service-providers, presented in adjusted odds ratios, N=1680

Figures:

Figure 1: Sample size

Caption: Sample size by each round of assessments

Figure 2: Performance of conducting pulse oximetry assessments

Caption: Performance of conducting pulse oximetry assessments by IMCI-service providers among children presenting with cough/difficulty-in-breathing, presented in percentages with 95% CI, (N=1680). Each of the bars indicate a distinct implementation outcome indicator. The first green bar represents adoption, the blue bars represent feasibility, the yellow bars represent fidelity, the brown bar represents appropriateness, the purple bars represent acceptability and the light blue bar at the end represents sustainability.

Figure 3: Variability in performance of conducting pulse oximetry assessments

Caption: Variability in performance of conducting pulse oximetry assessments by individual IMCI service-providers, presented in percentage. The heterogeneity statistics I^2 (i.e. proportion of heterogeneity between estimates that is not due to chance) and Tau^2 (i.e. the magnitude of the heterogeneity) were significant at 5% level of significance.

Figure 4: Performance time for conducting pulse oximetry assessment

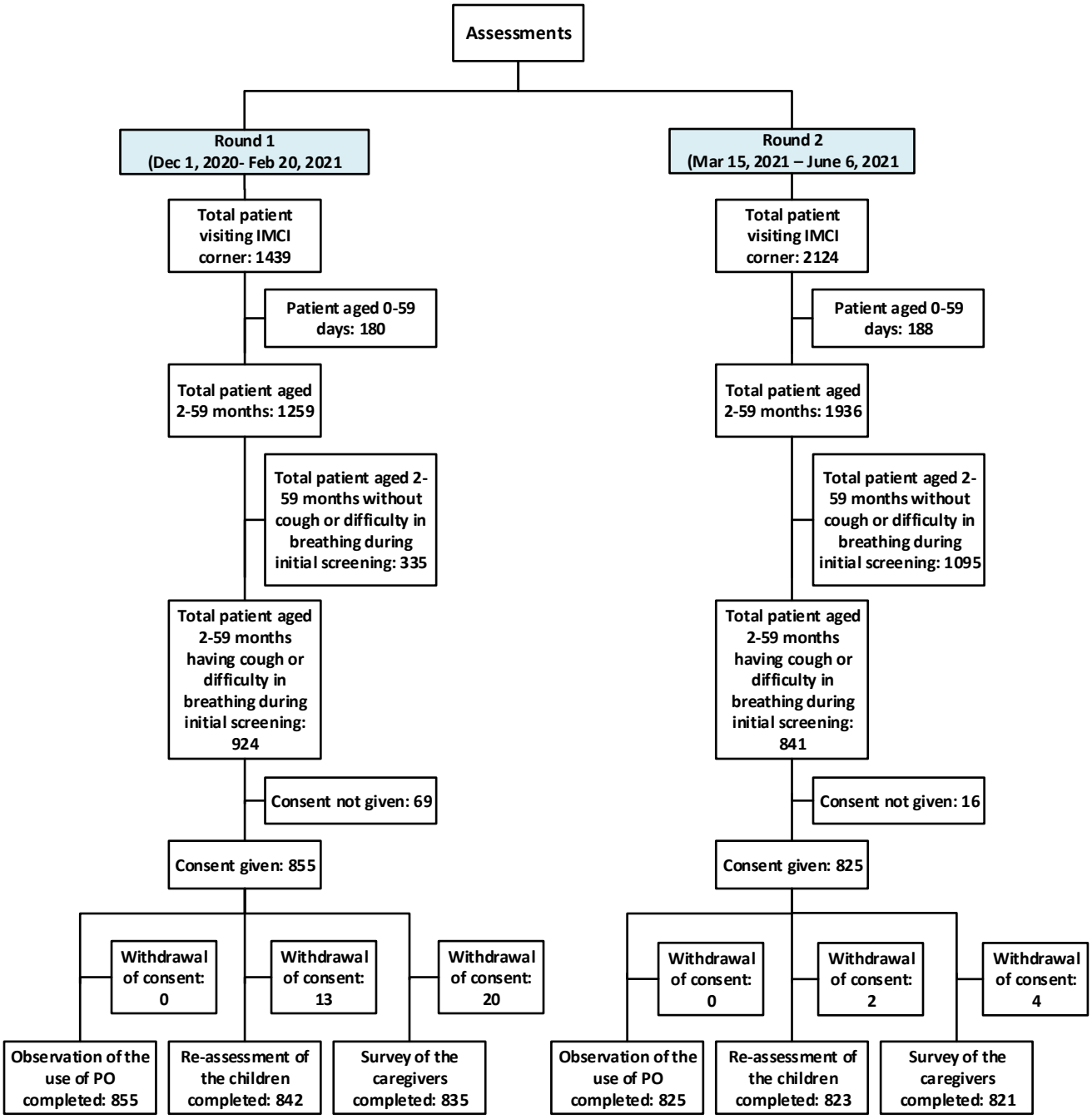
Caption: Performance time for conducting pulse oximetry assessment by patient-, provider-, and facility-related factors and by individual IMCI-service providers, presented in median seconds with IQR

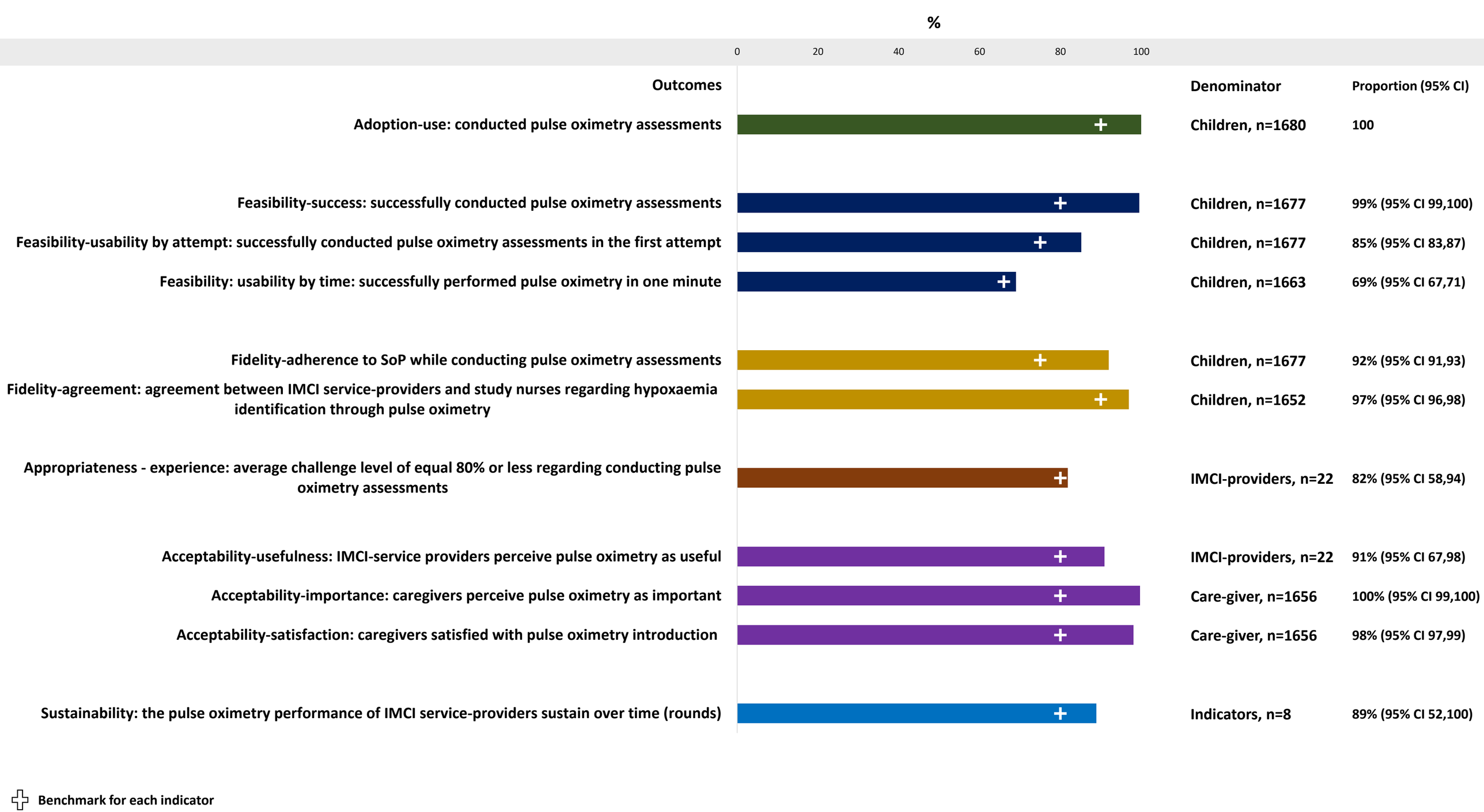
Figure 5: Device-, patient-, environment- and user-related barriers and challenges

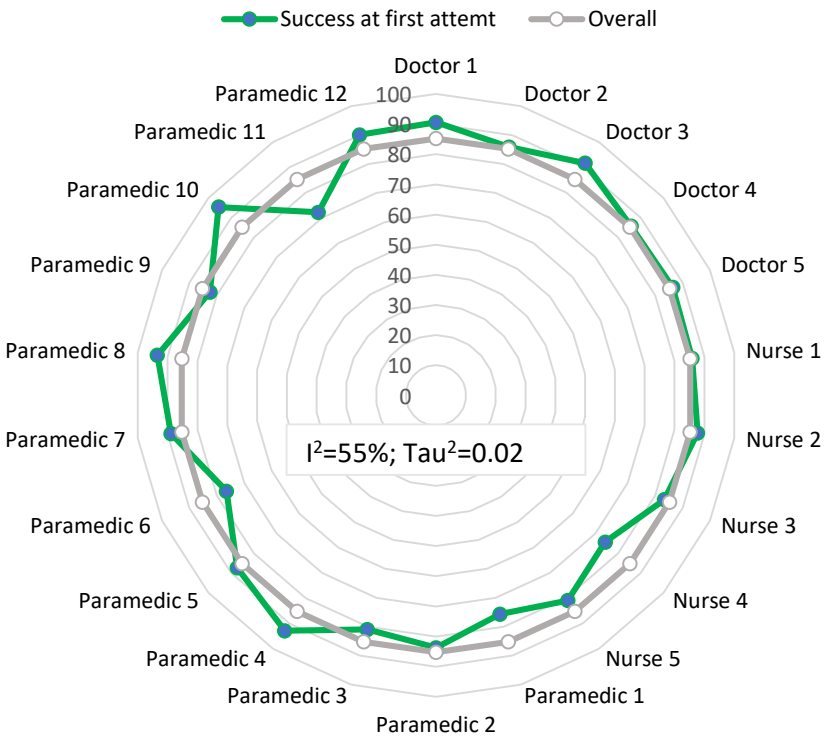
Caption: Device-, patient-, environment- and user-related barriers and challenges faced by the IMCI service-providers during pulse oximetry assessments, presented in mean score with SD based on a five-point Likert Scale, N=22. The light green shaded region indicates lower level of challenges and light red shaded region indicates higher level of challenges in in performing pulse oximetry assessments.

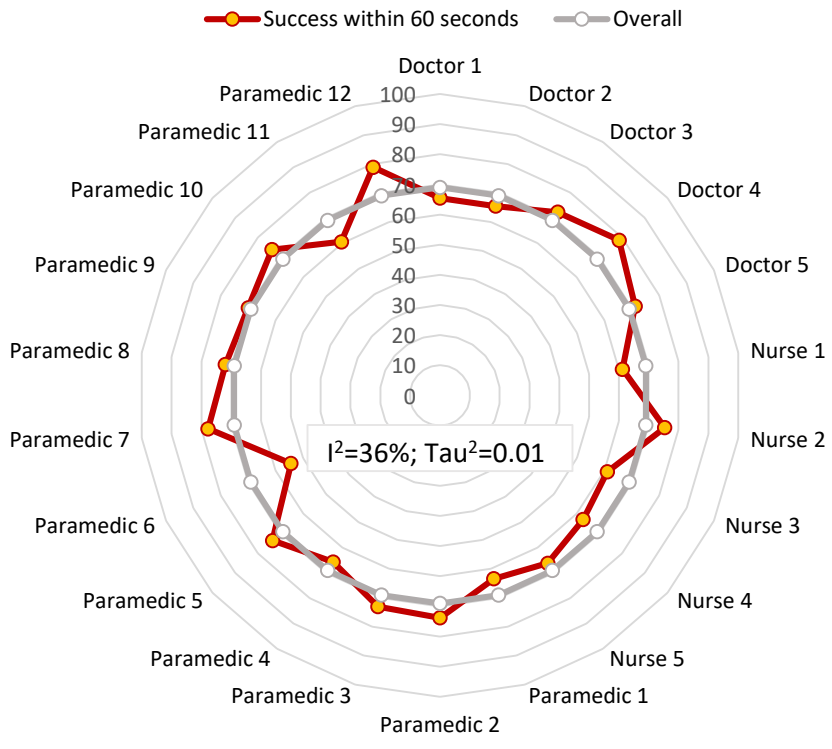
Figure 6: Agreement between IMCI service-providers and study appointed nurses using prevalence-adjusted and bias-adjusted kappa (PABAK)

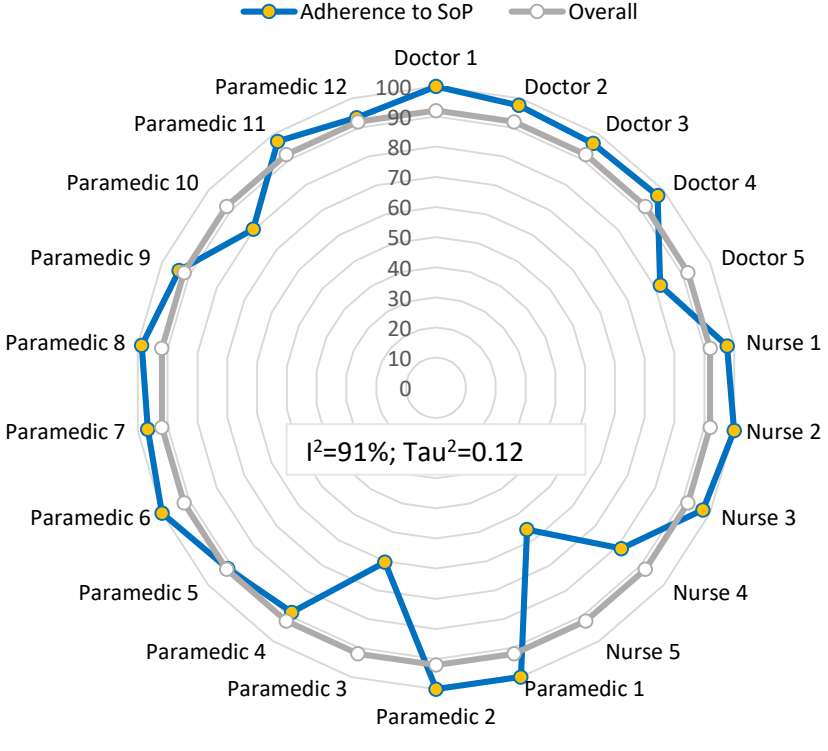
Caption: Agreement between IMCI service-providers and study appointed nurses using prevalence-adjusted and bias-adjusted kappa (PABAK) - by patient-related, provider-related and facility-related factors and by individual IMCI service providers, presented as coefficient and 95% CI. The light red and yellow shaded regions indicate lower agreement PABAK score and the green shaded regions indicate higher agreement PABAK score.

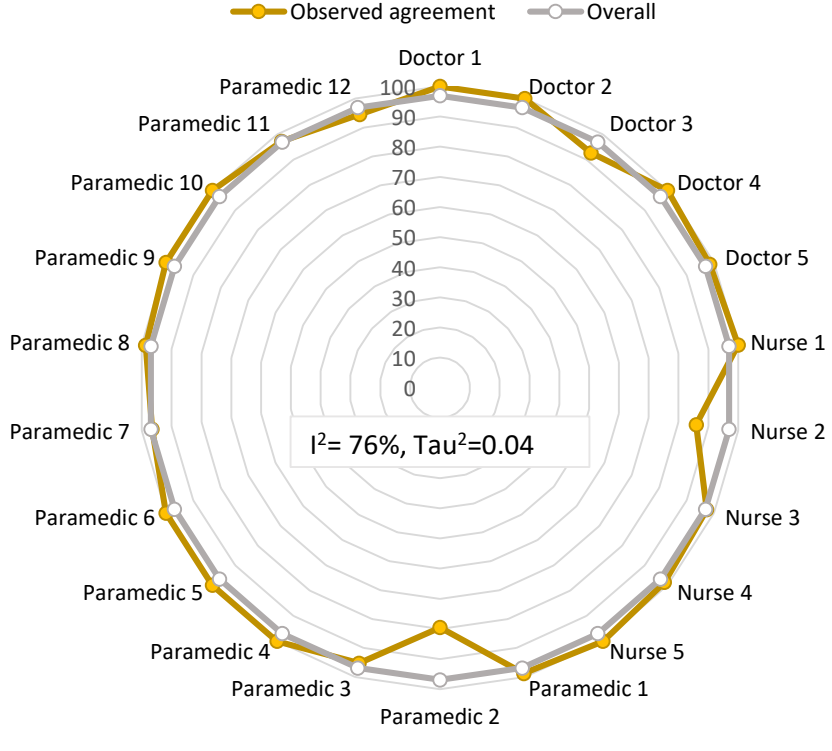

Assessments
Round 1
(Dec 1, 2020- Feb 20, 2021
Round 2
(Mar 15, 2021 – June 6, 2021
Total patient visiting IMCI corner: 1439
Patient aged 0-59 days: 180
Total patient aged 2-59 months: 1259
Total patient aged 2-59 months without cough or difficulty in breathing during initial screening: 335
Total patient aged 2-59 months having cough or difficulty in breathing during initial screening: 924
Consent not given: 69
Consent given: 855
Withdrawal of consent: 0
Withdrawal of consent: 13
Withdrawal of consent: 20
Observation of the use of PO completed: 855
Re-assessment of the children completed: 842
Survey of the caregivers completed: 835
Total patient visiting IMCI corner: 2124
Patient aged 0-59 days: 188
Total patient aged 2-59 months: 1936
Total patient aged 2-59 months without cough or difficulty in breathing during initial screening: 1095
Total patient aged 2-59 months having cough or difficulty in breathing during initial screening: 841
Consent not given: 16
Consent given: 825
Withdrawal of consent: 0
Withdrawal of consent: 2
Withdrawal of consent: 4
Observation of the use of PO completed: 825
Re-assessment of the children completed: 823
Survey of the caregivers completed: 821


%
0
20
40
60
80
100
Outcomes
Denominator
Proportion (95% CI)
Adoption-use: conducted pulse oximetry assessments
Children, n=1680
100
Feasibility-success: successfully conducted pulse oximetry assessments
Children, n=1677
99% (95% CI 99,100)
Feasibility-usability by attempt: successfully conducted pulse oximetry assessments in the first attempt
Children, n=1677
85% (95% CI 83,87)
Feasibility: usability by time: successfully performed pulse oximetry in one minute
Children, n=1663
69% (95% CI 67,71)
Fidelity-adherence to SoP while conducting pulse oximetry assessments
Children, n=1677
92% (95% CI 91,93)
Fidelity-agreement: agreement between IMCI service-providers and study nurses regarding hypoxaemia identification through pulse oximetry
Children, n=1652
97% (95% CI 96,98)
Appropriateness - experience: average challenge level of equal 80% or less regarding conducting pulse oximetry assessments
IMCI-providers, n=22
82% (95% CI 58,94)
Acceptability-usefulness: IMCI-service providers perceive pulse oximetry as useful
IMCI-providers, n=22
91% (95% CI 67,98)
Acceptability-importance: caregivers perceive pulse oximetry as important
Care-giver, n=1656
100% (95% CI 99,100)
Acceptability-satisfaction: caregivers satisfied with pulse oximetry introduction
Care-giver, n=1656
98% (95% CI 97,99)
Sustainability: the pulse oximetry performance of IMCI service-providers sustain over time (rounds)
Indicators, n=8
89% (95% CI 52,100)
Benchmark for each indicator

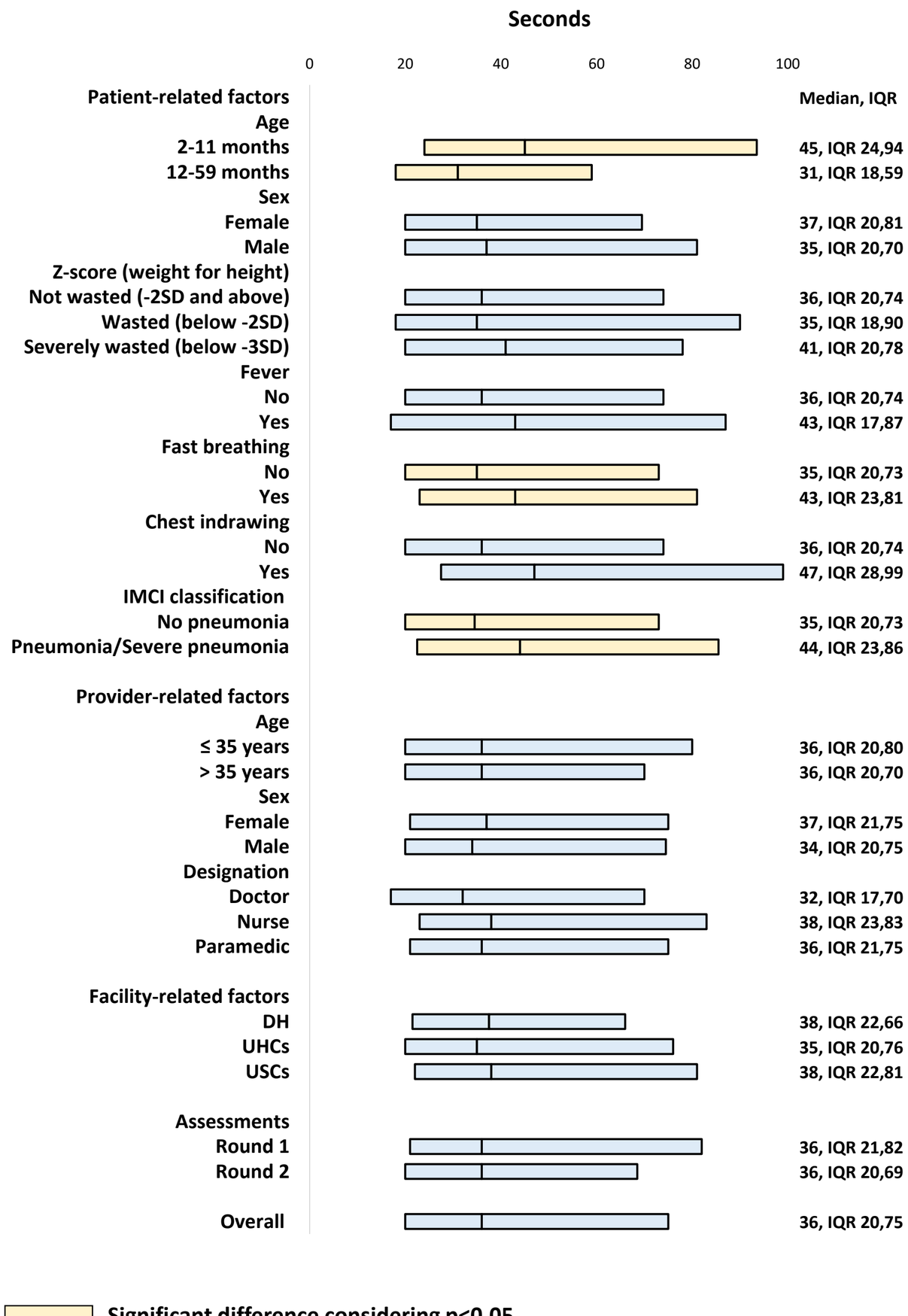

Success at first attemt
Overall
Doctor 1
Doctor 2
Doctor 3
Doctor 4
Doctor 5
Nurse 1
Nurse 2
Nurse 3
Nurse 4
Nurse 5
Paramedic 1
Paramedic 2
Paramedic 3
Paramedic 4
Paramedic 5
Paramedic 6
Paramedic 7
Paramedic 8
Paramedic 9
Paramedic 10
Paramedic 11
Paramedic 12
100
90
80
70
60
50
40
30
20
10
0
I²=55%; Tau²=0.02


Success within 60 seconds
Overall
Doctor 1
Doctor 2
Doctor 3
Doctor 4
Doctor 5
Nurse 1
Nurse 2
Nurse 3
Nurse 4
Nurse 5
Paramedic 1
Paramedic 2
Paramedic 3
Paramedic 4
Paramedic 5
Paramedic 6
Paramedic 7
Paramedic 8
Paramedic 9
Paramedic 10
Paramedic 11
Paramedic 12
100
90
80
70
60
50
40
30
20
10
0
I²=36%; Tau²=0.01


Adherence to SoP
Overall
Doctor 1
Doctor 2
Doctor 3
Doctor 4
Doctor 5
Nurse 1
Nurse 2
Nurse 3
Nurse 4
Nurse 5
Paramedic 1
Paramedic 2
Paramedic 3
Paramedic 4
Paramedic 5
Paramedic 6
Paramedic 7
Paramedic 8
Paramedic 9
Paramedic 10
Paramedic 11
Paramedic 12
100
90
80
70
60
50
40
30
20
10
0
I²=91%; Tau²=0.12

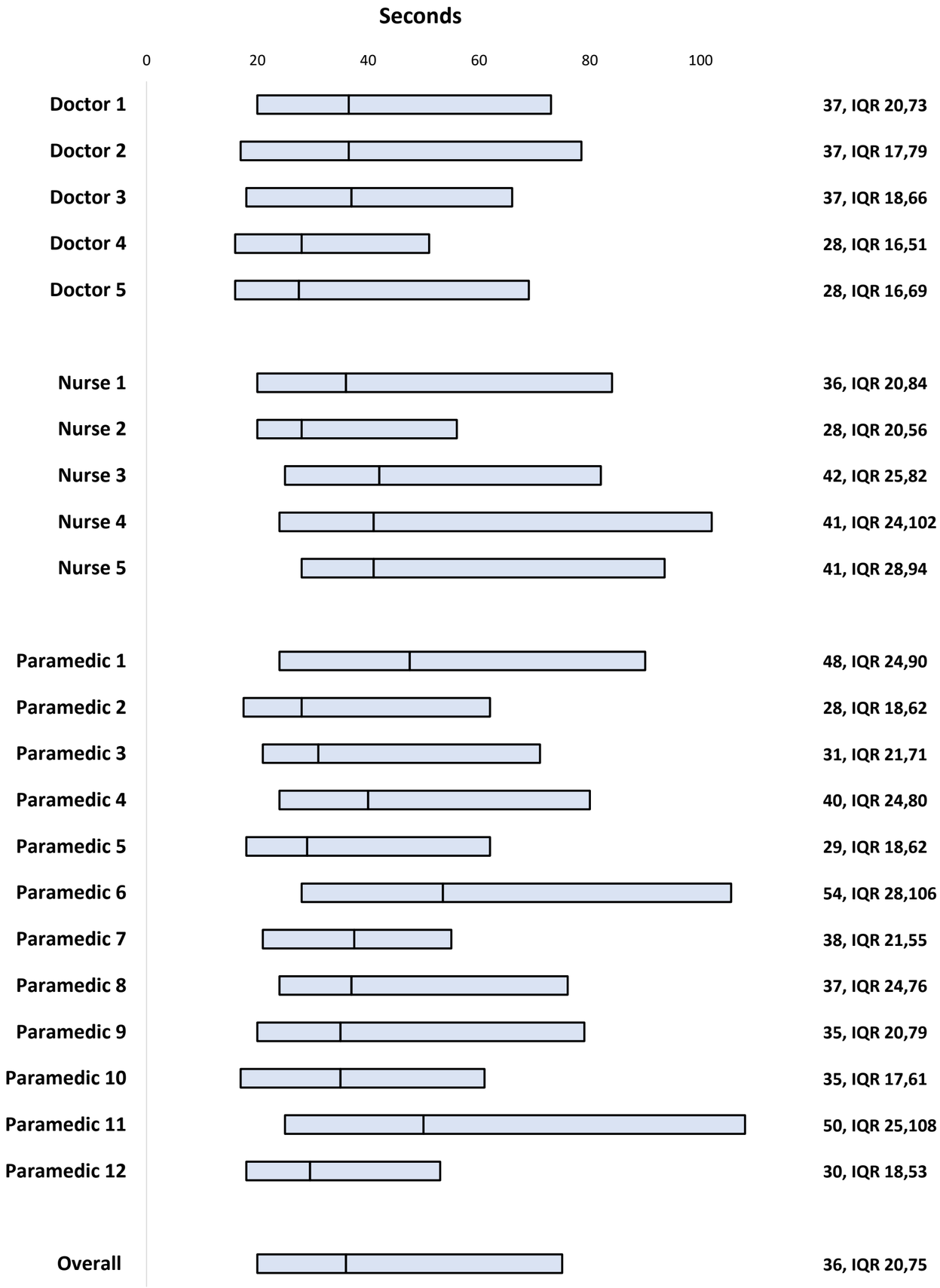

Observed agreement
Overall
Doctor 1
Doctor 2
Doctor 3
Doctor 4
Doctor 5
Nurse 1
Nurse 2
Nurse 3
Nurse 4
Nurse 5
Paramedic 1
Paramedic 2
Paramedic 3
Paramedic 4
Paramedic 5
Paramedic 6
Paramedic 7
Paramedic 8
Paramedic 9
Paramedic 10
Paramedic 11
Paramedic 12
100
90
80
70
60
50
40
30
20
10
0
I²= 76%, Tau²=0.04

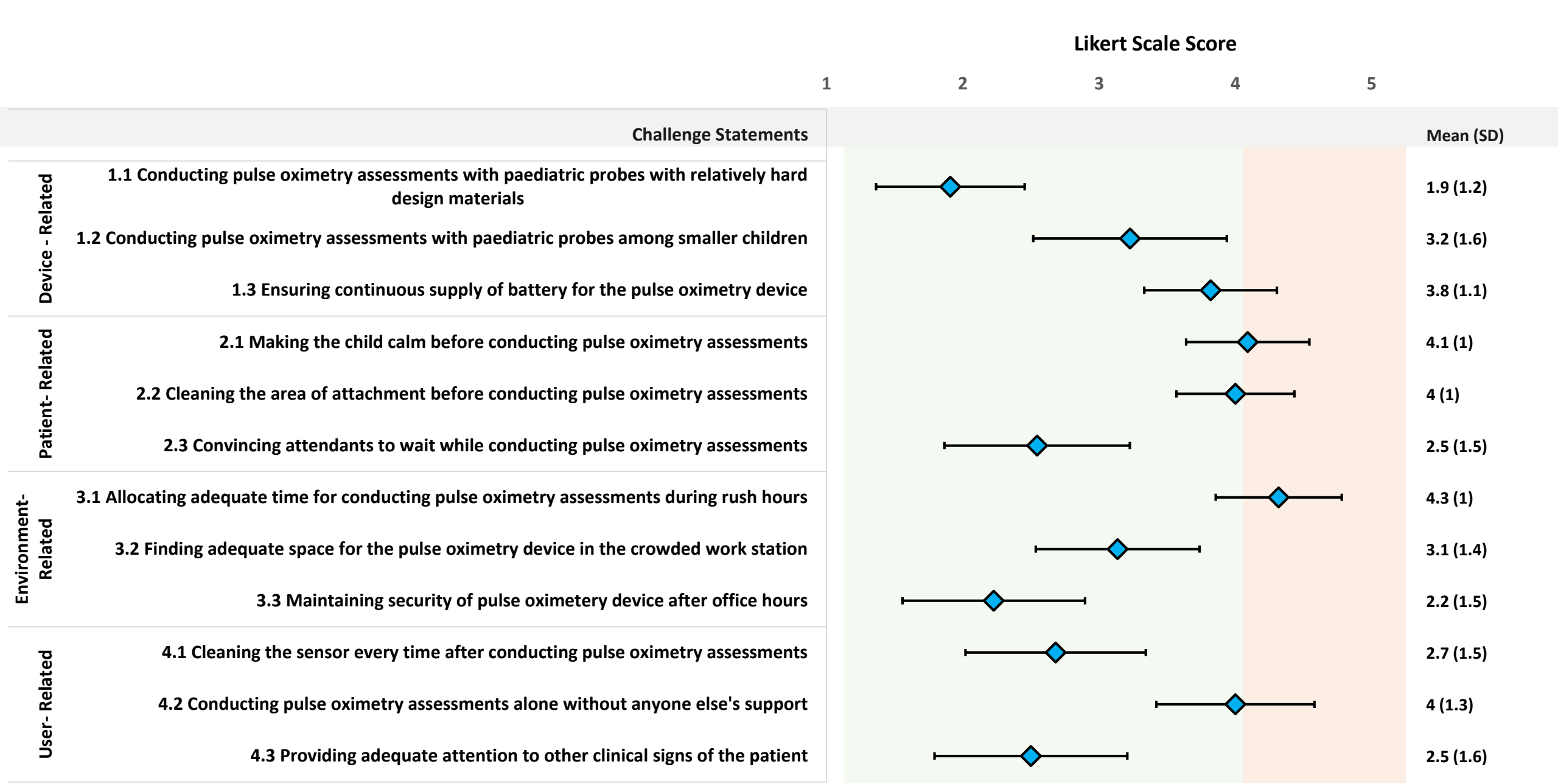
By patient-, provider-, facility-related factors



Significant difference considering p<0.05

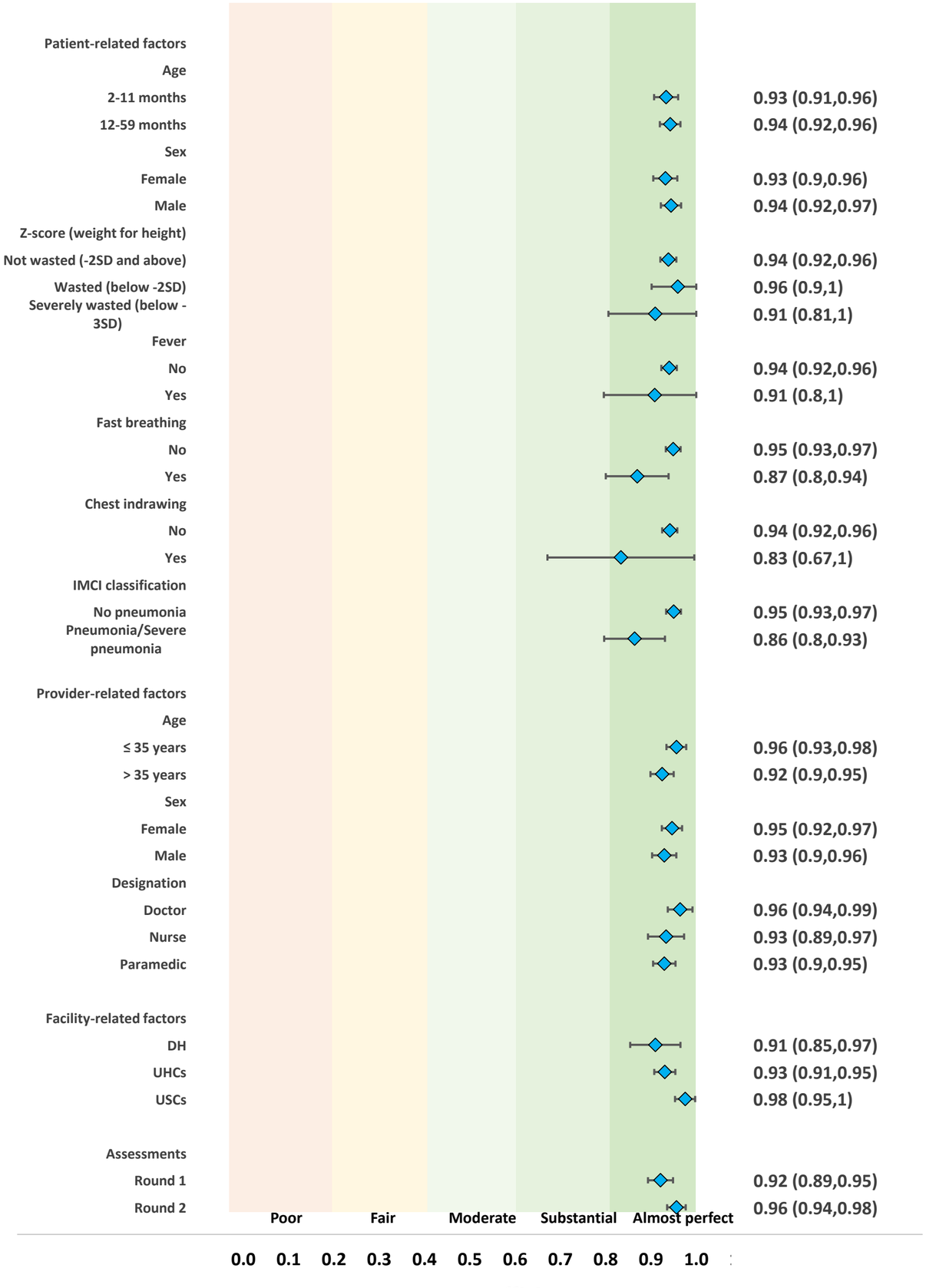
By IMCI service-provider



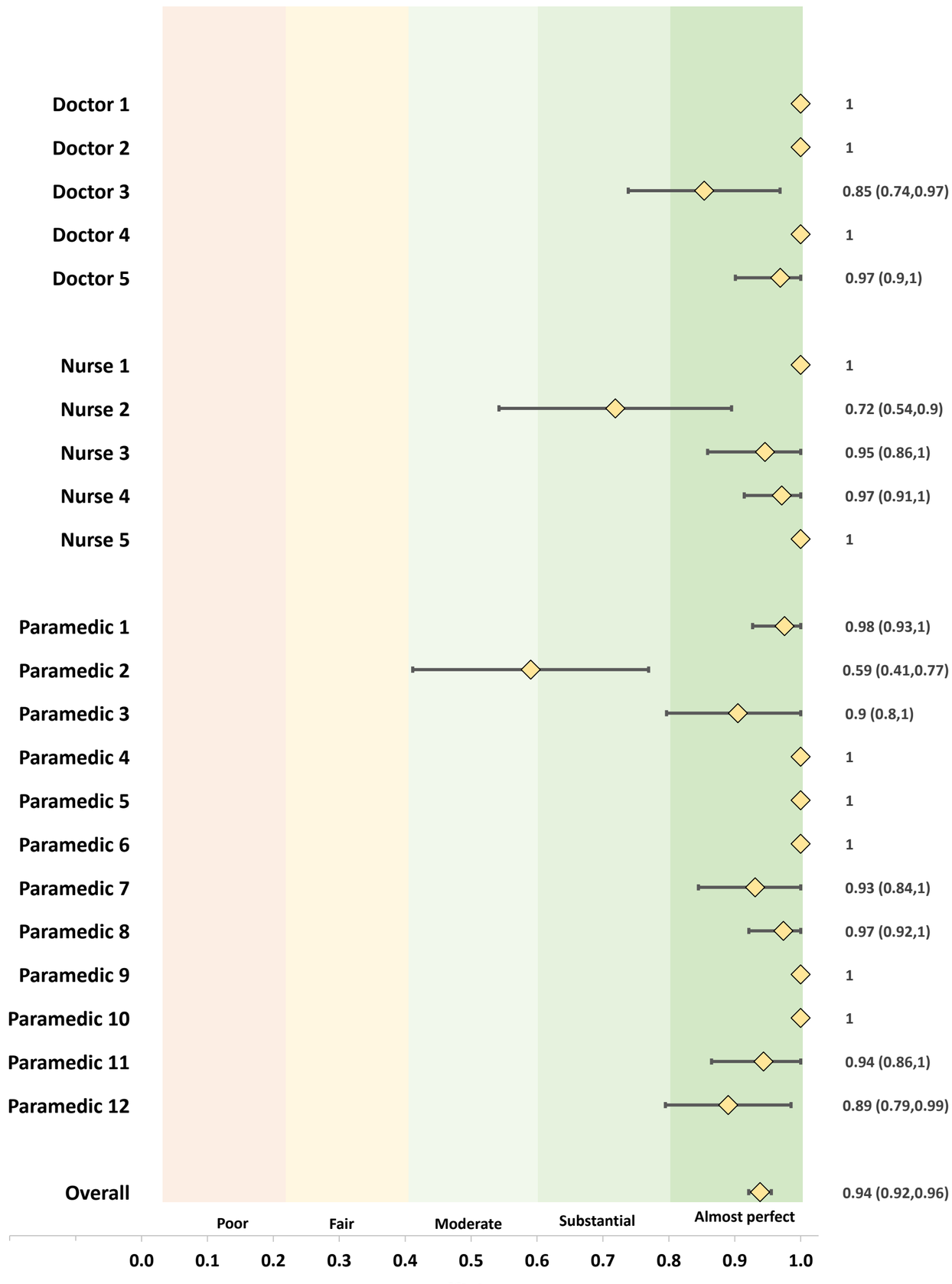

Likert Scale Score
1
2
3
4
5
Challenge Statements
Mean (SD)
Device - Related
1.1 Conducting pulse oximetry assessments with paediatric probes with relatively hard design materials
1.9 (1.2)
1.2 Conducting pulse oximetry assessments with paediatric probes among smaller children
3.2 (1.6)
1.3 Ensuring continuous supply of battery for the pulse oximetry device
3.8 (1.1)
Patient- Related
2.1 Making the child calm before conducting pulse oximetry assessments
4.1 (1)
2.2 Cleaning the area of attachment before conducting pulse oximetry assessments
4 (1)
2.3 Convincing attendants to wait while conducting pulse oximetry assessments
2.5 (1.5)
Environment-Related
3.1 Allocating adequate time for conducting pulse oximetry assessments during rush hours
4.3 (1)
3.2 Finding adequate space for the pulse oximetry device in the crowded work station
3.1 (1.4)
3.3 Maintaining security of pulse oximetery device after office hours
2.2 (1.5)
User- Related
4.1 Cleaning the sensor every time after conducting pulse oximetry assessments
2.7 (1.5)
4.2 Conducting pulse oximetry assessments alone without anyone else's support
4 (1.3)
4.3 Providing adequate attention to other clinical signs of the patient
2.5 (1.6)

Prevalence-adjusted bias-adjusted kappa

By patient-, provider- and facility-related factors

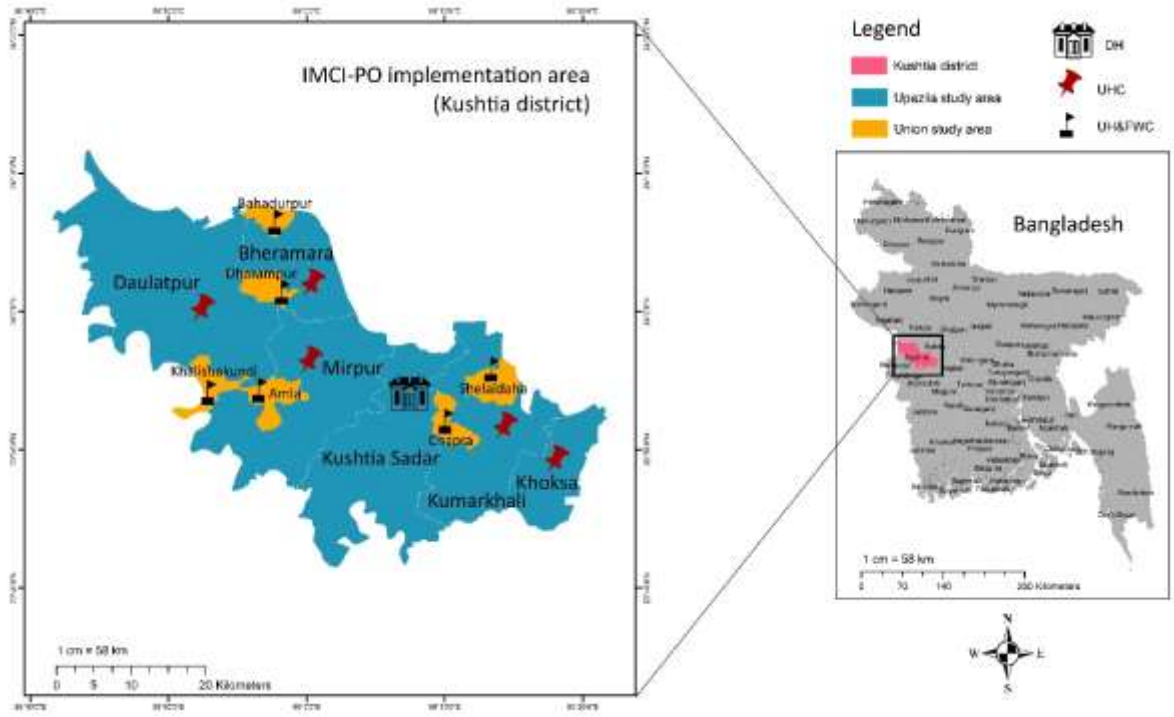


By IMCI service-provider



Supplementary material 1: Study site and health facilities.

Caption: Study site and health facilities selected for introducing pulse oximetry in Kushtia, Bangladesh.



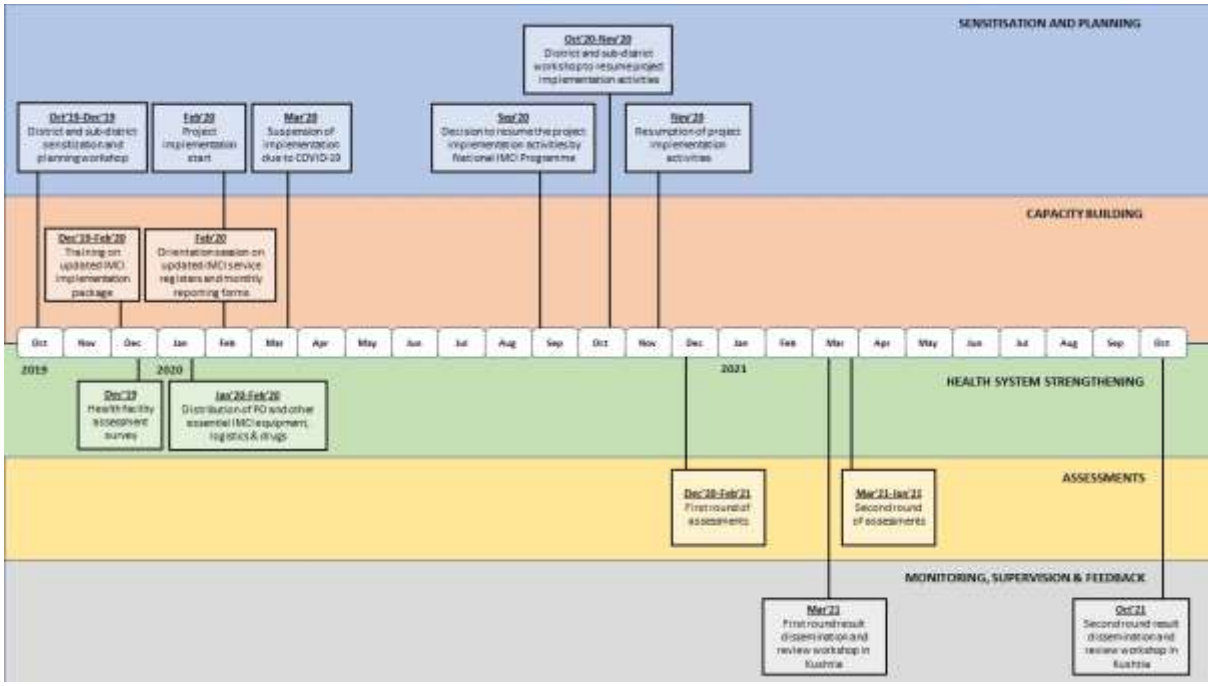
Supplementary material 2: Type, staffing pattern, service availability and IMCI service utilisation of health facilities.

Caption: Type, staffing pattern, service availability and IMCI service utilisation of health facilities selected for introducing pulse oximetry.

Name	Type of Health Facility	Indoor service	Separate paediatric indoor	Emergency service	Outdoor service	IMCI service	Separate IMCI corner	IMCI utilisation								
								All children aged 2-59 months			Severe Pneumonia			Pneumonia		
								2019	2020	2021	2019	2020	2021	2019	2020	2021
Kushtia DH	District Hospital	Yes, 250-bedded	Available	Available	Available	Available	Available	20,294	12,299	13,656	3,218	697	52	3,888	744	408
Kumarkhali UHC	Upazila Health Complex	Yes, 50-bedded	Not Available	Available	Available	Available	Available	18,495	6,636	8,891	367	227	267	655	309	307
Bheramara UHC	Upazila Health Complex	Yes, 50-bedded	Not Available	Available	Available	Available	Available	5,066	3,150	5,355	32	2	8	877	379	443
Mirpur UHC	Upazila Health Complex	Yes, 50-bedded	Not Available	Available	Available	Available	Available	9,072	4,386	4,610	16	4	0	16	1	11
Khoksa UHC	Upazila Health Complex	Yes, 50-bedded	Not Available	Available	Available	Available	Available	10,820	6,578	4,815	128	31	1	3,039	610	42
Daulatpur UHC	Upazila Health Complex	Yes, 50-bedded	Not Available	Available	Available	Available	Available	6,349	4,262	3,465	505	313	171	672	654	293
Shelaidaha USC	Union Sub-Centres	Not Available	Not Applicable	Not Available	Available	Available	Not Available	1,129	1,913	750	0	0	36	151	218	77
Saota USC	Union Sub-Centres	Not Available	Not Applicable	Not Available	Available	Available	Not Available	1,274	932	798	0	0	57	30	92	148
Bahadurpur USC	Union Sub-Centres	Not Available	Not Applicable	Not Available	Available	Available	Not Available	1,469	1,009	1,103	24	178	17	623	193	63
Dharampur USC	Union Sub-Centres	Not Available	Not Applicable	Not Available	Available	Available	Not Available	2,784	877	955	0	0	0	1,094	311	0
Amla USC	Union Sub-Centres	Not Available	Not Applicable	Not Available	Available	Available	Not Available	490	888	618	0	0	0	0	40	214
Khalishakundi USC	Union Sub-Centres	Not Available	Not Applicable	Not Available	Available	Available	Not Available	444	299	747	12	0	0	407	247	3

Supplementary material 3: Important milestones.

Caption: Important milestones for the design, development, and demonstration of the district implementation model.



Supplementary material 4: Primary and secondary research questions and analysis plan.

Caption: Primary and secondary research questions and analysis plan based on paper objectives.

WHO's Implementation Outcome Variable	Research questions for performing pulse oximetry in routine outpatient settings	Statistical test	Rationale and details
	Primary Research Questions		
a) Adoption	**I.** Use: Do IMCI service-providers conduct pulse oximetry assessments?	percentage	Rates presented using percentage.
b) Feasibility	**II.** Success: Can IMCI service- providers successfully conduct pulse oximetry assessments?	Percentage with 95% Confidence Interval	Rates presented using percentage and confidence interval.
	III. Usability by attempt: Can IMCI service-providers successfully conduct pulse oximetry assessments at the first attempt?	Percentage with 95% Confidence Interval	Rates presented using percentage and confidence interval.
	IV. Usability by time: Can IMCI service-providers successfully conduct pulse oximetry assessments within one minute?	Percentage with 95% Confidence Interval	Rates presented using percentage and confidence interval.
c) Fidelity	**V.** Adherence: Do IMCI service-providers follow Standard Operating Procedure (SoP) while conducting pulse oximetry assessments?	Percentage with 95% Confidence Interval	Rates presented using percentage and confidence interval.
	VI. Agreement: Can IMCI service-providers identify hypoxaemia through pulse oximetry?	Percentage with 95% Confidence Interval	Rates presented using percentage and confidence interval.
d) Appropriateness	**VII.** Experience: Do IMCI service- providers conduct pulse oximetry assessments with reasonably low barriers and challenges?	Mean score from 5-point Likert scale with 95% confidence interval	Mean score with confidence interval reported to present the barriers and challenges of performing pulse oximetry to present the central tendency and dispersion of the likert statement scores.
e) Acceptability	**VIII.** Usefulness: Do IMCI service-providers perceive pulse oximetry as useful?	Percentage with 95% Confidence Interval	Rates presented using percentage and confidence interval.
	IX. Importance: Do the caregivers perceive pulse oximetry as important?	Percentage with 95% Confidence Interval	Rates presented using percentage and confidence interval.
	X. Satisfaction: Are the caregivers satisfied with pulse oximetry introduction in routine IMCI services?	Percentage with 95% Confidence Interval	Rates presented using percentage and confidence interval.
f) Sustainability	**XI.** Sustainability: Does the pulse oximetry performance of IMCI service-providers sustain over time (rounds)?	Percentage with 95% Confidence Interval	Rates presented using percentage and confidence interval.
	Secondary Research Questions		

WHO's Implementation Outcome Variable	Research questions for performing pulse oximetry in routine outpatient settings	Statistical test	Rationale and details
Feasibility	**XII.** Can IMCI service-providers successfully conduct pulse oximetry assessments in two attempts?	Percentage with 95% Confidence Interval	Rates presented using percentage and confidence interval.
	XIII. Can IMCI service-providers successfully conduct pulse oximetry in three attempts?	Percentage with 95% Confidence Interval	Rates presented using percentage and confidence interval.
	XIV. Do various patient-, provider- and facility-related factors influence successfully conducting pulse oximetry assessments at the first attempt?	Percentage with 95% Confidence Interval	We assume correlation within the assessments by each assessor. Therefore, GEE has been performed for accounting for this correlation in analysis. Wald statistics used for checking adequacy of model.
	XV. Is there any variation in successfully conducting pulse oximetry assessments at the first attempt by individual IMCI service-providers?	Proportion with heterogeneity statistics across individual assessors (i.e. I2 an Tau2 statistics)	We assumed random variation within assessments by each assessor. Heterogeneity statistics I^2 was used to report the proportion of between assessor variability which is not due to chance and Tau^2 has been reported to report the actual between assessor variability.
	XVI. Can IMCI service-providers successfully conduct pulse oximetry assessment in three minutes?	Percentage with 95% Confidence Interval	Rates presented using percentage and confidence interval.
	XVII. Can IMCI service-providers successfully conduct pulse oximetry assessment in five minutes?	Percentage with 95% Confidence Interval	Rates presented using percentage and confidence interval.
	XVIII. Do various patient-, provider-, and facility-related factors influence successfully conducting pulse oximetry assessments within one minute?	Generalized Estimating Equation reporting odds ratios with 95% confidence interval	We assume correlation within the assessments by each assessor. Therefore, GEE has been performed for accounting for this correlation in analysis. Wald statistics used for checking adequacy of model.
	XIX. Is there any variation in successfully conducting pulse oximetry assessments within one minute by individual IMCI service-providers?	Proportion with heterogeneity statistics across individual assessors (i.e. I2 an Tau2 statistics)	We assumed random variation within assessments by each assessor. Heterogeneity statistics I^2 was used to report the proportion of between assessor

WHO's Implementation Outcome Variable	Research questions for performing pulse oximetry in routine outpatient settings	Statistical test	Rationale and details
			variability which is not due to chance and Tau^2 has been reported to report the actual between assessor variability.
	XX. What is the performance time for successfully conducting pulse oximetry assessments?	Median with Interquartile range (IQR)	Shapiro-Wilk test presented the non-normality of the distribution of the time taken for measurement of SpO_2 . Hence, median times were reported with IQR.
	XXI. Do various patient-, provider-, and facility-related factors influence performance time for successfully conducting pulse oximetry assessments?	Mood's Median Test	Shapiro-Wilk test presented the non-normality of the distribution of the time taken for measurement of SpO_2. Hence, median times were reported with IQR and non-parametric equality of median tests have been performed.
	XXII. Is there any variation in performance time for successfully conducting pulse oximetry assessments by individual IMCI service-providers?	Mood's Median Test	Shapiro-Wilk test presented the non-normality of the distribution of the time taken for measurement of SpO_2. Hence, median times were reported with IQR and non-parametric equality of median tests have been performed.
Fidelity	**XIII.** Do IMCI service-providers ensure the baby was calm before conducting pulse oximetry assessments?	Percentage with 95% Confidence Interval	Rates presented using percentage and confidence interval.
	XIV. Do they place the probe appropriately before conducting pulse oximetry assessments?	Percentage with 95% Confidence Interval	Rates presented using percentage and confidence interval.
	XXV. Do various patient-, provider-, and facility-related factors influence adhering to Standard Operating Procedure (SoP) while conducting pulse oximetry assessments?	Generalized Estimating Equation reporting odds ratios with 95% confidence interval	We assume correlation within the assessments by each assessor. Therefore, GEE has been performed for accounting for this correlation in analysis. Wald statistics used for checking adequacy of model.
	XVI. Is there any variation in adhering to Standard Operating Procedure (SoP) while conducting pulse oximetry	Proportion with heterogeneity statistics across individual assessors	We assumed random variation within assessments by each assessor. Heterogeneity statistics I^2 was used to

WHO's Implementation Outcome Variable	Research questions for performing pulse oximetry in routine outpatient settings	Statistical test	Rationale and details
	assessment by individual IMCI-service providers?	(i.e. I2 an Tau2 statistics)	report the proportion of between assessor variability which is not due to chance and Tau^2 has been reported to report the actual between assessor variability.
	XVII. Do IMCI service-providers adhere to cleanliness practices before conducting pulse oximetry assessments?	Percentage with 95% Confidence Interval	Rates presented using percentage and confidence interval.
	VIII. Do various patient-, provider-, and facility-related factors influence adhering to cleanliness practices while conducting pulse oximetry assessments?	Generalized Estimating Equation reporting odds ratios with 95% confidence interval	We assume correlation within the assessments by each assessor. Therefore, GEE has been performed for accounting for this correlation in analysis. Wald statistics used for checking adequacy of model.
	XIX. Is there any variation in adhering to cleanliness practices while conducting pulse oximetry assessments by individual IMCI service-providers?	Proportion with heterogeneity statistics across individual assessors (i.e. I2 an Tau2 statistics)	We assumed random variation within assessments by each assessor. Heterogeneity statistics I^2 was used to report the proportion of between assessor variability which is not due to chance and Tau^2 has been reported to report the actual between assessor variability.
	XXX. Do various patient-, provider-, and facility-related factors influence agreement of hypoxaemia identification (SpO2<94%) thorough pulse oximetry?	Generalized Estimating Equation reporting odds ratios with 95% confidence interval	We assume correlation within the assessments by each assessor. Therefore, GEE has been performed for accounting for this correlation in analysis. Wald statistics used for checking the adequacy of model.
	XXI. Is there any variation in agreement of hypoxaemia identification (SpO2<94%) through pulse oximetry by individual IMCI service-providers?	Proportion with heterogeneity statistics across individual assessors (i.e. I2 and Tau2 statistics)	We assumed random variation within assessments by each assessor. Heterogeneity statistics I^2 was used to report the proportion of between assessor variability which is not due to chance and Tau^2 has been reported to report the actual between assessor variability.

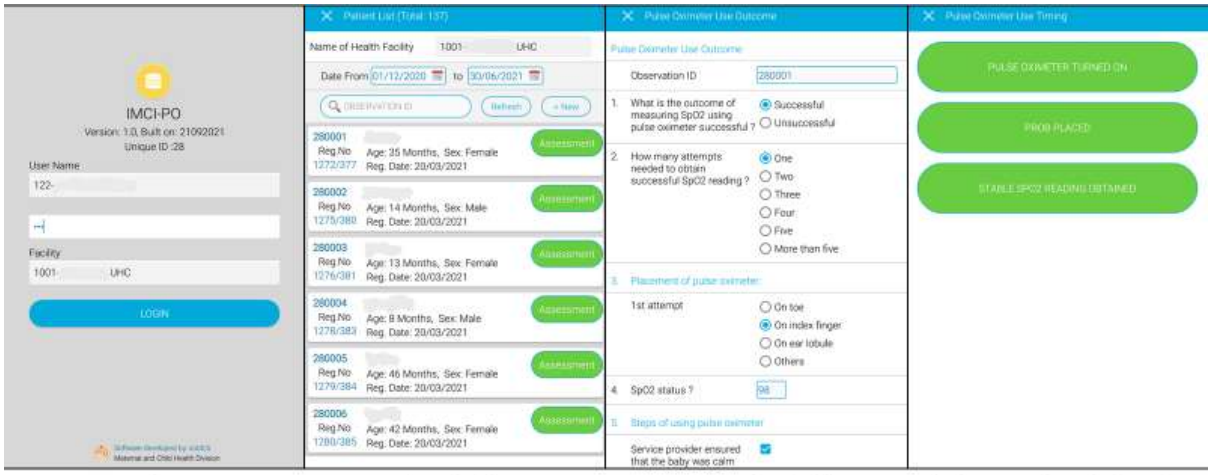
Supplementary material 5: Background characteristics.

Caption: Background characteristics of the data collection team.

Data collector	Data collection type	Age (in years)	Sex	Educational qualification	Experience (in years)
Nurse 1	Observation	24	Female	Diploma in Nursing & Midwifery	3
Nurse 2	Observation	22	Female	Diploma in Nursing & Midwifery	2
Nurse 3	Re-assessment	24	Female	Diploma in Nursing & Midwifery	2
Nurse 4	Re-assessment	23	Male	Diploma in Nursing & Midwifery	1
Paramedic 1	Exit interview	28	Male	Diploma in Medical Faculty	7
Paramedic 2	Exit interview	24	Female	Diploma in Medical Faculty	6
Data extractor 1	Data Extraction	30	Male	Master of Social Science	6
Data extractor 2	Data Extraction	31	Male	Master of Arts	3

Supplementary material 6: Snapshots.

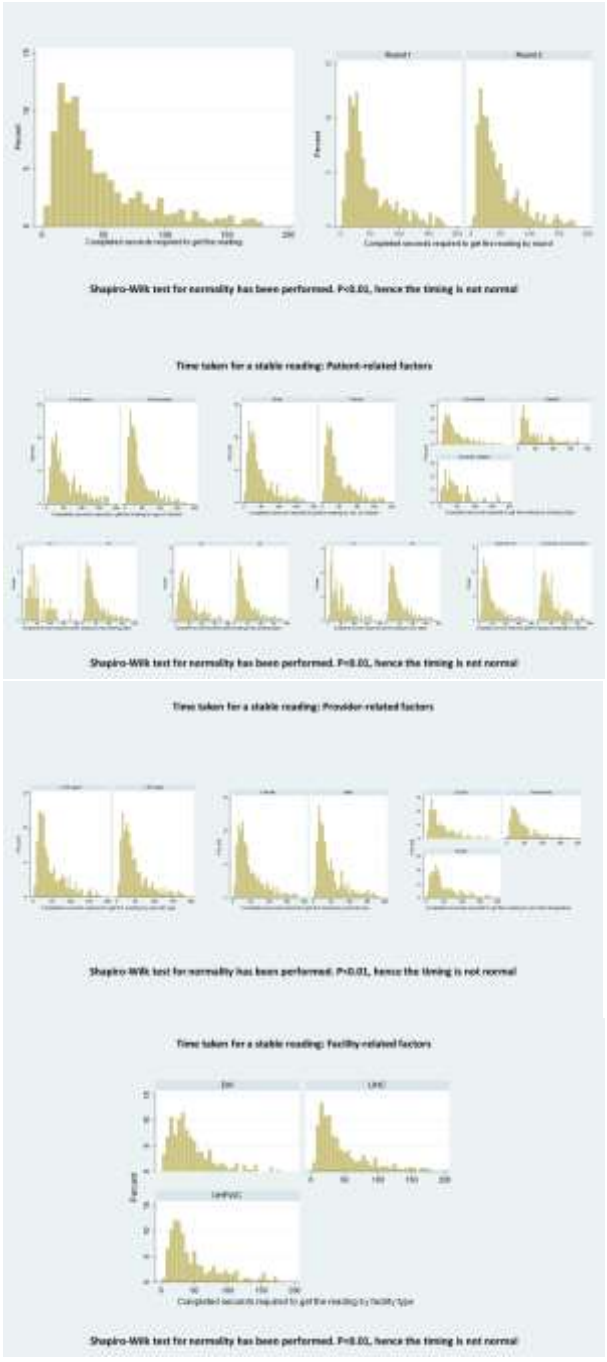
Caption: Snapshots of the survey app.



a. Log-in page **b. Patient list** **c. Observation checklist** **d. Time-stamping option for pulse oximetry timing**

Supplementary material 7: Normality distribution of timing.

Caption: Normality distribution of timing using the Shapiro–Wilk test.



Supplementary material 8: Background characteristics of the IMCI service-providers.

Caption: Background characteristics of the IMCI service-providers by rounds of assessment.

	Round 1		Round 2		All rounds	
	n	%	n	%	n	%
Service provider characteristics						
Age						
≤ 35 years	10	46	10	46	10	46
> 35 years	12	55	12	55	12	55
Sex						
Male	10	46	10	46	10	46
Female	12	55	12	55	12	55
Designation						
Doctor	5	23	5	23	5	23
Nurse	5	23	5	23	5	23
Paramedic	12	55	12	55	12	55
Facility type						
District Hospital	3	14	3	14	3	14
Sub-District Hospital	13	59	13	59	13	59
Union-level Health Centre	6	27	6	27	6	27
Total	22	100	22	100	22	100

Supplementary material 9: Background characteristics of the children presenting with cough/difficulty-in-breathing.

Caption: Background characteristics of the children presenting with cough/difficulty-in-breathing by rounds of assessment.

	Round 1		Round 2		All rounds	
	n	%	n	%	n	%
Patient characteristics						
Age						
2-11 months	355	42	374	45	729	43
12-59 months	500	59	451	55	951	57
Sex						
Male	455	53	453	55	908	54
Female	400	47	372	45	772	46
Z-score (weight for height)						
Not wasted (-2SD and above)	775	92	725	88	1500	90
Wasted (below -2SD)	36	4	62	8	98	6
Severely wasted (below -3SD)	30	4	36	4	66	4
Missing	14		2		16	
Fever						
No	811	95	765	93	1576	94
Yes	44	5	60	7	104	6
Fast breathing						
No	734	88	726	88	1460	88
Yes	102	12	97	12	199	12
Missing	19		2		21	
Chest indrawing						
No	823	98	793	96	1616	97
Yes	18	2	30	4	48	3
Missing	14		2		16	
IMCI classification						
No pneumonia	727	86	717	87	1444	87
Pneumonia/Severe pneumonia	114	14	106	13	220	13
Missing	14		2			
Total	855	51	825	49	1680	100

Supplementary material 10: Number of children assessed by background characteristics of the IMCI services-providers.

Caption: Number of children assessed by background characteristics of the IMCI services-providers by rounds of assessment.

	Round 1		Round 2		All rounds	
	n	%	n	%	n	%
Provider characteristics						
Age						
≤ 35 years	374	44	363	44	737	44
> 35 years	481	56	462	56	943	56
Missing						
Sex						
Male	388	45	385	47	773	46
Female	467	55	440	53	907	54
Missing						
Designation						
Doctor	199	23	198	24	397	24
Nurse	190	22	177	22	367	22
Paramedic	466	55	450	55	916	55
Missing						
Facility characteristics						
District Hospital	132	15	119	14	251	15
Sub-District Hospital	515	60	504	61	1019	61
Union-level Health Centre	208	24	202	25	410	24
Missing						

Supplementary material 11: Number of assessments by IMCI service-providers.

Caption: Number of assessments by IMCI service-providers, by round.

	Number of assessments		
	Round 1	Round 2	All rounds
Doctor 1	45	40	85
Doctor 2	45	40	85
Doctor 3	41	42	83
Doctor 4	35	42	77
Doctor 5	33	34	67
Nurse 1	43	42	85
Nurse 2	33	32	65
Nurse 3	44	34	78
Nurse 4	33	37	70
Nurse 5	37	32	69
Paramedic 1	41	42	83
Paramedic 2	45	41	86
Paramedic 3	31	32	63
Paramedic 4	35	35	70
Paramedic 5	36	35	71
Paramedic 6	34	34	68
Paramedic 7	47	43	90
Paramedic 8	36	40	76
Paramedic 9	42	38	80
Paramedic 10	34	32	66
Paramedic 11	38	34	72
Paramedic 12	47	44	91

Supplementary material 12: Influence of several patient-, provider-, and facility-related factors on successfully conducting pulse oximetry assessments at the first attempt by IMCI services-providers.

Caption: Influence of several patient-, provider-, and facility-related factors on successfully conducting pulse oximetry assessments at the first attempt by IMCI services-providers presented in adjusted odds ratios, N=1680.

		Success at first attempt								
	N	%	OR	Lower	Upper	P value	AOR	Lower	Upper	P value
Patient characteristics										
Age										
2-11 months	582	79.80	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
12-59 months	847	89.30	2.15	1.63	2.83	0.00	2.20	1.65	2.93	0.00
Sex										
Female	634	82.20	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Male	795	87.70	1.51	1.15	1.98	0.00	1.54	1.16	2.04	0.00
Chest indrawing										
No	1384	85.60	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Yes	38	79.20	0.59	0.30	1.19	0.14	0.68	0.28	1.65	0.40
Fast breathing										
No	1250	85.60	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Yes	169	84.90	0.94	0.62	1.42	0.77	1.03	0.30	3.56	0.96
Fever										
No	1346	85.40	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Yes	83	82.20	0.77	0.46	1.30	0.33	0.99	0.52	1.91	0.99
IMCI classification										
No pneumonia	1236	85.60	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Pneumonia/Severe pneumonia	186	84.50	0.91	0.62	1.35	0.66	1.06	0.30	3.78	0.93
Z-score (weight for height)										
Not wasted (-2SD and above)	1287	85.80	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Wasted (below -2SD)	81	82.70	0.80	0.46	1.37	0.41	0.82	0.47	1.43	0.48
Severely wasted (below -3SD)	54	81.80	0.75	0.40	1.43	0.39	0.80	0.41	1.55	0.50
Service provider characteristics										
Age										
≤ 35 years	625	84.90	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
> 35 years	804	85.40	1.05	0.70	1.57	0.81	1.08	0.72	1.62	0.72
Sex										
Female	774	85.40	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Male	655	85.00	0.98	0.65	1.46	0.90	0.88	0.54	1.44	0.61
Designation										
Doctor	349	88.10	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Nurse	302	82.50	0.64	0.36	1.12	0.12	0.60	0.34	1.05	0.07
Paramedic	778	85.00	0.77	0.47	1.26	0.30	0.82	0.46	1.45	0.49
Facility characteristics										
District Hospital	221	88.00	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Sub-District Hospital	863	84.90	0.77	0.42	1.41	0.39	0.91	0.49	1.72	0.78
Health Centre	345	84.10	0.73	0.37	1.42	0.35	0.76	0.36	1.62	0.48
Assessments										
Round 1	727	85.30	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Round 2	702	85.10	0.98	0.75	1.28	0.89	0.98	0.74	1.30	0.89

Supplementary material 13: Influence of several patient-, provider-, and facility-related factors on successfully conducting pulse oximetry assessments within one minute by IMCI services-providers.

Caption: Influence of several patient-, provider-, and facility-related factors on successfully conducting pulse oximetry assessments within one minute by IMCI services-providers, presented in adjusted odds ratios, N=1680.

		Success within one minute								
	N	%	OR	Lower	Upper	P value	AOR	Lower	Upper	P value
Patient characteristics										
Age										
2-11 months	439	61	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
12-59 months	709	75	1.95	1.58	2.41	0.00	2.05	1.65	2.55	0.00
Sex										
Female	509	67	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Male	639	71	1.20	0.97	1.48	0.09	1.21	0.98	1.50	0.08
IMCI classification										
No pneumonia	998	70	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Pneumonia/Severe pneumonia	144	66	0.82	0.61	1.11	0.20	0.88	0.32	2.42	0.81
Chest indrawing										
No	1112	69	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Yes	30	63	0.69	0.38	1.25	0.22	0.90	0.44	1.84	0.77
Fast breathing										
No	1009	70	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Yes	131	66	0.84	0.62	1.15	0.29	1.08	0.40	2.91	0.89
Fever										
No	1083	69	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Yes	65	65	0.81	0.53	1.23	0.32	0.79	0.49	1.27	0.33
Z-score (weight for height)										
Not wasted (-2SD and above)	1036	70	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Wasted (below -2SD)	62	65	0.80	0.52	1.23	0.31	0.79	0.51	1.24	0.30
Severely wasted (below -3SD)	44	67	0.86	0.51	1.46	0.58	0.89	0.52	1.53	0.67
Service provider characteristics										
Age										
≤ 35 years	488	67	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
> 35 years	660	71	1.18	0.92	1.51	0.19	1.17	0.90	1.53	0.23
Sex										
Female	608	67	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Male	540	71	1.18	0.92	1.51	0.20	1.05	0.78	1.43	0.74
Designation										
Doctor	276	70	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Nurse	237	65	0.78	0.55	1.11	0.17	0.77	0.55	1.08	0.13
Paramedic	635	70	0.98	0.72	1.32	0.88	1.03	0.73	1.45	0.86
Facility characteristics										
District Hospital	177	71	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Sub-District Hospital	701	70	0.95	0.65	1.38	0.78	1.06	0.72	1.55	0.78
Health Centre	270	67	0.83	0.55	1.26	0.39	0.81	0.51	1.29	0.38
Assessments										
Round 1	560	67	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Round 2	588	72	1.26	1.02	1.55	0.03	1.30	1.05	1.62	0.02

Supplementary material 14: Influence of several patient-, provider-, and facility-related factors on adhering to SoPs while conducting pulse oximetry assessments by IMCI services-providers.

Caption: Influence of several patient-, provider-, and facility-related factors on adhering to SoPs while conducting pulse oximetry assessments by IMCI services-providers presented in adjusted odds ratios, N=1680.

		Adherence to SoP of PO use								
	n	%	OR	Lower	Upper	P value	AOR	Lower	Upper	P value
Patient characteristics										
Age										
2-11 months	674	92.50	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
12-59 months	868	91.60	0.99	0.72	1.36	0.95	1.06	0.69	1.61	0.80
Sex										
Female	719	93.30	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Male	823	90.80	0.81	0.59	1.12	0.20	0.69	0.46	1.05	0.09
Z-score (weight for height)										
Not wasted (-2SD and above)	1378	91.90	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Wasted (below -2SD)	91	92.90	1.04	0.53	2.05	0.91	0.75	0.29	1.94	0.55
Severely wasted (below -3SD)	64	97.00	1.86	0.64	5.37	0.25	1.59	0.33	7.72	0.56
Chest indrawing										
No	1488	92.10	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Yes	45	93.80	0.79	0.33	1.88	0.59	0.81	0.19	3.55	0.79
Fast breathing										
No	1349	92.40	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Yes	179	89.90	0.66	0.43	1.03	0.07	0.60	0.07	5.43	0.65
Fever										
No	1452	92.10	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Yes	90	89.10	0.65	0.37	1.16	0.15	0.50	0.18	1.36	0.17
IMCI classification										
No pneumonia	1334	92.40	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Pneumonia/Severe pneumonia	199	90.50	0.68	0.44	1.04	0.08	1.32	0.14	12.10	0.81
Service provider characteristics										
Age										
≤ 35 years	686	93.20	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
> 35 years	856	91.00	0.74	0.22	2.49	0.63	0.29	0.15	0.53	0.00
Sex										
Female	813	89.70	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Male	729	94.60	2.09	0.64	6.76	0.22	2.98	1.34	6.63	0.01
Designation										
Doctor	377	95.20	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Paramedic	846	92.50	0.62	0.12	3.22	0.57	1.88	0.55	6.43	0.31
Nurse	319	87.20	0.36	0.06	2.04	0.25	0.42	0.16	1.10	0.08
Facility characteristics										
District Hospital	243	96.80	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Sub-District Hospital	943	92.80	0.39	0.03	4.79	0.46	0.03	0.00	0.25	0.00
Health Centre	356	86.80	0.21	0.02	2.67	0.23	0.00	0.00	0.05	0.00
Assessments										
Round 1	725	85.10	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Round 2	817	99.00	15.98	5.67	45.00	0.00	28.62	11.03	74.29	0.00

Supplementary material 15: Influence of several patient-, provider-, and facility-related factors on agreement of identifying hypoxaemia through pulse oximetry between IMCI services-providers and study nurses.

Caption: Influence of several patient-, provider-, and facility-related factors on agreement of identifying hypoxaemia through pulse oximetry between IMCI services-providers and study nurses, presented in adjusted odds ratios, N=1680.

		Observed agreement (94% SpO2)								
	N	%	OR	Lower	Upper	P value	AOR	Lower	Upper	P value
Patient characteristics										
Age										
2-11 months	696	96.7	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
12-59 months	905	97.1	1.23	0.71	2.13	0.47	1.19	0.67	2.11	0.55
Sex										
Female	733	96.6	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Male	868	97.2	1.01	0.59	1.75	0.97	1.07	0.60	1.89	0.82
IMCI classification										
No pneumonia	1396	97.5	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Pneumonia/Severe pneumonia	205	93.2	0.41	0.21	0.80	0.01	0.38	0.06	2.40	0.30
Chest indrawing										
No	1557	97.1	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Yes	44	91.7	0.58	0.16	2.12	0.41	1.35	0.33	5.53	0.68
Fast breathing										
No	1412	97.4	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Yes	186	93.5	0.42	0.21	0.84	0.01	1.00	0.16	6.15	1.00
Fever										
No	1518	97	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Yes	83	95.4	0.78	0.26	2.36	0.67	0.92	0.30	2.84	0.89
Z-score (weight for height)										
Not wasted (-2SD and above)	1443	96.9	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Wasted (below -2SD)	95	97.9	1.52	0.37	6.15	0.56	1.46	0.36	5.95	0.60
Severely wasted (below -3SD)	63	95.5	0.75	0.22	2.55	0.65	0.75	0.21	2.59	0.64
Service provider characteristics										
Age										
≤ 35 years	711	97.8	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
> 35 years	890	96.2	0.67	0.15	2.92	0.60	1.10	0.27	4.44	0.89
Sex										
Female	867	97.3	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Male	734	96.5	0.84	0.20	3.49	0.81	0.72	0.10	5.31	0.75
Designation										
Doctor	384	98.2	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Nurse	346	96.6	0.48	0.05	5.15	0.55	0.49	0.06	4.17	0.51
Paramedic	871	96.5	0.52	0.06	4.42	0.55	0.30	0.04	2.12	0.23
Facility characteristics										
District Hospital	232	95.5	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Sub-District Hospital	970	96.5	1.30	0.23	7.42	0.77	1.33	0.15	11.38	0.80
Health Centre	399	98.8	3.69	0.29	47.41	0.32	4.97	0.36	68.53	0.23
Assessments										
Round 1	801	96	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Round 2	800	97.8	1.82		1.00	3.30	0.05	1.76	0.96	3.23	0.07

Supplementary material 16: Influence of several patient-, provider-, and facility-related factors on optimum cleanliness practices by IMCI services-providers.

Caption: Influence of several patient-, provider-, and facility-related factors on optimum cleanliness practices by IMCI services-providers, presented in adjusted odds ratios, N=1680.

		Adherence to cleanliness practices								
	N	%	OR	Lower	Upper	P value	AOR	Lower	Upper	P value
Patient characteristics										
Age										
2-11 months	555	76.10	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
12-59 months	651	68.70	0.69	0.55	0.86	0.00	0.66	0.51	0.85	0.00
Sex										
Female	566	73.40	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Male	640	70.60	0.87	0.70	1.08	0.21	0.92	0.71	1.18	0.49
IMCI classification										
No pneumonia	1038	71.90	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Pneumonia/Severe pneumonia	160	72.70	1.04	0.76	1.43	0.80	1.17	0.34	3.98	0.81
Chest indrawing										
No	1166	72.20	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Yes	32	66.70	0.77	0.42	1.42	0.41	0.48	0.21	1.12	0.09
Fast breathing										
No	1050	71.90	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Yes	145	72.90	1.05	0.75	1.46	0.78	0.90	0.27	3.00	0.86
Fever										
No	1138	72.20	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Yes	68	67.30	0.79	0.52	1.22	0.29	0.59	0.34	1.02	0.06
Z-score (weight for height)										
Not wasted (-2SD and above)	1074	71.60	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Wasted (below -2SD)	75	76.50	1.29	0.80	2.09	0.29	1.04	0.59	1.81	0.90
Severely wasted (below -3SD)	49	74.20	1.14	0.65	2.01	0.64	1.45	0.74	2.85	0.28
Service provider characteristics										
Age										
≤ 35 years	569	77.30	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
> 35 years	637	67.70	0.61	0.49	0.77	0.00	1.07	0.79	1.46	0.66
Sex										
Female	645	71.20	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Male	561	72.80	1.08	0.87	1.34	0.48	0.33	0.23	0.46	0.00
Designation										
Doctor	253	63.90	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Paramedic	669	73.10	1.54	1.19	1.98	0.00	2.63	1.82	3.79	0.00
Nurse	284	77.60	1.96	1.42	2.70	0.00	1.77	1.17	2.69	0.01
Facility characteristics										
District Hospital	91	36.30	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Sub-District Hospital	823	81.00	7.50	5.55	10.13	0.00	20.34	13.10	31.60	0.00
Health Centre	292	71.20	4.35	3.11	6.08	0.00	6.96	4.14	11.73	0.00
Assessments										
Round 1	512	60.10	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Round 2	694	84.10	3.52	2.79	4.44	0.00	4.82	3.68	6.32	0.00

Supplementary material 17: Summary of findings on the secondary research questions.

Caption: Summary of findings on the secondary research questions based on paper objectives.

Outcome		Secondary Research Questions	Answers
Feasibility	1	Can they successfully conduct pulse oximetry assessments in two attempts?	96%, 95% CI (95,97)
	2	Can they successfully conduct pulse oximetry assessments in three attempts?	99%, 95% CI (98,99)
	3	Do various patient-, provider- and facility- factors influence successfully conducting pulse oximetry assessments at the first attempt?	Supplementary material 13
	4	Is there any variation in successfully conducting pulse oximetry assessments at the first attempt by individual IMCI service-providers?	Figure-3
	5	Can IMCI service-providers successfully conduct pulse oximetry assessments in three minutes?	94%, 95% CI (92,95)
	6	Can MCI service-providers successfully conduct pulse oximetry assessments in five minutes?	98%, 95% CI (97,98)
	7	Do various patient-, provider-, and facility- factors influence successfully conducting pulse oximetry assessments within one minute?	Supplementary material 14
	8	Is there any variation in successfully conducting pulse oximetry assessments within one minute by individual IMCI-service providers?	Figure-3
	9	What is the performance time for successfully conducting pulse oximetry assessments?	Figure-4
	10	Do various patient-, provider-, and facility-related factors influence performance time for successfully performing pulse oximetry	Figure-4
	11	Is there any variation in performance time for successfully performing pulse oximetry by individual IMCI service-providers?	Figure-4
Fidelity	12	Do the IMCI service providers ensure the baby was calm before conducting pulse oximetry assessment?	93%, 95% CI (91,94)
	13	Do the IMCI service providers place the probe appropriately while conducting pulse oximetry assessments?	99%, 95% CI (98,99)
	14	Do various patient-, provider-, and facility- factors influence adhering to Standard Operating Procedure (SoP) while conducting pulse oximetry assessments?	Supplementary material 15
	15	Is there any variation in adhering to Standard Operating Procedure (SoP) while conducting pulse oximetry assessments by individual IMCI service-providers?	Figure-3
	16	Do the IMCI service-providers adhere to cleanliness practices before conducting pulse oximetry assessments?	72%, 95% CI (70,74)
	17	Do various patient-, provider-, and facility- factors influence adhering to cleanliness practices before conducting pulse oximetry assessments?	Supplementary material 17
	18	Is there any variation in adhering to cleanliness practices before conducting pulse oximetry assessment by individual IMCI service-providers?	Supplementary material 19
	19	Do various patient-, provider-, and facility-related factors influence agreement of hypoxaemia identification (SpO2<94%) through pulse oximetry?	Supplementary material 16
	20	Is there any variation in agreement of hypoxaemia identification (SpO2<94%) through pulse oximetry by individual IMCI service-providers?	Figure-3