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Opportunities and barriers in paediatric pulse oximetry for pneumonia in low-resource clinical settings: a qualitative evaluation from Malawi and Bangladesh

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3 1 **Title:** Opportunities and barriers in paediatric pulse oximetry for pneumonia in low-resource clinical
4 2 settings: a qualitative evaluation from Malawi and Bangladesh
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1
2
3 30 **Abstract**
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5 31 *Objective:* To gain an understanding of what challenges pulse oximetry for paediatric pneumonia
6 management poses, how it has changed service provision and what would improve this device for
7 use across paediatric clinical settings in low-income countries.
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10 34 *Design:* Focus group discussions (FGDs), with purposive sampling and thematic analysis using a
11 framework approach.
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13

14 36 *Setting:* Community, front line outpatient and hospital outpatient and inpatient settings in Malawi
15 and Bangladesh, which provide paediatric pneumonia care.
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18 38 *Participants:* Healthcare providers (HCPs) from Malawi and Bangladesh who had received training in
19 pulse oximetry and had been using oximeters in routine paediatric care, including community
20 healthcare workers, non-physician clinicians or medical assistants, and hospital-based nurses and
21 doctors.
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23
24

25 42 *Results:* We conducted six FGDs, with 23 participants from Bangladesh and 26 from Malawi. We
26 identified five emergent themes: trust; value; user-related experience; sustainability and design.
27 HCPs discussed the confidence gained through using oximeters, resulting in improved trust from
28 caregivers and valuing the device; although there were conflicts between the weight given to clinical
29 judgement versus oximeter results. HCPs reported the ease of using oximeters, but identified
30 movement and physically smaller children as measurement challenges. Challenges in sustainability
31 related to battery durability and replacement parts, however many HCPs had used the same device
32 longer than four years demonstrating robustness within these settings. Desirable features included
33 back-up power banks and integrated respiratory rate and thermometer capability.
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42 51 *Conclusions:* Pulse oximetry was generally deemed valuable by HCPs for use as a spot-check device
43 in a range of paediatric low-income clinical settings. Areas highlighted as challenges by HCPs, and
44 therefore opportunities for re-design, included battery charging and durability, probe fit and
45 sensitivity in paediatric populations.
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3 55 **Strengths and Limitations**
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- 5 56 • This is the first study to report on end-user perceptions of opportunities, challenges and
6 57 desirable design features of pulse oximeters used for paediatric pneumonia management in
7 58 low-resource settings, including community and outpatient providers.
8
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10 59 • Pulse oximeters were valued by healthcare providers, but challenges were highlighted with
11 60 use in smaller and moving children. Desirable features to improve pulse oximeters for low-
12 61 resource paediatric settings included improved battery life, integrated respiratory rate and
13 62 temperature, and quicker results.
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17 63 • A key strength was the wide range of healthcare provider perspectives included, from
18 64 community to referral hospital settings in South Asia and sub-Saharan Africa.
19
20 65 • The study was limited to participant's experience of using specific pulse oximeters and
21 66 therefore may lack generalizability to other paediatric pulse oximeters not used in these
22 67 settings.
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69 Introduction

70 Several interventions, such as Pneumococcal conjugate vaccine (PCV) and standardised guidelines
71 for diagnosis and treatment, have led to reductions in pneumonia morbidity and mortality over the
72 last twenty years ^{1,2}. However, in spite of these gains, pneumonia remains the leading cause of
73 infectious mortality amongst children globally, with the vast majority of the burden falling in sub-
74 Saharan Africa and south Asia ³. To accelerate reductions in pneumonia mortality, further
75 refinement of diagnosis and treatment pathways are needed, including correct referral and access to
76 oxygen treatment ⁴.

77 Pulse oximetry non-invasively measures peripheral arterial oxyhemoglobin saturation (SpO₂).
78 Hypoxemia (defined as an SpO₂ <90%) is included in the World Health Organization (WHO)
79 guidelines as a pneumonia danger sign ⁵, and is associated with increased mortality from
80 pneumonia, as well as other illnesses like malaria ⁶⁻⁸. Recent evidence from Malawi has also
81 indicated that a SpO₂ 90-92% is predictive of mortality amongst children hospitalized with
82 pneumonia ⁸.

83 While some studies have attempted to predict hypoxemia in children with pneumonia using a
84 combination of clinical signs, there has been mixed success ⁹⁻¹¹. Clinical signs alone fail to identify a
85 proportion of hypoxemic children based on the current WHO guidelines, which results in a missed
86 opportunity for referral and appropriate treatment ^{12,13}. In addition, the subjectivity of clinical signs
87 can lead to variation in care – especially among community healthcare workers (CHWs), who often
88 lack ongoing supervision.

89 Pulse oximeters have been successfully used in low-resource paediatric settings, but are yet to be
90 widely adopted, particularly during outpatient care ^{14,15}. The Ethiopian Ministry of Health has
91 demonstrated leadership in this area, setting up an initiative in 2016 to ensure oximetry and oxygen
92 therapy are available nationally across the healthcare system ¹⁶. However, Ethiopia is an exception,
93 with implementation of oximetry in other developing countries continuing to be slow.
94 Implementation barriers cited include cost, lack of appropriately designed, robust oximeters and
95 universal paediatric probes and issues with training and supervision ¹⁷.

96 In order to better understand current barriers to use of pulse oximetry by healthcare providers
97 (HCPs) in a range of healthcare settings, and explore opportunities that this technology provides,
98 input from end-users is needed ¹⁸. With the ultimate goal of designing a universal paediatric probe
99 for all levels of healthcare services in resource-poor settings, we aimed to gain an understanding of
100 the challenges of pulse oximetry, how its use has changed service provision and how current devices

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3 101 could be improved for these settings. This end-user perspective is currently limited in the literature
4 102 and is essential to ensure investment in pulse oximetry is sustainable and effective.
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9 104 **Methods**

10 105 We conducted a qualitative study with HCPs from different levels of the healthcare system in Malawi
11 106 (Mchinji district, central region) and Bangladesh (Sylhet district, northeast region) from May – July
12 107 2016, as part of a wider programme of work aiming to design a universal paediatric oximeter probe.
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16 108 Setting:

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20 109 In Malawi there are three levels of government provided healthcare: CHWs (locally known as Health
21 110 Surveillance Assistants), health centres and district hospitals. CHWs conduct weekly or bi-weekly
22 111 village clinics and home visits providing basic integrated community case management (iCCM) for
23 112 paediatric infections^{19 20}. Health centres are outpatient facilities run by nurses, clinical officers or
24 113 medical assistants, and District Hospitals have inpatient facilities with capacity for oxygen treatment.
25
26 114 In Bangladesh, the study was conducted at Projahnmo, a research consortium comprised of Johns
27 115 Hopkins University and several local non-governmental organizations in partnership with the
28 116 Bangladesh Ministry of Family Health and Welfare. Current Projahnmo activities are integrated
29 117 within three government-operated sub-district hospitals, called Upazila Health Complexes (UHCs),
30 118 and the referral government hospital in Sylhet city (Osmani Medical College), all of which are staffed
31 119 by physicians and nurses. The UHCs operate outpatient clinics for children under five and provide
32 120 basic inpatient paediatric care, including oxygen. The majority of government provided inpatient
33 121 care is provided at Osmani Medical College. Female CHWs employed by Projahnmo conduct
34 122 bimonthly household surveillance, with a subset of CHWs providing weekly surveillance as a part of a
35 123 PCV effectiveness study. Projahnmo CHWs conduct basic clinical assessments and refer ill children
36 124 for care at the UHCs; they do not administer medicines themselves.
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46 125 Currently pulse oximetry is not part of standard care in the community or health centre setting in
47 126 either Malawi or Bangladesh. In Mchinji, pulse oximetry was successfully introduced into all three
48 127 healthcare settings in 2012 as part of a PCV research project, using the Acare Technology AH-MX
49 128 manufactured Lifebox® oximeter and universal adult clip probe¹². Since 2015, a National Institutes of
50 129 Health-funded study (K01TW009988) trained and supplied all Projahnmo clinical staff in Bangladesh,
51 130 including CHWs, with pulse oximeters to screen children for hypoxemia, using the Masimo Rad5®
52 131 oximeter and the LNCS® Y-I Multisite wrap probe (Figure 1).
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3 132 Design:
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5 133 We conducted focus group discussions (FGDs). We planned three FGDs in each country, aiming to
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7 134 recruit between 6 and 10 people for each FGD (up to 60 participants in total). The groups were
8
9 135 planned to be CHWs, health centre or UHC staff, and referral hospital staff separately. Conducting
10
11 136 separate FGDs for the different types of healthcare workers was to allow context-specific discussions
12
13 137 and encourage participants with varying training backgrounds to feel confident about raising
14
15 138 challenges relevant to their specific setting.

16 139 Sampling:
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18 140 HCPs were purposefully sampled from sites where pulse oximetry had been introduced, and the
19
20 141 participants had received some form of training or mentorship in oximetry. Participants were
21
22 142 identified by local researchers (BZ in Malawi and SA in Bangladesh) to be a representative sample of
23
24 143 HCPs from their setting (e.g. small and large health centres, inpatient wards and outpatient
25
26 144 departments in the hospital), and contacted directly by phone. All HCPs contacted participated.
27
28 145 Participants were reimbursed for their travel costs and provided with refreshments.

29 146 Procedure:
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31 147 FGDs were led by local researchers with experience in conducting qualitative research, with support
32
33 148 from a facilitator with knowledge of pulse oximeters. The FGDs were divided into two sections, the
34
35 149 first addressing the participants' personal experience with using pulse oximeters. The topic guide
36
37 150 included: positive and negative experiences, and possible improvements and challenges (Web
38
39 151 appendix 1). During the second part of the discussion, the participants were presented with different
40
41 152 probe designs and given an opportunity to use them for an hour. Following this, the discussion
42
43 153 addressed positive and negative aspects of the different designs to encourage critical thinking of
44
45 154 possible design solutions to the current limitations of a universal paediatric probe.

46 155 The FGDs were audio recorded and then transcribed. The participants were told to answer in English
47
48 156 or their native tongue (Chichewa, Bangla or Sylheti), depending on their preference and ease of
49
50 157 expressing concepts. Recordings were transcribed and translated where necessary. Translations for
51
52 158 Malawi were done by BZ and EK together until final transcripts were agreed, and by an independent
53
54 159 professional service for Bangladesh.

54 160 Analysis:
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56 161 We analysed the data thematically using a framework approach, as an appropriate method for a
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58 162 multi-disciplinary team conducting health research²¹. This process involves five steps:
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3 163 familiarisation, identifying a thematic framework, indexing, mapping and interpretation²². The
4 164 transcripts and notes from the FGDs were printed and coded on paper, with the coding matrix
5 165 created in Microsoft Excel. CK and KF independently familiarised themselves and indexed the data,
6 166 and the emergent themes were discussed until a consensus was reached on the mapping and
7 167 interpretation of the data. This interpretation was shared with the local researchers (BZ and EK in
8 168 Malawi; EDM and MI in Bangladesh) for further discussion until all were in agreement.

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13 169 Ethics:

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16 170 Written informed consent was obtained from all FGD participants. This study was reviewed and
17 171 approved by the University College London research ethics committee (8075/003), Johns Hopkins
18 172 Medicine Institutional Review Board (IRB00047406), the Malawi National Health Sciences Research
19 173 Committee (16/4/1570) and Bangladesh Medical Research Council (BMRC/NREC/2013-2016/1272).

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26 175 **Results**

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28 176 We conducted six FGDs, with 23 participants from Bangladesh and 26 from Malawi (Table 1). We
29 177 identified five emergent themes: trust; value; user-related experience; sustainability and design.

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32 178 Trust

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34 179 Trust emerged as a theme both in terms of how the HCPs interpret the oximetry results, and how
35 180 caregivers interact with HCPs and the pulse oximeter. We found that all cadres of HCPs in both sites
36 181 had an awareness of the fallibility of the oximetry readings, specifically relating to lower SpO₂ values.
37 182 For SpO₂ levels which were deemed abnormal, <90% up to <95% according to different participants,
38 183 HCPs stated that they would often re-check the result before making a referral or treatment
39 184 decision:

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45 185 *"if we see it is 89% we change the probe or change the finger" (Hospital, Bangladesh)*

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47 186 However, questioning the validity of these lower SpO₂ results in the context of a child's clinical
48 187 condition was only discussed by the HCPs who worked in the hospital setting. This difference in the
49 188 trust placed in the SpO₂ results by different types of HCPs suggests that more in-depth clinical
50 189 training and understanding of the technology may result in different clinical applications:

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54
55 190 *"sometimes the pulse oximeter can give readings which you are not comfortable with according to*
56 191 *the presentation of the child [...] most of the time when it happens like that, we just use our*
57 192 *judgement" (Hospital, Malawi)*

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2
3 193 An outcome of using pulse oximeters for pneumonia diagnosis was a change in parental and
4 194 community understanding and perceptions of care, with HCPs discussing increased trust in their
5 195 referral and treatment decisions. This worked in two ways, firstly with the oximeter acting as a direct
6 196 feedback and education tool:

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10 197 *"if the mother is able to read you can show the exact figure and she will accept the treatment of*
11 198 *oxygen, [before] it was very difficult to explain the role or the importance of the oxygen machine and*
12 199 *some mothers refused"* (Hospital, Malawi)

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16 200 Secondly, in Malawi HCPs projected that the oximeters had improved clinical care, and therefore
17 201 outcomes, which led caregivers to be more inclined to accept the referral or treatment being
18 202 recommended, especially in the case of oxygen:

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20
21 203 *"[previously] in the village they were saying that when a child is put on the oxygen machine it*
22 204 *facilitates death, therefore it was making problems, but this time because children are put on oxygen*
23 205 *earlier they survive, it's because we knew the saturation"* (Health centre, Malawi)

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27 206 Value

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30 207 The theme of value relates to the inherent value of improved decision making, HCPs perceived self-
31 208 value (i.e. confidence) in their clinical work, and the physical value placed on maintaining a working
32 209 pulse oximeter. As pneumonia is classified using a range of non-specific and often subjective clinical
33 210 signs, HCPs discussed the positive addition of this more objective measure:

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37 211 *"...by looking at this we can understand how much respiratory distress is in there. Of course this helps*
38 212 *us a lot."* (Health Centre, Bangladesh)

39
40
41 213 In both sites HCPs from frontline settings (CHWs, health centres and UHCs) stated that the pulse
42 214 oximeters had changed the way they work and given them confidence in making referral decisions.
43 215 Interestingly however, in the referral hospital setting in Bangladesh where staff training is higher,
44 216 very little value was placed on the pulse oximeter for improving their clinical performance, with the
45 217 ability to conduct chest x-rays, lung ultra-sound and their clinical judgement valued more highly:

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47
48 218 *"...its sensitivity and specificity is very negligible to be taken as a diagnostic tool."* (Hospital,
49 219 Bangladesh)

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53
54 220 In Bangladesh the CHWs reported pride in using the oximeters. In Malawi, the CHWs (who
55 221 individually own the oximeters) placed a physical value on the oximeters and discussed the personal
56 222 effort, such as paying out of pocket for charging, they put in to maintaining a working device:

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3 223 *"...we have been trying all that is humanly possible to take care of these things, but it only becomes a*
4 224 *problem when it comes to the issue of charging."* (CHW, Malawi)

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7 225 This was also reflected at the health centre, where not all facilities have electricity and one or two
8 226 staff are responsible for assessing children; at the referral hospital however this was not discussed,
9 227 with oximeters belonging to the ward, which has a more consistent power supply. Ward-based
10 228 ownership was discussed as a challenge by hospital staff, suggesting individual ownership could
11 229 result in improved care and maintenance.

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16 230 *"...some of the clinicians do not take care of them, so when the machine is not working it means the*
17 231 *whole department is affected"* (Hospital, Malawi)

18
19
20 232 User-related experience

21
22 233 HCPs at all levels discussed their experiences of using pulse oximeters in children under 5-years,
23 234 presenting challenges, their solutions and perceptions of usability. The time taken to get a
24 235 measurement ranged widely, with CHWs in Bangladesh agreeing measurements took less than 1
25 236 minute but in Malawi that it could take up to 20 minutes. The factors that increased the time taken
26 237 to get a measurement were consistently cited as movement and physically smaller children, and in
27 238 Malawi dirty toes making measurements difficult:

28
29
30 239 *"Getting readings from irritable babies is a bit tough and it takes time."* (Health centre, Bangladesh)

31
32
33 240 *"...using it on a child up to six months of age, sometimes it has been a problem because these*
34 241 *children have got small fingers, so although we use toes sometimes they are also small and the child*
35 242 *is afraid so they start crying. So we have got other things we can give a child to play with but it is a*
36 243 *little bit of a problem, but at the end we get the results."* (CHW, Malawi)

37
38
39 244 Solutions to these challenging children included asking caregivers to breastfeed, giving them a toy to
40 245 distract them, and simply waiting. The term used frequently to describe challenging children was
41 246 'fear', with the HCPs stating that children are afraid of having the measurements taken and even
42 247 that the sensors' red light caused this fear. Despite these issues in small and agitated infants, the
43 248 oximeters were considered easy to use:

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45
46 249 *"...it's not complicated, it doesn't need complicated education for a healthcare worker to use, with a*
47 250 *good explanation from a colleague or friend you are able to use it."* (Hospital, Malawi)

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3 251 There was also the acknowledgement that time to reading was not as important as getting the
4
5 252 correct measurement; for some respondents, the reason some measurements take longer is the
6
7 253 desire to get a reliable reading. This included cleaning the child's digits or repositioning the probe:
8
9 254 *"...taking longer does not mean that one doesn't know the procedure, but sometime it's because you*
10
11 255 *want to give the correct reading."* (CHW, Malawi)

12
13 256 A key challenge reported by frontline HCPs in Malawi was around keeping the oximeter charged; this
14
15 257 was not considered a significant challenge in Bangladesh. However, here they had issues with
16
17 258 ensuring the oximeter remained dry and protected during rains and being fully waterproof was
18
19 259 desirable. Depending on usage, battery life was reported as 1 week – 2 months. In Malawi, none of
20
21 260 the CHWs and only some of the health centres have access to electricity for charging the re-usable
22
23 261 batteries, and therefore they reported travelling to use commercial charging services:

24
25 262 *"Most of the times we take the pulse oximeter to the trading centre and charge it, then we pay for*
26
27 263 *that only to make sure that we are working, but sometimes you also feel you become bankrupt."*
28
29 264 (Health centre, Malawi)

30 Sustainability

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32 266 Sustainability was discussed in terms of the device's durability, and the need for continued
33
34 267 professional development. Generally the pulse oximeters were thought of as robust and durable,
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36 268 with some of the HCPs having used their device for over four years without replacements. However,
37
38 269 the battery was highlighted as the least durable part of the device, and there was a perception that
39
40 270 when the battery was worn down the readings became less reliable.

41
42 271 *"There is a matter with the battery too, if the battery is not enough the reading takes a long time to*
43
44 272 *appear. It sometimes gives false negative readings."* (Hospital, Bangladesh)

45
46 273 This related to the HCPs suggestion of having on-going maintenance support rather than wanting
47
48 274 replacement devices. HCPs described the need for on-going training and support, but also expressed
49
50 275 a desire for more in-depth education on how oximetry works which goes beyond the basic training
51
52 276 to take a reliable measurement:

53
54 277 *"A person gets used to what they are doing once they have been oriented. I think sometimes it's also*
55
56 278 *good for you and your team to orient us on how this thing works [...] the way this thing works, we*
57
58 279 *don't know"* (Health centre, Malawi)

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2
3 280 In terms of keeping the devices clean, we found conflicting opinions between Malawi and
4
5 281 Bangladesh. Malawi deemed the probes easy to clean and store securely, although the light colour
6
7 282 and materials of the device was thought to show dirt easily. However, in Bangladesh cleaning was
8
9 283 described as burdensome; this likely reflects the different devices and therefore methods needed for
10
11 284 cleaning, or different perceptions of the importance and frequency of cleaning.

12 285 *"It is hard work to clean it with hexsol and cotton after coming back from the field every day. If we*
13
14 286 *could get something else to clean it with so that we can clean once a week, I don't like cleaning it*
15
16 287 *every day."* (CHW, Bangladesh)

17
18 288 Design

19
20 289 The key challenges mentioned repeatedly across sites and HCP cadres were the battery, sensitivity of
21
22 290 the probe in relation to movement or low perfusion, and the probe fit in younger children. Box 1
23
24 291 summarises the design features requested or suggested to improve the pulse oximeters for use in
25
26 292 these low-resource settings.

27
28 293 The oximeters which HCPs used were designed for continuous monitoring; therefore oxygen
29
30 294 saturation is not a single static result. This was seen as a negative, with HCPs in both sites wanting
31
32 295 the ability to stop at a result and even store measurements (e.g. a blood glucose monitor):

33 296 *"Readings would fluctuate if the baby moves. We don't want that. After getting the actual reading it*
34
35 297 *should stay fixed."* (CHW, Bangladesh)

36
37 298 In Bangladesh specifically, the CHWs stated a preference for numbers or bars to indicate
38
39 299 measurement quality, rather than a dynamic waveform display. This opinion was not reflected in
40
41 300 Malawi, which could be a result of using different devices or different training. A specific challenge
42
43 301 presented by CHWs in Malawi was the use of the oximeter in direct sunlight; CHWs often hold clinics
44
45 302 outside and they faced the combined challenges of bright sunlight and dust, both of which they
46
47 303 reported as challenges in taking measurements.

48 304 *"...it returns the correct results when you are in the shade, but while you are in sunlight it fails to*
49
50 305 *determine good results."* (CHW, Malawi)

51
52 306 Positive design features included the portability of devices, the ease of using them and perceived
53
54 307 durability, with little direct criticism of the oximeters that the HCPs had been using:

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56 308 *"...of the things I like most about using the pulse oximeter, the first one is the portability, because I*
57
58 309 *can use it anywhere."* (Hospital, Malawi)

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6 311 **Discussion**

7
8 312 We investigated end-user experiences of using pulse oximeters by a range of different HCPs across
9
10 313 clinical settings in Malawi and Bangladesh. The FGDs highlighted similarities in experience, such as
11
12 314 challenges in battery durability, the difficulty of small and agitated children and the positive impact
13
14 315 of oximeters on clinical practice. However, there were key differences between Malawi and
15
16 316 Bangladesh and between HCP cadres.

17
18 317 Of note was the difference in perceived ease of cleaning, which was seen as more burdensome in
19
20 318 Bangladesh. This is likely associated with the Y-shaped wrap probe design, compared to the more
21
22 319 easily cleaned clip design used in Malawi (Figure 1). Interestingly though, most critiques were similar
23
24 320 between sites, highlighting some of the major challenges of using pulse oximetry in children –
25
26 321 namely movement, low perfusion and small digits. This consistency between sites suggests these
27
28 322 challenges are not device dependent and therefore a specifically designed re-usable device for
29
30 323 universal paediatric use in low-resource settings is needed.

31
32 324 We identified differences in the sense of value placed on the oximeters by HCPs, with the higher
33
34 325 trained HCPs attributing less value to the results than the HCPs with more limited training. Those
35
36 326 with more training valued their clinical judgement more and were more willing to question the
37
38 327 accuracy of SpO₂ results. This poses interesting lessons for scaling-up implementation and training,
39
40 328 as despite perceptions that obtaining a SpO₂ measurement is generally easy, the interpretation of
41
42 329 the result is more nuanced. Sustained mentorship and more in-depth training were desired by the
43
44 330 HCPs, and this needs to be considered as part of any implementation programme.

45
46 331 As the oximeters were used as spot-check devices rather than continuous monitors, as would
47
48 332 generally be found in operating theatres or high-dependency care in high-income settings, many of
49
50 333 the suggested design changes related to improving the devices for this process. One example of this
51
52 334 was the need for improved battery-life and charging, with HCPs highlighting their limited ability to
53
54 335 easily access charging points, unlike high-income inpatient settings. Consistently, the desire for
55
56 336 quicker, static results and a movement tolerant probe with improved fit on younger infants was
57
58 337 important. Unexpected issues, such as usability in direct sunlight, emphasize the importance of end-
59
60 338 user engagement in product development as clinical devices designed for high-income settings
339 would not need to be robust to outdoor use.

340
341 340 The idea of a pulse oximeter being able to improve trust between a caregiver and healthcare
provider poses potentially exciting opportunities for improving referral and treatment for paediatric

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3 342 pneumonia. Early diagnosis and treatment as downstream in the health system as possible, ideally to
4 343 the level of CHWs, are key strategies for improving pneumonia outcomes and therefore reducing
5 344 morbidity and mortality burden²³. Therefore, an objective and simple clinical tool with in-built
6 345 decision support, e.g. auditory or visual alarms when the SpO₂ is outside of normal range, presents
7 346 an opportunity for caregiver education and empowerment in the referral decision-making process.
8 347 Recent data from Malawi supports this notion. Frontline Malawian HCPs using pulse oximeters
9 348 during routine outpatient care demonstrated that among children with pneumonia who were
10 349 clinically eligible for referral, children with a SpO₂ <90% were more than twice as likely to have been
11 350 correctly referred compared to those with a SpO₂ ≥90%¹². Interestingly, this has not necessarily been
12 351 the case with other more objective diagnostic tools, with examples of rapid diagnostic malaria tests
13 352 leading to provider-caregiver tensions around treatments^{24 25}.

14 353 This study was potentially subject to social-desirability bias, with healthcare workers expressing
15 354 opinions which they thought the facilitators wanted to hear. The purpose of the study was explained
16 355 to the participants during the consent process, and was highlighted as an opportunity for them to
17 356 contribute to the design of a revised paediatric oximeter and probe. To mitigate this potential bias,
18 357 the facilitators encouraged the participants to be critical throughout, and the FGDs were conducted
19 358 amongst peers, rather than between different HCP cadres with different educational backgrounds
20 359 and social dynamics. Both positive and negative views were given in both Malawi and Bangladesh,
21 360 and by different types of HCPs, therefore we do not feel this bias is likely to have impacted our
22 361 findings.

23 362 Overall pulse oximeters were valued by HCPs, despite challenges with charging, maintenance and
24 363 speed of achieving accurate readings in moving or smaller children. This implies that making
25 364 improvements to currently available oximeters and probes could further facilitate successful
26 365 implementation of this technology at the community through to the hospital level for routine
27 366 paediatric care. Based on these data, we recommend that efforts to re-design a pulse oximeter for
28 367 paediatric spot-checks focus on improvements to battery durability, better fit for smaller digits and
29 368 the speed at which readings are obtained; these were all important challenges which did not
30 369 necessarily have local solutions presented. More substantive design changes could focus on
31 370 alternative power and charging systems (e.g. solar charging) and '3-in-1' devices which include
32 371 respiratory rate and temperature measurements.

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3 372 **Acknowledgments**
4

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6
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14

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20
21 381

22
23
24 382 **Conflict of Interest**

25
26 383 Authors declare no conflicts of interest.
27
28 384

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30
31 385 **Author contributions**

32
33 386 The qualitative study was designed and topic guides developed by IWi, IWa, CK and EDM, and the
34
35 387 field manual written by CK. In Malawi, BZ and EK arranged, conducted, transcribed and translated
36
37 388 the FGDs. In Bangladesh SA and MI arranged and conducted the FGDs. The data was coded and
38
39 389 analysed by CK and KF. The manuscript was written by CK, with considerable input from KF and EDM.
40
41 390 All authors read, commented and approved the manuscript.
42

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45 392 **Data Sharing Statement**

46
47 393 Anonymised transcripts can be shared, following the signing of a data sharing agreement, subject to
48
49 394 approval from the relevant National ethics committees. For further information please contact Dr.
50
51 395 Carina King: c.king@ucl.ac.uk.
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Table 1: Summary of the FGD participants and their work experience			
	Community level	Health centre or Upazila Health Complex	Hospital
BANGLADESH			
Total participants	8	7	8
Job titles (number)	Community healthcare worker (8)	Physician (4) Medical officer (3)	Senior staff nurse (1) Associate professor (2) ICU staff (1) Anaesthesiologist (1) Assistant registrar (1) Intern medical officer (1)
Work experience (mean, range)	1.7 years (0.6 – 4)	2.3 years (1 – 6)	14.7 years (0.5 – 32)
MALAWI			
Total participants	9	8	9
Job titles	Community healthcare worker (8) Vital signs assistant (1)	Medical assistant (7) Medical technician (1)	Clinical officer (3) Nurse midwife (3) Medical assistant (3)
Years' work experience (mean)	10.6 years (5 – 20)	8.3 years (3 – 23)	8.1 years (4 – 13)

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463 **Panel 1:** Suggestions of desirable features or improvements

Challenge:	Design suggestion:
Probe fit	Supplied with multiple sizes of probes for different ages A single cable with multiple probes that can be changed (e.g. clipped into the cable) Softer material for a more comfortable fit
Probe placement	Probe made of transparent material so sensor placement on the nail can be seen
Cleaning	Alcohol wipes provided for easier cleaning Different colour probe to make it easier to see the dirt, but does not look dirty quickly
Power	Solar powered charger with rechargeable batteries Back-up power bank Supplied with a spare battery
Agitated children	Toy feature in the device to distract the child Improve the sensitivity of the device to be quicker Improve the sensitivity of the device to tolerate movement
Integrated spot-check device	Store results in a memory that can later be accessed Static oxygen saturation result display '3-in-1' device which includes temperature and respiratory rate measurements as well Shorter cable length for easier portability

464

465 **Figure 1:** Pulse oximeters and probe used by healthcare providers in routine clinical care

- 466 a. Lifebox® oximeter and adult universal clip probe used in Malawi (accessed on 1st July 2017
467 from: www.lifebox.org)



468

- 469 b. Masimo Rad5® oximeter and LNCS® Y-I Multisite wrap probe used in Bangladesh (accessed on
470 1st July 2017 from: www.pacificmedicalsupply.com)



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Web Appendix 1 – Topic Guide

- What is your experience of using pulse oximeters in children?
- What have been the main issues you've encountered when using pulse oximeters?
- What have been the things you like most about using the pulse oximeters?
- What type of probes have you used? Have any been better than others? Why?
- Thinking about the probes, we would like to hear your feedback about some aspects of using them: ease of putting and keeping the probe on the child, durability, ease of taking a reading, ease of keeping it clean and storage
- Thinking about the oximeter, we would like to hear your feedback about some aspects of using them: ease of reading the display, durability, battery life and charging, time taken to get a reading
- What things would make the probe and pulse oximeter easier to use?
- What things would make the probe and pulse oximeter harder to use?

BMJ Open

Opportunities and barriers in paediatric pulse oximetry for pneumonia in low-resource clinical settings: a qualitative evaluation from Malawi and Bangladesh

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SCHOLARONE™
Manuscripts

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3 1 **Title:** Opportunities and barriers in paediatric pulse oximetry for pneumonia in low-resource clinical
4 2 settings: a qualitative evaluation from Malawi and Bangladesh
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9 4 **Authors:** Carina King^{1*}, Nicholas Boyd², Isabeau Walker², Beatiwel Zadutsa³, Abdullah H. Baqui⁴,
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56 29 **Word Count:** 4,039
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3 30 **Abstract**
4

5 31 *Objective:* To gain an understanding of what challenges pulse oximetry for paediatric pneumonia
6
7 32 management poses, how it has changed service provision and what would improve this device for
8
9 33 use across paediatric clinical settings in low-income countries.

10
11 34 *Design:* Focus group discussions (FGDs), with purposive sampling and thematic analysis using a
12
13 35 framework approach.

14
15 36 *Setting:* Community, front line outpatient and hospital outpatient and inpatient settings in Malawi
16
17 37 and Bangladesh, which provide paediatric pneumonia care.

18
19 38 *Participants:* Healthcare providers (HCPs) from Malawi and Bangladesh who had received training in
20
21 39 pulse oximetry and had been using oximeters in routine paediatric care, including community
22
23 40 healthcare workers, non-physician clinicians or medical assistants, and hospital-based nurses and
24
25 41 doctors.

26
27 42 *Results:* We conducted six FGDs, with 23 participants from Bangladesh and 26 from Malawi. We
28
29 43 identified five emergent themes: trust; value; user-related experience; sustainability; and design.
30
31 44 HCPs discussed the confidence gained through using oximeters, resulting in improved trust from
32
33 45 caregivers and valuing the device; although there were conflicts between the weight given to clinical
34
35 46 judgement versus oximeter results. HCPs reported the ease of using oximeters, but identified
36
37 47 movement and physically smaller children as measurement challenges. Challenges in sustainability
38
39 48 related to battery durability and replacement parts were reported, however many HCPs had used
40
41 49 the same device longer than four years demonstrating robustness within these settings. Desirable
42
43 50 features included back-up power banks and integrated respiratory rate and thermometer capability.

44
45 51 *Conclusions:* Pulse oximetry was generally deemed valuable by HCPs for use as a spot-check device
46
47 52 in a range of paediatric low-income clinical settings. Areas highlighted as challenges by HCPs, and
48
49 53 therefore opportunities for re-design, included battery charging and durability, probe fit and
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51 54 sensitivity in paediatric populations.
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3 55 **Strengths and Limitations**
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- 5 56 • This is the first study to report on end-user perceptions of opportunities, challenges and
6 57 desirable design features of pulse oximeters used for paediatric pneumonia management in
7 58 low-resource settings, including community and outpatient providers.
8
9 59 • A key strength was the wide range of healthcare provider perspectives included, from
10 60 community to referral hospital settings in South Asia and sub-Saharan Africa.
11
12 61 • The study was limited to participant's experience of using specific pulse oximeters and
13 62 therefore may lack generalizability to other paediatric pulse oximeters not used in these
14 63 settings.
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16 64

65 Introduction

66 Several interventions, such as Pneumococcal conjugate vaccine (PCV) and standardised guidelines
67 for diagnosis and treatment, have led to reductions in pneumonia morbidity and mortality over the
68 last twenty years^{1,2}. However, in spite of these gains, pneumonia remains the leading cause of
69 infectious mortality amongst children globally, with the vast majority of the burden falling in sub-
70 Saharan Africa and south Asia³. To accelerate reductions in pneumonia mortality, further
71 refinement of diagnosis and treatment pathways are needed, including correct referral and access to
72 oxygen treatment⁴.

73 Pulse oximetry non-invasively measures peripheral arterial oxyhemoglobin saturation (SpO₂).
74 Hypoxemia (defined as an SpO₂ <90%) is included in the World Health Organization (WHO)
75 guidelines as a pneumonia danger sign⁵, and is associated with increased mortality from
76 pneumonia, as well as other illnesses like malaria⁶⁻⁸. Recent evidence from Malawi has also
77 indicated that a SpO₂ 90-92% is predictive of mortality amongst children hospitalized with
78 pneumonia⁸.

79 While some studies have attempted to predict hypoxemia in children with pneumonia using a
80 combination of clinical signs, there has been mixed success⁹⁻¹¹. Clinical signs alone fail to identify a
81 proportion of hypoxemic children based on the current WHO guidelines, which results in a missed
82 opportunity for referral and appropriate treatment^{12,13}. In addition, the subjectivity of clinical signs
83 can lead to variation in care – especially among community healthcare workers (CHWs), who often
84 lack ongoing supervision.

85 Pulse oximeters have been successfully used in low-resource paediatric settings, but are yet to be
86 widely adopted, particularly during outpatient care^{14,15}. The Ethiopian Ministry of Health has
87 demonstrated leadership in this area, setting up an initiative in 2016 to ensure oximetry and oxygen
88 therapy are available nationally across the healthcare system¹⁶. However, Ethiopia is an exception,
89 with implementation of oximetry in other developing countries continuing to be slow.
90 Implementation barriers cited include cost, lack of appropriately designed, robust oximeters and
91 universal paediatric probes and issues with training and supervision¹⁷.

92 In order to better understand current barriers to use of pulse oximetry by healthcare providers
93 (HCPs) in a range of healthcare settings, and explore opportunities that this technology provides,
94 input from end-users is needed¹⁸. With the ultimate goal of designing a universal paediatric probe
95 for all levels of healthcare services in resource-poor settings, we aimed to gain an understanding of
96 the challenges of pulse oximetry, how its use has changed service provision and how current devices

97 could be improved for these settings. This end-user perspective is currently limited in the literature
98 and is essential to ensure investment in pulse oximetry is sustainable and effective.

99

100 **Methods**

101 We conducted a qualitative study with HCPs from different levels of the healthcare system in from
102 one site in Malawi (Mchinji district, central region) and one in Bangladesh (Sylhet district, northeast
103 region) from May – July 2016, as part of a wider programme of work aiming to design a universal
104 paediatric oximeter probe.

105 Setting:

106 In Malawi there are three levels of government provided healthcare: CHWs (locally known as Health
107 Surveillance Assistants), health centres and district hospitals. CHWs conduct weekly or bi-weekly
108 village clinics and home visits providing basic integrated community case management (iCCM) for
109 paediatric infections^{19 20}. Health centres are outpatient facilities run by nurses, clinical officers or
110 medical assistants, and District Hospitals have inpatient facilities with capacity for oxygen treatment.
111 In Mchinji, pulse oximetry was successfully introduced into all three healthcare settings in 2012 as
112 part of a PCV research project, using the Aicare Technology AH-MX manufactured Lifebox® oximeter
113 and universal adult clip probe (Figure 1a)¹².

114 In Bangladesh, the study was conducted at Projahnmo, a research consortium comprised of Johns
115 Hopkins University and several local non-governmental organizations in partnership with the
116 Bangladesh Ministry of Family Health and Welfare. Current Projahnmo activities are integrated
117 within three government-operated sub-district hospitals, called Upazila Health Complexes (UHCs),
118 and the referral government hospital in Sylhet city (Osmani Medical College), all of which are staffed
119 by physicians and nurses. The UHCs operate outpatient clinics for children under five and provide
120 basic inpatient paediatric care, including oxygen. The majority of government provided inpatient
121 care is provided at Osmani Medical College. Female CHWs employed by Projahnmo conduct
122 bimonthly household surveillance, with a subset of CHWs providing weekly surveillance as a part of a
123 PCV effectiveness study. Projahnmo CHWs conduct basic clinical assessments and refer ill children
124 for care at the UHCs; they do not administer medicines themselves. Since 2015, a National Institutes
125 of Health-funded study (K01TW009988) trained and supplied all Projahnmo clinical staff in
126 Bangladesh, including CHWs, with pulse oximeters to screen children for hypoxemia, using the
127 Masimo Rad5® oximeter and the LNCS® Y-I Multisite wrap probe (Figure 1b).

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3 128 In Malawi, CHWs individually own the oximeters, and facilities were given a device for each clinic or
4 129 ward, while in Bangladesh, Projahnmo owns the oximeters and individual healthcare providers are
5
6 130 responsible for routine care and maintenance of the devices. Oximetry was not included in the
7
8 131 Malawi paediatric guidelines, and Bangladesh did not have national paediatric pneumonia guidelines
9 132 at the time of the study.

10
11 133 Design:

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14 134 We conducted focus group discussions (FGDs). We planned three FGDs in each country, aiming to
15 135 recruit between 6 and 10 people for each FGD (up to 60 participants in total). This number of groups
16 136 was agreed upon before data collection began, driven by practical considerations given few
17 137 healthcare workers in either setting have experience using pulse oximeters with children. The groups
18 138 were planned to be CHWs, health centre or UHC staff, and referral hospital staff separately.
19
20 139 Conducting separate FGDs for the different types of healthcare workers was to allow context-specific
21 140 discussions and encourage participants with varying training backgrounds to feel confident about
22 141 raising challenges relevant to their specific setting.

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27 142 Sampling:

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29 143 HCPs were purposefully sampled from sites where pulse oximetry had been introduced, and the
30 144 participants had received some form of training or mentorship in oximetry. Participants were
31 145 identified by local researchers (BZ in Malawi and SA in Bangladesh) to be a representative sample of
32 146 HCPs from their setting (e.g. small and large health centres, inpatient wards and outpatient
33 147 departments in the hospital), and contacted directly by phone. All HCPs contacted participated.
34 148 Participants were reimbursed for their travel costs to the local healthcare facility and provided with
35 149 refreshments.

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41 150 Procedure:

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43 151 FGDs were led by local researchers with experience in conducting qualitative research, with support
44 152 from a facilitator with knowledge of pulse oximeters. The FGDs were divided into two sections, the
45 153 first addressing the participants' personal experience with using pulse oximeters. The topic guide
46 154 included: positive and negative experiences, and possible improvements and challenges (Web
47 155 appendix 1). During the second part of the discussion, the participants were presented with different
48 156 probe designs and given an opportunity to use them for an hour (Web appendix 2). Following this,
49 157 the discussion addressed positive and negative aspects of the different designs to encourage critical
50 158 thinking of possible design solutions to the current limitations of a universal paediatric probe.
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3 159 The FGDs were audio recorded and then transcribed, along with the facilitators notes. Questions
4 160 were asked in a mix of English and local dialects depending on understanding and ease of expression
5 161 (Chichewa, Bangla or Sylheti) and participants were told to answer in their preferred language.
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7 162 Responses were clarified by facilitators if there was an issue with language and understanding
8
9 163 between participants. Recordings were transcribed and translated where necessary. Translations for
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11 164 Malawi were done by BZ and EK together until final transcripts were agreed, and by an independent
12
13 165 professional service for Bangladesh.

14 15 166 Analysis:

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17 167 We analysed the data thematically using a framework approach, as an appropriate method for a
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19 168 multi-disciplinary team conducting health research²¹. This process involves five steps:
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21 169 familiarisation, identifying a thematic framework, indexing, mapping and interpretation²². The
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23 170 transcripts and notes from the FGDs were printed and coded on paper, with the coding matrix
24
25 171 created in Microsoft Excel. CK and KF independently familiarised themselves and indexed the data,
26
27 172 and the emergent themes were discussed until a consensus was reached on the mapping and
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29 173 interpretation of the data. This interpretation was shared with the local researchers (BZ and EK in
30
31 174 Malawi; EDM and MI in Bangladesh) for further discussion until all were in agreement.

32 33 175 Ethics:

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35 176 Written informed consent was obtained from all FGD participants. This study was reviewed and
36
37 177 approved by the University College London research ethics committee (8075/003), Johns Hopkins
38
39 178 Medicine Institutional Review Board (IRB00047406), the Malawi National Health Sciences Research
40
41 179 Committee (16/4/1570) and Bangladesh Medical Research Council (BMRC/NREC/2013-2016/1272).

42
43 180

44 45 181 **Results**

46
47 182 We conducted six FGDs, with 23 participants from Bangladesh and 26 from Malawi (Table 1). We
48
49 183 identified five emergent themes: trust; value; user-related experience; sustainability; and design.

50 51 184 Trust

52
53 185 Trust emerged as a theme both in terms of how the HCPs interpret the oximetry results, and how
54
55 186 caregivers interact with HCPs and the pulse oximeter. We found that all cadres of HCPs in both sites
56
57 187 had an awareness of the fallibility of the oximetry readings, specifically relating to lower SpO₂ values.
58
59 188 For SpO₂ levels which were deemed abnormal, <90% up to <95% according to different participants,

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3 189 HCPs stated that they would often re-check the result before making a referral or treatment
4 190 decision:

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6
7 191 *"if we see it is 89% we change the probe or change the finger" (Hospital, Bangladesh)*

8
9 192 However, questioning the validity of these lower SpO₂ results in the context of a child's clinical
10 193 condition was only discussed by the HCPs who worked in the hospital setting. This difference in the
11 194 trust placed in the SpO₂ results by different types of HCPs suggests that more in-depth clinical
12 195 training and understanding of the technology may result in different clinical applications:

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15
16 196 *"sometimes the pulse oximeter can give readings which you are not comfortable with according to*
17 197 *the presentation of the child [...] most of the time when it happens like that, we just use our*
18 198 *judgement"* (Hospital, Malawi)

19
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21
22 199 An outcome of using pulse oximeters for pneumonia diagnosis was a change in parental and
23 200 community understanding and perceptions of care, with HCPs discussing increased trust in their
24 201 referral and treatment decisions. This worked in two ways, firstly with the oximeter acting as a direct
25 202 feedback and education tool:

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28
29 203 *"if the mother is able to read you can show the exact figure and she will accept the treatment of*
30 204 *oxygen, [before] it was very difficult to explain the role or the importance of the oxygen machine and*
31 205 *some mothers refused"* (Hospital, Malawi)

32
33
34 206 Secondly, in Malawi HCPs projected that the oximeters had improved clinical care, and therefore
35 207 outcomes, which led caregivers to be more inclined to accept the referral or treatment being
36 208 recommended, especially in the case of oxygen:

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39
40 209 *"[previously] in the village they were saying that when a child is put on the oxygen machine it*
41 210 *facilitates death, therefore it was making problems, but this time because children are put on oxygen*
42 211 *earlier they survive, it's because we knew the saturation"* (Health centre, Malawi)

43 44 45 212 Value

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48 213 The theme of value relates to the inherent value of improved decision making, HCPs perceived self-
49 214 value (i.e. confidence) in their clinical work, and the physical value placed on maintaining a working
50 215 pulse oximeter. As pneumonia is classified using a range of non-specific and often subjective clinical
51 216 signs, HCPs discussed the positive addition of this more objective measure:

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54
55 217 *"...by looking at this we can understand how much respiratory distress is in there. Of course this helps*
56 218 *us a lot."* (Health Centre, Bangladesh)

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2
3 219 In both sites HCPs from frontline settings (CHWs, health centres and UHCs) stated that the pulse
4 220 oximeters had changed the way they work and given them confidence in making referral decisions.
5
6 221 Interestingly however, in the referral hospital setting in Bangladesh where staff training is higher,
7
8 222 very little value was placed on the pulse oximeter for improving their clinical performance, with the
9
10 223 ability to conduct chest x-rays, lung ultra-sound and their clinical judgement valued more highly:

11 224 *"...its sensitivity and specificity is very negligible to be taken as a diagnostic tool."* (Hospital,
12
13 225 Bangladesh)

14
15 226 In Bangladesh the CHWs reported pride in using the oximeters. In Malawi, the CHWs placed a
16
17 227 physical value on the oximeters and discussed the personal effort, such as paying out of pocket to
18
19 228 travel commercial charging services, they put in to maintaining a working device:

20
21 229 *"...we have been trying all that is humanly possible to take care of these things, but it only becomes a
22
23 230 problem when it comes to the issue of charging."* (CHW, Malawi)

24
25 231 This was also reflected at the health centre, where not all facilities have electricity and one or two
26
27 232 staff are responsible for assessing children. At the referral hospital however this was not discussed,
28
29 233 with oximeters belonging to the ward, which has a more consistent power supply. Ward-based
30
31 234 ownership was discussed as a challenge, suggesting individual ownership could result in improved
32
33 235 care and maintenance as having a device in working order would not be dependent on the
34
35 236 performance of others.

36
37 237 *"...some of the clinicians do not take care of them, so when the machine is not working it means the
38
39 238 whole department is affected"* (Hospital, Malawi)

39 User-related experience

40
41 240 HCPs at all levels discussed their experiences of using pulse oximeters in children under 5-years,
42
43 241 presenting challenges, their solutions and perceptions of usability. The time taken to get a
44
45 242 measurement ranged widely, with CHWs in Bangladesh agreeing measurements took less than 1
46
47 243 minute but in Malawi that it could take up to 20 minutes. The factors that increased the time taken
48
49 244 to get a measurement were consistently cited as movement and physically smaller children, and in
50
51 245 Malawi dirty toes making measurements difficult:

52 246 *"Getting readings from irritable babies is a bit tough and it takes time."* (Health centre, Bangladesh)

53
54 247 *"...using it on a child up to six months of age, sometimes it has been a problem because these
55
56 248 children have got small fingers, so although we use toes sometimes they are also small and the child*

1
2
3 249 *is afraid so they start crying. So we have got other things we can give a child to play with but it is a*
4 250 *little bit of a problem, but at the end we get the results.”* (CHW, Malawi)

6
7 251 Solutions to these challenging children included asking caregivers to breastfeed, giving them a toy to
8 252 distract them, and simply waiting. The term used frequently to describe challenging children was
9
10 253 ‘fear’, with the HCPs stating that children are afraid of having the measurements taken. This fear was
11 254 associated with the sensors’ red light which frightened children, the anticipation of pain, or just
12
13 255 being an unknown. All of these could result in the child being agitated, crying and uncooperative.
14
15 256 Despite these issues in small and agitated infants, the oximeters were considered easy to use:

16
17 257 *“...it’s not complicated, it doesn’t need complicated education for a healthcare worker to use, with a*
18 258 *good explanation from a colleague or friend you are able to use it.”* (Hospital, Malawi)

20
21 259 There was also the acknowledgement that time to reading was not as important as getting the
22 260 correct measurement; for some respondents, the reason some measurements take longer is the
23
24 261 desire to get a reliable reading. This included cleaning the child’s digits or repositioning the probe:

25
26 262 *“...taking longer does not mean that one doesn’t know the procedure, but sometime it’s because you*
27 263 *want to give the correct reading.”* (CHW, Malawi)

28
29
30 264 A key challenge reported by frontline HCPs in Malawi was around keeping the oximeter charged; this
31 265 was not considered a significant challenge in Bangladesh. However, here they had issues with
32
33 266 ensuring the oximeter remained dry and protected during rains and being fully waterproof was
34
35 267 desirable. Depending on usage, battery life was reported as 1 week – 2 months.

36 37 268 Sustainability

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39
40 269 Sustainability was discussed in terms of the device’s durability, and the need for continued
41 270 professional development. Generally the pulse oximeters were thought of as robust and durable,
42
43 271 with some of the HCPs having used their device for over four years without replacements. However,
44
45 272 the battery was highlighted as the least durable part of the device, and there was a perception that
46
47 273 when the battery was worn down the readings became less reliable.

48
49 274 *“There is a matter with the battery too, if the battery is not enough the reading takes a long time to*
50 275 *appear. It sometimes gives false negative readings.”* (Hospital, Bangladesh)

51
52 276 This related to the HCPs suggestion of having on-going maintenance support rather than wanting
53
54 277 replacement devices. HCPs described the need for on-going training and support, but also expressed

278 a desire for more in-depth education on how oximetry works which goes beyond the basic training
279 to take a reliable measurement:

280 *“A person gets used to what they are doing once they have been oriented. I think sometimes it’s also*
281 *good for you and your team to orient us on how this thing works [...] the way this thing works, we*
282 *don’t know”* (Health centre, Malawi)

283 In terms of keeping the devices clean and properly stored, an important factor for prolonging shelf-
284 life, we found conflicting opinions between Malawi and Bangladesh. Malawi deemed the probes
285 easy to clean and store securely, although the light colour and materials of the device was thought
286 to show dirt easily. However, in Bangladesh cleaning was described as burdensome; this likely
287 reflects the different devices and therefore methods needed for cleaning, or different perceptions of
288 the importance and frequency of cleaning.

289 *“It is hard work to clean it with hexsol and cotton after coming back from the field every day. If we*
290 *could get something else to clean it with so that we can clean once a week, I don’t like cleaning it*
291 *every day.”* (CHW, Bangladesh)

292 Design

293 The key challenges mentioned repeatedly across sites and HCP cadres were the battery, sensitivity of
294 the probe in relation to movement or low perfusion, and the probe fit in younger children. Panel 1
295 summarises the design features requested or suggested to improve the pulse oximeters for use in
296 these low-resource settings. Suggestions covered the probe, such as having detachable probes of
297 different sizes, charging and battery life, such as additional power packs and solar charging, and
298 features to help with agitated children.

299 The oximeters which HCPs used were designed for continuous monitoring; therefore oxygen
300 saturation is not a single static result. This was seen as a negative, with HCPs in both sites wanting
301 the ability to stop at a result and even store measurements (e.g. a blood glucose monitor):

302 *“Readings would fluctuate if the baby moves. We don’t want that. After getting the actual reading it*
303 *should stay fixed.”* (CHW, Bangladesh)

304 In Bangladesh specifically, the CHWs stated a preference for numbers or bars to indicate
305 measurement quality, rather than a dynamic waveform display. This opinion was not reflected in
306 Malawi, which could be a result of using different devices or different training. A specific challenge
307 presented by CHWs in Malawi was the use of the oximeter in direct sunlight; CHWs often hold clinics

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3 308 outside and they faced the combined challenges of bright sunlight and dust, both of which they
4 309 reported as challenges in taking measurements.

5
6 310 *"...it returns the correct results when you are in the shade, but while you are in sunlight it fails to*
7 311 *determine good results."* (CHW, Malawi)

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10 312 Positive design features included the portability of devices, the ease of using them and perceived
11 313 durability, with little direct criticism of the oximeters that the HCPs had been using:

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14 314 *"...of the things I like most about using the pulse oximeter, the first one is the portability, because I*
15 315 *can use it anywhere."* (Hospital, Malawi)

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19 20 21 317 **Discussion**

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23 318 We investigated end-user experiences of using pulse oximeters by a range of different HCPs across
24 319 clinical settings in Malawi and Bangladesh. The FGDs highlighted similarities in experience, such as
25 320 challenges in battery durability, the difficulty of small and agitated children and the positive impact
26 321 of oximeters on clinical practice. However, there were key differences between the providers'
27 322 experiences in Malawi and Bangladesh and between HCP cadres.

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31 323 Of note was the difference in perceived ease of cleaning, which was seen as more burdensome in
32 324 Bangladesh. This is likely associated with the Y-shaped wrap probe design, compared to the more
33 325 easily cleaned clip design used in Malawi (Figure 1). Interestingly though, most critiques were similar
34 326 between sites, highlighting some of the major challenges of using pulse oximetry in children –
35 327 namely movement, low perfusion and small digits. This consistency between our sampled HCPs from
36 328 each site suggests these challenges are not device dependent and therefore a specifically designed
37 329 re-usable device for universal paediatric use in low-resource settings is needed.

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41 330 We identified differences in the sense of value placed on the oximeters by the HCPs, with the higher
42 331 trained HCPs attributing less value to the results than the HCPs with more limited training. Those
43 332 with more training valued their clinical judgement more and were more willing to question the
44 333 accuracy of SpO₂ results. This poses interesting lessons for scaling-up implementation and training,
45 334 as despite perceptions that obtaining a SpO₂ measurement is generally easy, the interpretation of
46 335 the result is more nuanced. Sustained mentorship and more in-depth training were desired by the
47 336 HCPs, and this needs to be considered as part of any implementation programme.

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3 337 As the oximeters were used as spot-check devices rather than continuous monitors, as would
4 338 generally be found in operating theatres or high-dependency care in high-income settings, many of
5 339 the suggested design changes related to improving the devices for this process. One example of this
6 340 was the need for improved battery-life and charging, with HCPs highlighting their limited ability to
7 341 easily access charging points, unlike high-income inpatient settings. Consistently, the desire for
8 342 quicker, static results and a movement tolerant probe with improved fit on younger infants was
9 343 important. Unexpected issues, such as usability in direct sunlight, emphasize the importance of end-
10 344 user engagement in product development as clinical devices designed for high-income settings
11 345 would not need to be robust to outdoor use.

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18 346 The idea of a pulse oximeter being able to improve trust between a caregiver and healthcare
19 347 provider poses potentially exciting opportunities for improving referral and treatment for paediatric
20 348 pneumonia. Early diagnosis and treatment as downstream in the health system as possible, ideally to
21 349 the level of CHWs, are key strategies for improving pneumonia outcomes and therefore reducing
22 350 morbidity and mortality burden²³. Therefore, an objective and simple clinical tool with in-built
23 351 decision support, e.g. auditory or visual alarms when the SpO₂ is outside of normal range, presents
24 352 an opportunity for caregiver education and empowerment in the referral decision-making process.
25 353 Recent data from Malawi supports the potential for oximetry to improve referral decision-making in
26 354 frontline settings, with HCPs more than twice as likely to correctly refer children with a SpO₂ <90%
27 355 compared to those with a SpO₂ ≥90% when using an oximeter during routine outpatient care¹².
28 356 Interestingly, this has not necessarily been the case with other more objective diagnostic tools, with
29 357 examples of rapid diagnostic malaria tests leading to provider-caregiver tensions around treatments
30 358^{24 25}.

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39 359 This study was potentially subject to social-desirability bias, with healthcare workers expressing
40 360 opinions which they thought the facilitators wanted to hear. The purpose of the study was explained
41 361 to the participants during the consent process, and was highlighted as an opportunity for them to
42 362 contribute to the design of a revised paediatric oximeter and probe. In addition, the groups in some
43 363 cases were mixed in terms of gender and job titles, possibly influencing participant's confidence in
44 364 expressing their views and experiences. To mitigate these potential biases, the facilitators
45 365 encouraged the all participants to contribute to the discussions and to be critical throughout. Both
46 366 positive and negative views were given in both Malawi and Bangladesh, and by different types of
47 367 HCPs, therefore we do not feel these biases detract from our findings. Finally, we were limited by
48 368 the number of groups we conducted; additional groups or a different sampling approach may have

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3 369 led to alternative perspectives being included, as the number was not driven by saturation.
4 370 Therefore the conclusions we draw need to be interpreted accordingly.
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7 371 Overall pulse oximeters were valued by the HCPs we sampled for this study, despite challenges with
8 372 charging, maintenance and speed of achieving accurate readings in moving or smaller children. This
9
10 373 implies that making improvements to currently available oximeters and probes could further
11 374 facilitate successful implementation of this technology at the community through to the hospital
12
13 375 level for routine paediatric care in these two settings. Based on these providers varied experiences,
14 376 we recommend that efforts to re-design a pulse oximeter for paediatric spot-checks focus on
15
16 377 improvements to battery durability, better fit for smaller digits and the speed at which readings are
17
18 378 obtained; these were all important challenges which did not necessarily have local solutions
19
20 379 presented. More substantive design changes could focus on alternative power and charging systems
21 380 (e.g. solar charging) and '3-in-1' devices which include respiratory rate and temperature
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23 381 measurements.
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388

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391

392 Conflict of Interest

393 Authors declare no conflicts of interest.

394

395 Author contributions

396 The qualitative study was designed and topic guides developed by IW_i, IW_a, CK and EDM, and the
397 field manual written by CK. Oversight of the study was conducted by CK, BN and BZ in Malawi and
398 EDM, AB and MI in Bangladesh. In Malawi, BZ and EK arranged, conducted, transcribed and
399 translated the FGDs. In Bangladesh SA and MI arranged and conducted the FGDs. The data was
400 coded and analysed by CK. The manuscript was written by CK, with considerable input from EDM.
401 IW_i, IW_a, EDM, BZ, EK, SA, MI, NB, AB and BN read, commented and approved the manuscript.

402

403 Data Sharing Statement

404 Anonymised transcripts can be shared, following the signing of a data sharing agreement, subject to
405 approval from the relevant National ethics committees. For further information please contact Dr.
406 Carina King: c.king@ucl.ac.uk.

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Table 1: Summary of the FGD participants and their work experience

	Community level	Health centre or Upazila Health Complex	Hospital
BANGLADESH			
Total participants	8	7	8
Job titles (number)	Community healthcare worker (8)	Physician (4) Medical officer (3)	Senior staff nurse (1) Associate professor (2) ICU staff (1) Anaesthesiologist (1) Assistant registrar (1) Intern medical officer (1)
Work experience (mean, range)	1.7 years (0.6 – 4)	2.3 years (1 – 6)	14.7 years (0.5 – 32)
MALAWI			
Total participants	9	8	9
Job titles	Community healthcare worker (8) Vital signs assistant (1)	Medical assistant (7) Medical technician (1)	Clinical officer (3) Nurse midwife (3) Medical assistant (3)
Years' work experience (mean)	10.6 years (5 – 20)	8.3 years (3 – 23)	8.1 years (4 – 13)

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474 **Panel 1:** Suggestions of desirable features or improvements given by healthcare providers

Challenge:	Design suggestion:
Probe fit	Supplied with multiple sizes of probes for different ages A single cable with multiple probes that can be changed (e.g. clipped into the cable) Softer material for a more comfortable fit
Probe placement	Probe made of transparent material so sensor placement on the nail can be seen
Cleaning	Alcohol wipes provided for easier cleaning Different colour probe to make it easier to see the dirt, but does not look dirty quickly
Power	Solar powered charger with rechargeable batteries Back-up power bank Supplied with a spare battery
Agitated children	Toy feature in the device to distract the child Improve the sensitivity of the device to be quicker Improve the sensitivity of the device to tolerate movement
Integrated spot-check device	Store results in a memory that can later be accessed Static oxygen saturation result display '3-in-1' device which includes temperature and respiratory rate measurements as well Shorter cable length for easier portability

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3 476 **Figure legends:**
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5 477 **Figure 1:** Pulse oximeters and probe used by healthcare providers in routine clinical care
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7 478 a. Lifebox® oximeter and adult universal clip probe used in Malawi (accessed on 1st July 2017
8 from: www.lifebox.org)
9 479

10 480 b. Masimo Rad5® oximeter and LNCS® Y-I Multisite wrap probe used in Bangladesh (accessed on
11 1st July 2017 from: www.pacificmedicalsupply.com)
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64x97mm (300 x 300 DPI)

Web Appendix 1 – Topic Guide

- What is your experience of using pulse oximeters in children?
- What have been the main issues you've encountered when using pulse oximeters?
- What have been the things you like most about using the pulse oximeters?
- What type of probes have you used? Have any been better than others? Why?
- Thinking about the probes, we would like to hear your feedback about some aspects of using them: ease of putting and keeping the probe on the child, durability, ease of taking a reading, ease of keeping it clean and storage
- Thinking about the oximeter, we would like to hear your feedback about some aspects of using them: ease of reading the display, durability, battery life and charging, time taken to get a reading
- What things would make the probe and pulse oximeter easier to use?
- What things would make the probe and pulse oximeter harder to use?

Appendix 2: Summary of pulse oximeter probes presented during focus group discussions with healthcare providers

Probe type	Figure	Product code
Neonatal wrap		Acare ASYNR-D1
Adult clip		Acare ASANR-D1
Paediatric clip		Acare ASPNR-D1
Ear clip		Nellcor U401-2HL
Adult boot		Acare ASSNR-D1
Paediatric boot		Nellcor U401-2EL

COREQ Checklist

No	Item	Guide questions/description	Page / evidence
Domain 1: Research team and reflexivity			
Personal Characteristics			
1.	Interviewer/ facilitator	Which author/s conducted the interview or focus group?	Pg 15, Author contributions
2.	Credentials	What were the researcher's credentials? <i>E.g. PhD, MD</i>	A mix of diploma, BSc, MSc and PhD
3.	Occupation	What was their occupation at the time of the study?	Pg 6, Methods: procedure
4.	Gender	Was the researcher male or female?	Both
5.	Experience and training	What experience or training did the researcher have?	Pg 6, 'Methods: Procedure'
Relationship with participants			
6.	Relationship established	Was a relationship established prior to study commencement?	No
7.	Participant knowledge of the interviewer	What did the participants know about the researcher? <i>e.g. personal goals, reasons for doing the research</i>	Pg 15, Discussion
8.	Interviewer characteristics	What characteristics were reported about the interviewer/facilitator? <i>e.g. Bias, assumptions, reasons and interests in the research topic</i>	Pg 15, Discussion
Domain 2: study design			
Theoretical framework			

No	Item	Guide questions/description	Page / evidence
9.	Methodological orientation and Theory	What methodological orientation was stated to underpin the study? <i>e.g. grounded theory, discourse analysis, ethnography, phenomenology, content analysis</i>	Pg 7, Methods: Analysis
Participant selection			
10.	Sampling	How were participants selected? <i>e.g. purposive, convenience, consecutive, snowball</i>	Pg 6, Methods: Sampling
11.	Method of approach	How were participants approached? <i>e.g. face-to-face, telephone, mail, email</i>	Pg 6, Sampling
12.	Sample size	How many participants were in the study?	Pg 7, Results and Table 1
13.	Non-participation	How many people refused to participate or dropped out? Reasons?	Pg 6, Sampling
Setting			
14.	Setting of data collection	Where was the data collected? <i>e.g. home, clinic, workplace</i>	Pg 6, Sampling
15.	Presence of non-participants	Was anyone else present besides the participants and researchers?	Pg 6, Methods: Procedure
16.	Description of sample	What are the important characteristics of the sample? <i>e.g. demographic data, date</i>	Table 1
Data collection			
17.	Interview guide	Were questions, prompts, guides provided by the authors? Was it pilot tested?	Appendix 1
18.	Repeat interviews	Were repeat interviews carried out? If yes, how many?	Not applicable

No	Item	Guide questions/description	Page / evidence
19.	Audio/visual recording	Did the research use audio or visual recording to collect the data?	Pg 7, Methods: Procedure
20.	Field notes	Were field notes made during and/or after the interview or focus group?	Pg 7, Methods: Procedure
21.	Duration	What was the duration of the interviews or focus group?	Between 1 and 2 hours
22.	Data saturation	Was data saturation discussed?	Pg 14, Discussion
23.	Transcripts returned	Were transcripts returned to participants for comment and/or correction?	This was not possible due to language potential barriers
Domain 3: analysis and findings			
Data analysis			
24.	Number of data coders	How many data coders coded the data?	Pg 7, Methods: Analysis
25.	Description of the coding tree	Did authors provide a description of the coding tree?	Pg 7, Methods: Analysis
26.	Derivation of themes	Were themes identified in advance or derived from the data?	Pg 7, Results
27.	Software	What software, if applicable, was used to manage the data?	Pg 7, Methods: Analysis
28.	Participant checking	Did participants provide feedback on the findings?	No, but discussed with local researchers (pg 7)

No	Item	Guide questions/description	Page / evidence
Reporting			
29.	Quotations presented	Were participant quotations presented to illustrate the themes / findings? Was each quotation identified? e.g. <i>participant number</i>	Throughout results section (pg 7 – 12)
30.	Data and findings consistent	Was there consistency between the data presented and the findings?	Throughout results section (pg 7 – 12)
31.	Clarity of major themes	Were major themes clearly presented in the findings?	Pg 7, Results
32.	Clarity of minor themes	Is there a description of diverse cases or discussion of minor themes?	Throughout results section (pg 7 – 12)

BMJ Open

Opportunities and barriers in paediatric pulse oximetry for pneumonia in low-resource clinical settings: a qualitative evaluation from Malawi and Bangladesh

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3 1 **Title:** Opportunities and barriers in paediatric pulse oximetry for pneumonia in low-resource clinical
4 settings: a qualitative evaluation from Malawi and Bangladesh
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7 3
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49 26

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52

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1
2
3 **30 Abstract**
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5 *31 Objective:* To gain an understanding of what challenges pulse oximetry for paediatric pneumonia
6 management poses, how it has changed service provision and what would improve this device for
7 use across paediatric clinical settings in low-income countries.
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10 *34 Design:* Focus group discussions (FGDs), with purposive sampling and thematic analysis using a
11 framework approach.
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13

14 *36 Setting:* Community, front line outpatient and hospital outpatient and inpatient settings in Malawi
15 and Bangladesh, which provide paediatric pneumonia care.
16
17

18 *38 Participants:* Healthcare providers (HCPs) from Malawi and Bangladesh who had received training in
19 pulse oximetry and had been using oximeters in routine paediatric care, including community
20 healthcare workers, non-physician clinicians or medical assistants, and hospital-based nurses and
21 doctors.
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24

25 *42 Results:* We conducted six FGDs, with 23 participants from Bangladesh and 26 from Malawi. We
26 identified five emergent themes: trust; value; user-related experience; sustainability; and design.
27 HCPs discussed the confidence gained through using oximeters, resulting in improved trust from
28 caregivers and valuing the device; although there were conflicts between the weight given to clinical
29 judgement versus oximeter results. HCPs reported the ease of using oximeters, but identified
30 movement and physically smaller children as measurement challenges. Challenges in sustainability
31 related to battery durability and replacement parts were reported, however many HCPs had used
32 the same device longer than four years demonstrating robustness within these settings. Desirable
33 features included back-up power banks and integrated respiratory rate and thermometer capability.
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40 *51 Conclusions:* Pulse oximetry was generally deemed valuable by HCPs for use as a spot-check device
41 in a range of paediatric low-income clinical settings. Areas highlighted as challenges by HCPs, and
42 therefore opportunities for re-design, included battery charging and durability, probe fit and
43 sensitivity in paediatric populations.
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3 55 **Strengths and Limitations**
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- 5 56 • This is the first study to report on end-user perceptions of opportunities, challenges and
6 57 desirable design features of pulse oximeters used for paediatric pneumonia management in
7 58 low-resource settings, including community and outpatient providers.
8
9 59 • A key strength was the wide range of healthcare provider perspectives included, from
10 60 community to referral hospital settings in South Asia and sub-Saharan Africa.
11
12 61 • The study was limited to participant's experience of using specific pulse oximeters and
13 62 therefore may lack generalizability to other paediatric pulse oximeters not used in these
14 63 settings.
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16 64

65 Introduction

66 Several interventions, such as Pneumococcal conjugate vaccine (PCV) and standardised guidelines
67 for diagnosis and treatment, have led to reductions in pneumonia morbidity and mortality over the
68 last twenty years ^{1,2}. However, in spite of these gains, pneumonia remains the leading cause of
69 infectious mortality amongst children globally, with the vast majority of the burden falling in sub-
70 Saharan Africa and south Asia ³. To accelerate reductions in pneumonia mortality, further
71 refinement of diagnosis and treatment pathways are needed, including correct referral and access to
72 oxygen treatment ⁴.

73 Pulse oximetry non-invasively measures peripheral arterial oxyhemoglobin saturation (SpO₂).
74 Hypoxemia (defined as an SpO₂ <90%) is included in the World Health Organization (WHO)
75 guidelines as a pneumonia danger sign ⁵, and is associated with increased mortality from
76 pneumonia, as well as other illnesses like malaria ⁶⁻⁸. Recent evidence from Malawi has also
77 indicated that a SpO₂ 90-92% is predictive of mortality amongst children hospitalized with
78 pneumonia ⁸.

79 While some studies have attempted to predict hypoxemia in children with pneumonia using a
80 combination of clinical signs, there has been mixed success ⁹⁻¹¹. Clinical signs alone fail to identify a
81 proportion of hypoxemic children based on the current WHO guidelines, which results in a missed
82 opportunity for referral and appropriate treatment ^{12,13}. In addition, the subjectivity of clinical signs
83 can lead to variation in care – especially among community healthcare workers (CHWs), who often
84 lack ongoing supervision.

85 Pulse oximeters have been successfully used in low-resource paediatric settings, but are yet to be
86 widely adopted, particularly during outpatient care ^{14,15}. The Ethiopian Ministry of Health has
87 demonstrated leadership in this area, setting up an initiative in 2016 to ensure oximetry and oxygen
88 therapy are available nationally across the healthcare system ¹⁶. However, Ethiopia is an exception,
89 with implementation of oximetry in other developing countries continuing to be slow.
90 Implementation barriers cited include cost, issues with training and supervision and the lack of
91 appropriately designed, robust oximeters and universal paediatric probes, although there are
92 several initiatives to develop devices for low-income settings (e.g. Lifebox[®] and the Phone
93 Oximeter[™])¹⁷⁻¹⁹.

94 In order to better understand current barriers to use of pulse oximetry by healthcare providers
95 (HCPs) in a range of healthcare settings, and explore opportunities that this technology provides,
96 input from end-users is needed ²⁰. With the ultimate goal of designing a universal paediatric probe

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3 97 for all levels of healthcare services in resource-poor settings, we aimed to gain an understanding of
4 98 the challenges of pulse oximetry, how its use has changed service provision and how current devices
5 99 could be improved for these settings. This end-user perspective is currently limited in the literature
6
7 100 and is essential to ensure investment in pulse oximetry is sustainable and effective.
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10 101

102 **Methods**

103 We conducted a qualitative study with HCPs from different levels of the healthcare system in from
104 one site in Malawi (Mchinji district, central region) and one in Bangladesh (Sylhet district, northeast
105 region) from May – July 2016, as part of a wider programme of work aiming to design a universal
106 paediatric oximeter probe.

107 Setting:

108 In Malawi there are three levels of government provided healthcare: CHWs (locally known as Health
109 Surveillance Assistants), health centres and district hospitals. CHWs conduct weekly or bi-weekly
110 village clinics and home visits providing basic integrated community case management (iCCM) for
111 paediatric infections^{21,22}. Health centres are outpatient facilities run by nurses, clinical officers or
112 medical assistants, and District Hospitals have inpatient facilities with capacity for oxygen treatment.
113 In Mchinji, pulse oximetry was successfully introduced into all three healthcare settings in 2012 as
114 part of a PCV research project, using the Acare Technology AH-MX manufactured Lifebox® oximeter
115 and universal adult clip probe (Figure 1a)¹².

116 In Bangladesh, the study was conducted at Projahnmo, a research consortium comprised of Johns
117 Hopkins University and several local non-governmental organizations in partnership with the
118 Bangladesh Ministry of Family Health and Welfare. Current Projahnmo activities are integrated
119 within three government-operated sub-district hospitals, called Upazila Health Complexes (UHCs),
120 and the referral government hospital in Sylhet city (Osmani Medical College), all of which are staffed
121 by physicians and nurses. The UHCs operate outpatient clinics for children under five and provide
122 basic inpatient paediatric care, including oxygen. The majority of government provided inpatient
123 care is provided at Osmani Medical College. Female CHWs employed by Projahnmo conduct
124 bimonthly household surveillance, with a subset of CHWs providing weekly surveillance as a part of a
125 PCV effectiveness study. Projahnmo CHWs conduct basic clinical assessments and refer ill children
126 for care at the UHCs; they do not administer medicines themselves. Since 2015, a National Institutes
127 of Health-funded study (K01TW009988) trained and supplied all Projahnmo clinical staff in

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3 128 Bangladesh, including CHWs, with pulse oximeters to screen children for hypoxemia, using the
4 129 Masimo Rad5® oximeter and the LNCS® Y-I Multisite wrap probe (Figure 1b).
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7 130 In Malawi, CHWs individually own the oximeters, and facilities were given a device for each clinic or
8 131 ward, while in Bangladesh, Projahnmo owns the oximeters and individual healthcare providers are
9
10 132 responsible for routine care and maintenance of the devices. Oximetry was not included in the
11 133 Malawi paediatric guidelines, and Bangladesh did not have national paediatric pneumonia guidelines
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13 134 at the time of the study.

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15 135 Design:

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18 136 We conducted focus group discussions (FGDs). We planned three FGDs in each country, aiming to
19 137 recruit between 6 and 10 people for each FGD (up to 60 participants in total). This number of groups
20 138 was agreed upon before data collection began, driven by practical considerations given few
21 139 healthcare workers in either setting have experience using pulse oximeters with children. The groups
22 140 were planned to be CHWs, health centre or UHC staff, and referral hospital staff separately.
23
24 141 Conducting separate FGDs for the different types of healthcare workers was to allow context-specific
25 142 discussions and encourage participants with varying training backgrounds to feel confident about
26
27 143 raising challenges relevant to their specific setting.

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31 144 Sampling:

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33 145 HCPs were purposefully sampled from sites where pulse oximetry had been introduced, and the
34 146 participants had received some form of training or mentorship in oximetry. Participants were
35 147 identified by local researchers (BZ in Malawi and SA in Bangladesh) to be a representative sample of
36 148 HCPs from their setting (e.g. small and large health centres, inpatient wards and outpatient
37 149 departments in the hospital), and contacted directly by phone. All HCPs contacted participated.
38 150 Participants were reimbursed for their travel costs to the local healthcare facility and provided with
39 151 refreshments.

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45 152 Procedure:

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47 153 FGDs were led by local researchers with experience in conducting qualitative research, with support
48 154 from a facilitator with knowledge of pulse oximeters. The FGDs were divided into two sections, the
49 155 first addressing the participants' personal experience with using pulse oximeters. The topic guide
50 156 included: positive and negative experiences, and possible improvements and challenges (Web
51 157 appendix 1). During the second part of the discussion, the participants were presented with different
52 158 probe designs and given an opportunity to use them for an hour (Web appendix 2). Following this,

159 the discussion addressed positive and negative aspects of the different designs to encourage critical
160 thinking of possible design solutions to the current limitations of a universal paediatric probe.

161 The FGDs were audio recorded and then transcribed, along with the facilitators notes. Questions
162 were asked in a mix of English and local dialects depending on understanding and ease of expression
163 (Chichewa, Bangla or Sylheti) and participants were told to answer in their preferred language.
164 Responses were clarified by facilitators if there was an issue with language and understanding
165 between participants. Recordings were transcribed and translated where necessary. Translations for
166 Malawi were done by BZ and EK together until final transcripts were agreed, and by an independent
167 professional service for Bangladesh.

168 Analysis:

169 We analysed the data thematically using a framework approach, as an appropriate method for a
170 multi-disciplinary team conducting health research²³. This process involves five steps:
171 familiarisation, identifying a thematic framework, indexing, mapping and interpretation²⁴. The
172 transcripts and notes from the FGDs were printed and coded on paper, with the coding matrix
173 created in Microsoft Excel. CK and KF independently familiarised themselves and indexed the data,
174 and the emergent themes were discussed until a consensus was reached on the mapping and
175 interpretation of the data. This interpretation was shared with the local researchers (BZ and EK in
176 Malawi; EDM and MI in Bangladesh) for further discussion until all were in agreement.

177 Ethics:

178 Written informed consent was obtained from all FGD participants. This study was reviewed and
179 approved by the University College London research ethics committee (8075/003), Johns Hopkins
180 Medicine Institutional Review Board (IRB00047406), the Malawi National Health Sciences Research
181 Committee (16/4/1570) and Bangladesh Medical Research Council (BMRC/NREC/2013-2016/1272).

182

183 **Results**

184 We conducted six FGDs, with 23 participants from Bangladesh and 26 from Malawi (Table 1). We
185 identified five emergent themes: trust; value; user-related experience; sustainability; and design.

186 Trust

187 Trust emerged as a theme both in terms of how the HCPs interpret the oximetry results, and how
188 caregivers interact with HCPs and the pulse oximeter. We found that all cadres of HCPs in both sites

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3 189 had an awareness of the fallibility of the oximetry readings, specifically relating to lower SpO₂ values.
4 190 For SpO₂ levels which were deemed abnormal, <90% up to <95% according to different participants,
5 191 HCPs stated that they would often re-check the result before making a referral or treatment
6 192 decision:

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10 193 *"if we see it is 89% we change the probe or change the finger" (Hospital, Bangladesh)*

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12 194 However, questioning the validity of these lower SpO₂ results in the context of a child's clinical
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14 195 condition was only discussed by the HCPs who worked in the hospital setting. This difference in the
15
16 196 trust placed in the SpO₂ results by different types of HCPs suggests that more in-depth clinical
17
18 197 training and understanding of the technology may result in different clinical applications:

19 198 *"sometimes the pulse oximeter can give readings which you are not comfortable with according to*
20 199 *the presentation of the child [...] most of the time when it happens like that, we just use our*
21
22 200 *judgement"* (Hospital, Malawi)

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24
25 201 An outcome of using pulse oximeters for pneumonia diagnosis was a change in parental and
26
27 202 community understanding and perceptions of care, with HCPs discussing increased trust in their
28
29 203 referral and treatment decisions. This worked in two ways, firstly with the oximeter acting as a direct
30
31 204 feedback and education tool:

32 205 *"if the mother is able to read you can show the exact figure and she will accept the treatment of*
33
34 206 *oxygen, [before] it was very difficult to explain the role or the importance of the oxygen machine and*
35
36 207 *some mothers refused"* (Hospital, Malawi)

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38 208 Secondly, in Malawi HCPs projected that the oximeters had improved clinical care, and therefore
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40 209 outcomes, which led caregivers to be more inclined to accept the referral or treatment being
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42 210 recommended, especially in the case of oxygen:

43 211 *"[previously] in the village they were saying that when a child is put on the oxygen machine it*
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45 212 *facilitates death, therefore it was making problems, but this time because children are put on oxygen*
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47 213 *earlier they survive, it's because we knew the saturation"* (Health centre, Malawi)

48 214 Value

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51 215 The theme of value relates to the inherent value of improved decision making, HCPs perceived self-
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53 216 value (i.e. confidence) in their clinical work, and the physical value placed on maintaining a working
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55 217 pulse oximeter. As pneumonia is classified using a range of non-specific and often subjective clinical
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57 218 signs, HCPs discussed the positive addition of this more objective measure:

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3 219 *"...by looking at this we can understand how much respiratory distress is in there. Of course this helps*
4 220 *us a lot."* (Health Centre, Bangladesh)

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7 221 In both sites HCPs from frontline settings (CHWs, health centres and UHCs) stated that the pulse
8 222 oximeters had changed the way they work and given them confidence in making referral decisions.
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10 223 Interestingly however, in the referral hospital setting in Bangladesh where staff training is higher,
11 224 very little value was placed on the pulse oximeter for improving their clinical performance, with the
12 225 ability to conduct chest x-rays, lung ultra-sound and their clinical judgement valued more highly:

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15 226 *"...its sensitivity and specificity is very negligible to be taken as a diagnostic tool."* (Hospital,
16 227 Bangladesh)

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19 228 In Bangladesh the CHWs reported pride in using the oximeters. In Malawi, the CHWs placed a
20 229 physical value on the oximeters and discussed the personal effort, such as paying out of pocket to
21 230 travel commercial charging services, they put in to maintaining a working device:

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25 231 *"...we have been trying all that is humanly possible to take care of these things, but it only becomes a*
26 232 *problem when it comes to the issue of charging."* (CHW, Malawi)

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29 233 This was also reflected at the health centre, where not all facilities have electricity and one or two
30 234 staff are responsible for assessing children. At the referral hospital however this was not discussed,
31 235 with oximeters belonging to the ward, which has a more consistent power supply. Ward-based
32 236 ownership was discussed as a challenge, suggesting individual ownership could result in improved
33 237 care and maintenance as having a device in working order would not be dependent on the
34 238 performance of others.

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39 239 *"...some of the clinicians do not take care of them, so when the machine is not working it means the*
40 240 *whole department is affected"* (Hospital, Malawi)

41 42 43 241 User-related experience

44
45 242 HCPs at all levels discussed their experiences of using pulse oximeters in children under 5-years,
46 243 presenting challenges, their solutions and perceptions of usability. The time taken to get a
47 244 measurement ranged widely, with CHWs in Bangladesh agreeing measurements took less than 1
48 245 minute but in Malawi that it could take up to 20 minutes. The factors that increased the time taken
49 246 to get a measurement were consistently cited as movement and physically smaller children, and in
50 247 Malawi dirty toes making measurements difficult:

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55 248 *"Getting readings from irritable babies is a bit tough and it takes time."* (Health centre, Bangladesh)

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3 249 *"...using it on a child up to six months of age, sometimes it has been a problem because these*
4 250 *children have got small fingers, so although we use toes sometimes they are also small and the child*
5 251 *is afraid so they start crying. So we have got other things we can give a child to play with but it is a*
6 252 *little bit of a problem, but at the end we get the results."* (CHW, Malawi)
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10 253 Solutions to these challenging children included asking caregivers to breastfeed, giving them a toy to
11 254 distract them, and simply waiting. The term used frequently to describe challenging children was
12 255 'fear', with the HCPs stating that children are afraid of having the measurements taken. This fear was
13 256 associated with the sensors' red light which frightened children, the anticipation of pain, or just
14 257 being an unknown. All of these could result in the child being agitated, crying and uncooperative.
15 258 Despite these issues in small and agitated infants, the oximeters were considered easy to use:

16 259 *"...it's not complicated, it doesn't need complicated education for a healthcare worker to use, with a*
17 260 *good explanation from a colleague or friend you are able to use it."* (Hospital, Malawi)
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19

20 261 There was also the acknowledgement that time to reading was not as important as getting the
21 262 correct measurement; for some respondents, the reason some measurements take longer is the
22 263 desire to get a reliable reading. This included cleaning the child's digits or repositioning the probe:

23 264 *"...taking longer does not mean that one doesn't know the procedure, but sometime it's because you*
24 265 *want to give the correct reading."* (CHW, Malawi)
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30 266 A key challenge reported by frontline HCPs in Malawi was around keeping the oximeter charged; this
31 267 was not considered a significant challenge in Bangladesh. However, here they had issues with
32 268 ensuring the oximeter remained dry and protected during rains and being fully waterproof was
33 269 desirable. Depending on usage, battery life was reported as 1 week – 2 months.
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40 270 Sustainability

41 271 Sustainability was discussed in terms of the device's durability, and the need for continued
42 272 professional development. Generally the pulse oximeters were thought of as robust and durable,
43 273 with some of the HCPs having used their device for over four years without replacements. However,
44 274 the battery was highlighted as the least durable part of the device, and there was a perception that
45 275 when the battery was worn down the readings became less reliable.

46 276 *"There is a matter with the battery too, if the battery is not enough the reading takes a long time to*
47 277 *appear. It sometimes gives false negative readings."* (Hospital, Bangladesh)
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3 278 This related to the HCPs suggestion of having on-going maintenance support rather than wanting
4 279 replacement devices. HCPs described the need for on-going training and support, but also expressed
5 280 a desire for more in-depth education on how oximetry works which goes beyond the basic training
6 281 to take a reliable measurement:

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9
10 282 *“A person gets used to what they are doing once they have been oriented. I think sometimes it’s also*
11 283 *good for you and your team to orient us on how this thing works [...] the way this thing works, we*
12 284 *don’t know”* (Health centre, Malawi)

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15 285 In terms of keeping the devices clean and properly stored, an important factor for prolonging shelf-
16 286 life, we found conflicting opinions between Malawi and Bangladesh. Malawi deemed the probes
17 287 easy to clean and store securely, although the light colour and materials of the device was thought
18 288 to show dirt easily. However, in Bangladesh cleaning was described as burdensome; this likely
19 289 reflects the different devices and therefore methods needed for cleaning, or different perceptions of
20 290 the importance and frequency of cleaning.

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25 291 *“It is hard work to clean it with hexsol and cotton after coming back from the field every day. If we*
26 292 *could get something else to clean it with so that we can clean once a week, I don’t like cleaning it*
27 293 *every day.”* (CHW, Bangladesh)

28 294 Design

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33 295 The key challenges mentioned repeatedly across sites and HCP cadres were the battery, sensitivity of
34 296 the probe in relation to movement or low perfusion, and the probe fit in younger children. Table 2
35 297 summarises the design features requested or suggested to improve the pulse oximeters for use in
36 298 these low-resource settings. Suggestions covered the probe, such as having detachable probes of
37 299 different sizes, charging and battery life, such as additional power packs and solar charging, and
38 300 features to help with agitated children.

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43 301 The oximeters which HCPs used were designed for continuous monitoring; therefore oxygen
44 302 saturation is not a single static result. This was seen as a negative, with HCPs in both sites wanting
45 303 the ability to stop at a result and even store measurements (e.g. a blood glucose monitor):

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49 304 *“Readings would fluctuate if the baby moves. We don’t want that. After getting the actual reading it*
50 305 *should stay fixed.”* (CHW, Bangladesh)

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53 306 In Bangladesh specifically, the CHWs stated a preference for numbers or bars to indicate
54 307 measurement quality, rather than a dynamic waveform display. This opinion was not reflected in
55 308 Malawi, which could be a result of using different devices or different training. A specific challenge

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3 309 presented by CHWs in Malawi was the use of the oximeter in direct sunlight; CHWs often hold clinics
4 310 outside and they faced the combined challenges of bright sunlight and dust, both of which they
5 311 reported as challenges in taking measurements.

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8 312 *"...it returns the correct results when you are in the shade, but while you are in sunlight it fails to*
9 313 *determine good results."* (CHW, Malawi)

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12 314 Positive design features included the portability of devices, the ease of using them and perceived
13 315 durability, with little direct criticism of the oximeters that the HCPs had been using:

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16 316 *"...of the things I like most about using the pulse oximeter, the first one is the portability, because I*
17 317 *can use it anywhere."* (Hospital, Malawi)

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21 22 319 **Discussion**

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25 320 We investigated end-user experiences of using pulse oximeters by a range of different HCPs across
26 321 clinical settings in Malawi and Bangladesh. The FGDs highlighted similarities in experience, such as
27 322 challenges in battery durability, the difficulty of small and agitated children and the positive impact
28 323 of oximeters on clinical practice. However, there were key differences between the providers'
29 324 experiences in Malawi and Bangladesh and between HCP cadres.

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33 325 Of note was the difference in perceived ease of cleaning, which was seen as more burdensome in
34 326 Bangladesh. This is likely associated with the Y-shaped wrap probe design, compared to the more
35 327 easily cleaned clip design used in Malawi (Figure 1). Interestingly though, most critiques were similar
36 328 between sites, highlighting some of the major challenges of using pulse oximetry in children –
37 329 namely movement, low perfusion and small digits. This consistency between our sampled HCPs from
38 330 each site suggests these challenges are not device dependent and therefore a specifically designed
39 331 re-usable device for universal paediatric use in low-resource settings is needed.

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45 332 We identified differences in the sense of value placed on the oximeters by the HCPs, with the higher
46 333 trained HCPs attributing less value to the results than the HCPs with more limited training. Those
47 334 with more training valued their clinical judgement more and were more willing to question the
48 335 accuracy of SpO₂ results. This poses interesting lessons for scaling-up implementation and training,
49 336 as despite perceptions that obtaining a SpO₂ measurement is generally easy, the interpretation of
50 337 the result is more nuanced. Sustained mentorship and more in-depth training were desired by the
51 338 HCPs, and this needs to be considered as part of any implementation programme.

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3 339 As the oximeters were used as spot-check devices rather than continuous monitors, as would
4 340 generally be found in operating theatres or high-dependency care in high-income settings, many of
5 341 the suggested design changes related to improving the devices for this process. One example of this
6 342 was the need for improved battery-life and charging, with HCPs highlighting their limited ability to
7 343 easily access charging points, unlike high-income inpatient settings. Consistently, the desire for
8 344 quicker, static results and a movement tolerant probe with improved fit on younger infants was
9 345 important. Unexpected issues, such as usability in direct sunlight, emphasize the importance of end-
10 346 user engagement in product development as clinical devices designed for high-income settings
11 347 would not need to be robust to outdoor use.

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18 348 The idea of a pulse oximeter being able to improve trust between a caregiver and healthcare
19 349 provider poses potentially exciting opportunities for improving referral and treatment for paediatric
20 350 pneumonia. Early diagnosis and treatment as downstream in the health system as possible, ideally to
21 351 the level of CHWs, are key strategies for improving pneumonia outcomes and therefore reducing
22 352 morbidity and mortality burden²⁵. Therefore, an objective and simple clinical tool with in-built
23 353 decision support, e.g. auditory or visual alarms when the SpO₂ is outside of normal range, presents
24 354 an opportunity for caregiver education and empowerment in the referral decision-making process.
25 355 Recent data from Malawi supports the potential for oximetry to improve referrals, with HCPs from
26 356 frontline settings more than twice as likely to correctly refer clinically-eligible children with a SpO₂
27 357 <90% compared to those with a SpO₂ ≥90% during routine outpatient care¹². Interestingly, this has
28 358 not necessarily been the case with other more objective diagnostic tools, with examples of rapid
29 359 diagnostic malaria tests leading to provider-caregiver tensions around treatments^{26 27}.

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38 360 This study was potentially subject to social-desirability bias, with healthcare workers expressing
39 361 opinions which they thought the facilitators wanted to hear. The purpose of the study was explained
40 362 to the participants during the consent process, and was highlighted as an opportunity for them to
41 363 contribute to the design of a revised paediatric oximeter and probe. In addition, the groups in some
42 364 cases were mixed in terms of gender and job titles, possibly influencing participant's confidence in
43 365 expressing their views and experiences. To mitigate these potential biases, the facilitators
44 366 encouraged the all participants to contribute to the discussions and to be critical throughout. Both
45 367 positive and negative views were given in both Malawi and Bangladesh, and by different types of
46 368 HCPs, therefore we do not feel these biases detract from our findings. Finally, we were limited by
47 369 the number of groups we conducted; additional groups or a different sampling approach may have
48 370 led to alternative perspectives being included, as the number was not driven by saturation.

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55 371 Therefore the conclusions we draw need to be interpreted accordingly.

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3 372 Overall pulse oximeters were valued by the HCPs we sampled for this study, despite challenges with
4 373 charging, maintenance and speed of achieving accurate readings in moving or smaller children. This
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6 374 implies that making improvements to currently available oximeters and probes could further
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8 375 facilitate successful implementation of this technology at the community through to the hospital
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10 376 level for routine paediatric care in these two settings. Based on these providers varied experiences,
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12 377 we recommend that efforts to re-design a pulse oximeter for paediatric spot-checks focus on
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14 378 improvements to battery durability, better fit for smaller digits and the speed at which readings are
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16 379 obtained; these were all important challenges which did not necessarily have local solutions
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18 380 presented. More substantive design changes could focus on alternative power and charging systems
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20 381 (e.g. solar charging) and '3-in-1' devices which include respiratory rate and temperature
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22 382 measurements.
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4

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6
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8
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10
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12
13 388 and Abu Abdullah Mohammad Hanif (Johns Hopkins University-Bangladesh).
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16 389

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23 393 **Conflict of Interest**

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25 394 Authors declare no conflicts of interest.
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30 396 **Author contributions**

31
32 397 The qualitative study was designed and topic guides developed by IW_i, IW_a, CK and EDM, and the
33
34 398 field manual written by CK. Oversight of the study was conducted by CK, BN and BZ in Malawi and
35
36 399 EDM, AB and MI in Bangladesh. In Malawi, BZ and EK arranged, conducted, transcribed and
37
38 400 translated the FGDs. In Bangladesh SA and MI arranged and conducted the FGDs. The data was
39
40 401 coded and analysed by CK. The manuscript was written by CK, with considerable input from EDM.
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42 402 IW_i, IW_a, EDM, BZ, EK, SA, MI, NB, AB and BN read, commented and approved the manuscript.
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46 404 **Data Sharing Statement**

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48 405 Anonymised transcripts can be shared, following the signing of a data sharing agreement, subject to
49
50 406 approval from the relevant National ethics committees. For further information please contact Dr.
51
52 407 Carina King: c.king@ucl.ac.uk.
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Table 1: Summary of the FGD participants and their work experience

	Community level	Health centre or Upazila Health Complex	Hospital
BANGLADESH			
Total participants	8	7	8
Job titles (number)	Community healthcare worker (8)	Physician (4) Medical officer (3)	Senior staff nurse (1) Associate professor (2) ICU staff (1) Anaesthesiologist (1) Assistant registrar (1) Intern medical officer (1)
Work experience (mean, range)	1.7 years (0.6 – 4)	2.3 years (1 – 6)	14.7 years (0.5 – 32)
MALAWI			
Total participants	9	8	9
Job titles	Community healthcare worker (8) Vital signs assistant (1)	Medical assistant (7) Medical technician (1)	Clinical officer (3) Nurse midwife (3) Medical assistant (3)
Years' work experience (mean)	10.6 years (5 – 20)	8.3 years (3 – 23)	8.1 years (4 – 13)

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481 **Table 2:** Suggestions of desirable features or improvements given by healthcare providers

Challenge:	Design suggestion:
Probe fit	Supplied with multiple sizes of probes for different ages A single cable with multiple probes that can be changed (e.g. clipped into the cable) Softer material for a more comfortable fit
Probe placement	Probe made of transparent material so sensor placement on the nail can be seen
Cleaning	Alcohol wipes provided for easier cleaning Different colour probe to make it easier to see the dirt, but does not look dirty quickly
Power	Solar powered charger with rechargeable batteries Back-up power bank Supplied with a spare battery
Agitated children	Toy feature in the device to distract the child Improve the sensitivity of the device to be quicker Improve the sensitivity of the device to tolerate movement
Integrated spot-check device	Store results in a memory that can later be accessed Static oxygen saturation result display '3-in-1' device which includes temperature and respiratory rate measurements as well Shorter cable length for easier portability

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3 483 **Figure legends:**
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5 484 **Figure 1:** Pulse oximeters and probe used by healthcare providers in routine clinical care
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7 485 a. Lifebox® oximeter and adult universal clip probe used in Malawi (accessed on 1st July 2017
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9 486 from: www.lifebox.org)

10 487 b. Masimo Rad5® oximeter and LNCS® Y-I Multisite wrap probe used in Bangladesh (accessed on
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12 488 1st July 2017 from: www.pacificmedicalsupply.com)
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64x97mm (300 x 300 DPI)

Web Appendix 1 – Topic Guide

- What is your experience of using pulse oximeters in children?
- What have been the main issues you've encountered when using pulse oximeters?
- What have been the things you like most about using the pulse oximeters?
- What type of probes have you used? Have any been better than others? Why?
- Thinking about the probes, we would like to hear your feedback about some aspects of using them: ease of putting and keeping the probe on the child, durability, ease of taking a reading, ease of keeping it clean and storage
- Thinking about the oximeter, we would like to hear your feedback about some aspects of using them: ease of reading the display, durability, battery life and charging, time taken to get a reading
- What things would make the probe and pulse oximeter easier to use?
- What things would make the probe and pulse oximeter harder to use?

Appendix 2: Summary of pulse oximeter probes presented during focus group discussions with healthcare providers

Probe type	Figure	Product code
Neonatal wrap		Acare ASYNR-D1
Adult clip		Acare ASANR-D1
Paediatric clip		Acare ASPNR-D1
Ear clip		Nellcor U401-2HL
Adult boot		Acare ASSNR-D1
Paediatric boot		Nellcor U401-2EL

COREQ Checklist

No	Item	Guide questions/description	Page / evidence
Domain 1: Research team and reflexivity			
Personal Characteristics			
1.	Interviewer/ facilitator	Which author/s conducted the interview or focus group?	Pg 15, Author contributions
2.	Credentials	What were the researcher's credentials? <i>E.g. PhD, MD</i>	A mix of diploma, BSc, MSc and PhD
3.	Occupation	What was their occupation at the time of the study?	Pg 6, Methods: procedure
4.	Gender	Was the researcher male or female?	Both
5.	Experience and training	What experience or training did the researcher have?	Pg 6, 'Methods: Procedure'
Relationship with participants			
6.	Relationship established	Was a relationship established prior to study commencement?	No
7.	Participant knowledge of the interviewer	What did the participants know about the researcher? <i>e.g. personal goals, reasons for doing the research</i>	Pg 15, Discussion
8.	Interviewer characteristics	What characteristics were reported about the interviewer/facilitator? <i>e.g. Bias, assumptions, reasons and interests in the research topic</i>	Pg 15, Discussion
Domain 2: study design			
Theoretical framework			

No	Item	Guide questions/description	Page / evidence
9.	Methodological orientation and Theory	What methodological orientation was stated to underpin the study? <i>e.g. grounded theory, discourse analysis, ethnography, phenomenology, content analysis</i>	Pg 7, Methods: Analysis
Participant selection			
10.	Sampling	How were participants selected? <i>e.g. purposive, convenience, consecutive, snowball</i>	Pg 6, Methods: Sampling
11.	Method of approach	How were participants approached? <i>e.g. face-to-face, telephone, mail, email</i>	Pg 6, Sampling
12.	Sample size	How many participants were in the study?	Pg 7, Results and Table 1
13.	Non-participation	How many people refused to participate or dropped out? Reasons?	Pg 6, Sampling
Setting			
14.	Setting of data collection	Where was the data collected? <i>e.g. home, clinic, workplace</i>	Pg 6, Sampling
15.	Presence of non-participants	Was anyone else present besides the participants and researchers?	Pg 6, Methods: Procedure
16.	Description of sample	What are the important characteristics of the sample? <i>e.g. demographic data, date</i>	Table 1
Data collection			
17.	Interview guide	Were questions, prompts, guides provided by the authors? Was it pilot tested?	Appendix 1
18.	Repeat interviews	Were repeat interviews carried out? If yes, how many?	Not applicable

No	Item	Guide questions/description	Page / evidence
19.	Audio/visual recording	Did the research use audio or visual recording to collect the data?	Pg 7, Methods: Procedure
20.	Field notes	Were field notes made during and/or after the interview or focus group?	Pg 7, Methods: Procedure
21.	Duration	What was the duration of the interviews or focus group?	Between 1 and 2 hours
22.	Data saturation	Was data saturation discussed?	Pg 14, Discussion
23.	Transcripts returned	Were transcripts returned to participants for comment and/or correction?	This was not possible due to language potential barriers
Domain 3: analysis and findings			
Data analysis			
24.	Number of data coders	How many data coders coded the data?	Pg 7, Methods: Analysis
25.	Description of the coding tree	Did authors provide a description of the coding tree?	Pg 7, Methods: Analysis
26.	Derivation of themes	Were themes identified in advance or derived from the data?	Pg 7, Results
27.	Software	What software, if applicable, was used to manage the data?	Pg 7, Methods: Analysis
28.	Participant checking	Did participants provide feedback on the findings?	No, but discussed with local researchers (pg 7)

No	Item	Guide questions/description	Page / evidence
Reporting			
29.	Quotations presented	Were participant quotations presented to illustrate the themes / findings? Was each quotation identified? e.g. <i>participant number</i>	Throughout results section (pg 7 – 12)
30.	Data and findings consistent	Was there consistency between the data presented and the findings?	Throughout results section (pg 7 – 12)
31.	Clarity of major themes	Were major themes clearly presented in the findings?	Pg 7, Results
32.	Clarity of minor themes	Is there a description of diverse cases or discussion of minor themes?	Throughout results section (pg 7 – 12)