

1 **Red reflex examination in reproductive and child health clinics for early detection of**  
2 **paediatric cataract and ocular media disorders: cross-sectional diagnostic accuracy and**  
3 **feasibility studies from Kilimanjaro, Tanzania**

4  
5 Running title: Red reflex testing in primary care clinics

6  
7

8

9 **Authors:**

10 Furahini G. Mndeme (MD)<sup>1,2,3</sup>, Blandina T. Mmbaga (PhD)<sup>4</sup>, Min J. Kim (MPH)<sup>5</sup>, Lucy Sinke (MSc)<sup>5</sup>, Louise Allen  
11 (MD)<sup>6</sup>, Evaista Mgya (MD)<sup>1,7</sup>, Andrew Bastawrous (PhD)<sup>3</sup>, David MacLeod(PhD)<sup>5</sup>, Matthew J. Burton (PhD)<sup>3</sup>, Clare  
12 Gilbert ( MD )<sup>3</sup>, Richard Bowman (MD)<sup>3</sup>

13

14

15 **Affiliations:**

16 1. Department of Ophthalmology, Kilimanjaro Christian Medical Centre, P.O. Box 3010, Moshi, Tanzania

17 2. Department of Ophthalmology, Kilimanjaro Christian Medical University Collage, P.O. Box 3010, Moshi, Tanzania

18 3. International Centre for Eye Health, London School of Hygiene & Tropical Medicine, London WC1E 7HT, UK

19 4. Kilimanjaro Clinical Research Institute, Kilimanjaro Christian Medical Centre, P.O. Box 2236, Moshi, Tanzania

20 5. Tropical Epidemiology Group, Faculty of Infectious Disease Epidemiology, London School of Hygiene & Tropical  
21 Medicine, London WC1E 7HT, UK

22 6. Department of Ophthalmology, Cambridge University Hospitals NHS Trust, Cambridge, CB2 0QQ, UK

23 7. Department of Ophthalmology, Bugando Medical Centre, P.O. Box 1370, Mwanza, Tanzania

24

25

26

27 **Corresponding author:**

28 Furahini Godfrey Mndeme, M.D.

29 International Centre for Eye Health,

30 Department of Clinical Research

31 Faculty of Infectious & Tropical Diseases,

32 London School of Hygiene & Tropical Medicine, London, UK

33 Keppel Street

34 London WC1E 7HT

35 UK

36 Tel. + 255 754 614522

37 E-Mail: Furahini.Mndeme@lshtm.ac.uk

38

39

40

41

42

43

44 **Word count: 3,154**

45

46 **Conflict of interest:** The authors do not have actual or potential conflict of interest in relation to this study.

47

48 **Funding:** This work was supported by the Queen Elizabeth Diamond Jubilee Trust-Welcome trust [grant code:  
49 ITCRZC6813]

50

51

52 **Synopsis:**

53 Sensitivities for screening tools were; CatCam 97.6%, Arclight 92.7%, Peek Retina 90.2%, and torchlight 7.3%.

54 Arclight was easier to use, 8.5%(7/24) children who failed community screening were true positive by Arclight.

55

56

57

58

59

60

61

62

63

64

65

66

67

68

69

70

71

72

73

74

75

76

77

78

79

80

81

82

83 **ABSTRACT**

84 **Background/Objectives:**

85 Late presentation of congenital cataract in the developing world has led to poor outcomes such that cataract is the  
86 leading cause of childhood blindness. Our hypothesis was that, Sensitivity of red-reflex testing is greater than  
87 sensitivity of torchlight examination; use of Arclight as screening tool for congenital cataract and retinoblastoma in  
88 primary care clinic is feasible. We aimed to compare sensitivity of new red reflex screening tools and assess the  
89 feasibility of Arclight red reflex screening in the community.

90

91 **Subject/Methods:**

92 We compared the diagnostic accuracy of four different screening tools for cataract and retinoblastoma performed by  
93 ophthalmic nurses, using a clinic based enriched sample of 41 positives and 60 negatives. We then conducted a separate  
94 feasibility study, training non-specialist community nurses. Following the training, community nurses examined 2,827  
95 children <5 years with Arclight who were attending their clinics for growth monitoring and immunization.

96

97 **Findings:**

98 Diagnostic accuracy study: estimated sensitivities were above 90% for Catcam, Arclight and PEEK retina but was 7%  
99 for torchlight. Estimated specificities were above 90% for Catcam, Arclight and torchlight and 87% for PEEK retina.  
100 Feasibility study: Twenty-four out of 2,728 children screened failed community screening, seven were true positive  
101 (six cataract, one retinoblastoma). Prevalence of bilateral cataract was 1.5/1000 (95% CI: 0.40-3.75 per 1000).

102

103 **Conclusion:**

104 Arclight and CatCam have high sensitivity than torchlight, are easy to learn and use by primary health care nurses. Use  
105 of penlight is poor quality care and should be removed from guidelines. Red reflex screening suggested higher cataract  
106 prevalence than previously reported.

107

108

109 **Key words:** Screening for infantile cataract; red reflex testing in primary care clinics.

110

111

112

113

114

115

116

117

118

119

120

121

122 **INTRODUCTION**

123 Cataract is now one of the most common causes of avoidable blindness in children in LMIC.[1-3] Visual outcomes  
124 following childhood cataract surgery in Sub-Saharan Africa (SSA) are poor, with only 44-62% of children achieving  
125 a postoperative visual acuity of 6/18 or better;[4, 5] late presentation is a major factor in this.[6, 7] In contrast, in high-  
126 income countries 72-91% achieve postoperative visual acuity of 6/18 or better.[8, 9] There is also a vast differential in  
127 morbidity and mortality from retinoblastoma between high and low income countries with a mortality of 70% in  
128 SSA,[10, 11] compared to less than 3% in high-income regions.[12, 13]

129  
130 Both childhood cataract and retinoblastoma can be detected by the red reflex test using a direct ophthalmoscope (DO).  
131 Current World Health Organization (WHO) documents relating to the detection of childhood eye disease do not  
132 recommend red reflex screening and refer only to vision testing and torchlight examination in primary eye care  
133 facilities,[14] This is a pragmatic decision relating to scarcity of and inexperience in using DO.[15, 16] However  
134 torchlight examination will only detect advanced cases of cataract and retinoblastoma. In contrast red reflex screening  
135 of neonates using a DO, is standard practice in many high-income countries.[17]

136  
137 In recent decades, the successful implementation of public health intervention programmes with vitamin A  
138 supplementation and high coverage measles immunization in SSA have led to a marked reduction in blinding corneal  
139 scarring. If the health workers who administer vitamin A and vaccinations to young children could also be trained to  
140 detect cataract and other pathology early, there is potential to achieve similar reductions in other causes of childhood  
141 blindness, through early detection and prompt treatment.[18]. Although red reflex screening is ideally carried out aged  
142 4-6 weeks, presentation lag times for congenital cataract and retinoblastoma are measured in years rather than weeks  
143 in our population (6.7), and therefore opportunistic use of the vaccination encounters during the first year of life for  
144 screening would be a potentially significant improvement.

145  
146 It is currently unclear which might be the most suitable screening approach for early childhood eye disease in a primary  
147 care setting. Although WHO pragmatically recommend torchlight, our experience and unpublished pilot data suggest  
148 that this results in under-ascertainment of cataract and retinoblastoma.

149  
150 We were interested in potential alternatives to the standard DO for assessing the red reflex. A novel low-cost and easy  
151 to use direct ophthalmoscope (Arclight) has been developed.[19] The device, which uses a light emitting diode (LED),  
152 is charged by a small solar panel in the casing, and costs USD \$7.50 when purchased in bulk. A second device is Peek

153 Retina,[20] which was developed as an adaptor for smartphones to permit examination of the retina (rather than to  
154 specifically examine the red reflex). It is comprised of a small adaptor with prisms and LED, which is attached on a  
155 smartphone and aligned with the phone camera. The prism provides coaxial illumination and uses the observation  
156 systems of the camera to capture images of the retina. Peek Retina is not designed for red reflex assessment but holds  
157 potential for differentiating normal and abnormal red reflex based on the co-axial light source. A third new device is  
158 the CatCam, a prototype comprising a modified smartphone with a co-axial infrared LED and infrared sensitive  
159 camera, which has an advantage of assessing the fundus reflex without causing pupil constriction and enabling transfer  
160 of digital images for remote reading. These new technologies offer the potential to make red reflex testing easier and  
161 more acceptable to primary health care workers. However, these devices have not been validated as screening tools  
162 for cataract or retinoblastoma in children.

163

164 Therefore, we aimed to compare the sensitivity and specificity of these three new screening devices with each other  
165 and with torchlight. Secondly, one of the devices (Arclight) was used in a pilot screening program in primary health  
166 care clinics providing services for young children, to investigate its feasibility and acceptability as a screening tool for  
167 childhood eye disease in the primary care setting. The paper covers 2 separate but related studies – sensitivity analysis  
168 required an enriched sample and therefore a hospital based study whereas real life feasibility requires community  
169 screening assessment, for which detection rates but not sensitivity can be measured.

170

## 171 **METHODS**

### 172 **Ethical approval**

173 This study was reviewed and approved by the Tanzanian National Institute for Medical Research Ethics Committee,  
174 the Kilimanjaro Christian Medical Centre Ethics Committee, and the London School of Hygiene & Tropical Medicine  
175 Ethics Committee. It adhered to the tenets of the Declaration of Helsinki. A staff member explained the nature of the  
176 study in detail in either Swahili or Maasai language. There was an opportunity to discuss and ask questions. Finally, if  
177 the parent or guardian agreed to allow the child to be enrolled into the study, this was documented on a consent form  
178 in Kiswahili, and witnessed by a third person.

179

### 180 **Diagnostic accuracy study**

181 To compare the sensitivity and specificities of four different screening methods for cataract and retinoblastoma  
182 performed by nurses, we conducted a prospective, cross-sectional, hospital-based, enriched sample study comparing

183 their diagnostic accuracy to the results of a full clinical examination performed by a consultant paediatric  
184 ophthalmologist. The study was designed according to ‘Standards for reporting diagnostic accuracy studies.’[21]

185

186 We recruited participants from children attending the paediatric ophthalmology clinic at Kilimanjaro Christian Medical  
187 Centre (KCMC), Moshi, Tanzania between November 2016 and March 2017. For this study, we required a mixed  
188 group of young children some of whom had cataract or retinoblastoma and some of whom did not. Prior to recruitment,  
189 all new patients presenting to the clinic underwent a preliminary red reflex test assessment by a junior paediatric  
190 ophthalmologist, independent of the other study procedures, using a direct ophthalmoscope without pupil dilation.  
191 Children under 5 years from consenting families were then recruited as potential positives (abnormal red reflex) or  
192 potential negatives (normal red reflex). All patients who had an abnormal red reflex or normal reflex were included in  
193 the first series from which the enriched sample was selected. Children with other obvious eye pathologies and whose  
194 carers were unwilling to provide consent were excluded.

195

196 Following recruitment, each child had both eyes examined using each of the four screening tests being compared:  
197 torchlight, Arlight, PeekRetina (model EC2Y5EJ, UK- using Sony 23 compact) and CatCam (prototype modified  
198 Google Nexus 5X with coaxial infrared LED peak wavelength 860nm). The examinations were conducted by four  
199 different ophthalmic nurses, with a different nurse performing each test on the child. The order of the tests was  
200 randomised for each child, using a simple random number table. The devices were rotated throughout the study so that  
201 each nurse assessed children using all four methods. The nurses were masked to each other’s findings. The nurse made  
202 a subjective judgement as to whether the red reflex was normal or abnormal. Examinations were performed in a dimly  
203 lit room and the pupils were not pharmacologically dilated.

204

205 Immediately after the nurses’ screening, all children had their pupils dilated using Tropicamide 0.8% with  
206 Phenylephrine hydrochloride 5%. They were then examined by a masked consultant paediatric ophthalmologist (GF)  
207 using a slit lamp and indirect ophthalmoscopy for the presence or absence of ocular disease, and if present, the  
208 diagnosis was established. This was the reference standard assessment. Each child was then assigned a final status as  
209 “true positive” or “true negative” based on the ophthalmologist’s findings. Only children with cataract or  
210 retinoblastoma were defined as true positives.

211

212

213

214 **Arclight screening in the primary care setting – feasibility study**

215 To investigate the feasibility of red reflex screening in a primary health care setting in Tanzania we conducted a  
216 prospective observational study. We recruited 24 Reproductive and Child Health (RCH) nurses who regularly examine  
217 children in 12 local RCH clinics. The nurses attended a two-day training seminar for red reflex screening with three  
218 new devices, Arclight, prototypes of Peek Retina and CatCam. At the end the trainer (GF) 1) assessed each nurse to  
219 check they had grasped the technique and were observed performing it with a baby of 6 months or under and 2) asked  
220 each trained nurse to provide feedback on the learning experience using a structured questionnaire.

221

222 Following the feedback during the nurse training, we selected the Arclight in the prospective screening study. Although  
223 CatCam performed better in the initial hospital based study, it was not possible to test CatCam in this large study due  
224 to the limited availability of devices at that time. Moreover, the good performance of Arclight in the initial comparative  
225 study and the positive qualitative feedback from the 24 RCH nurses meant that this was considered a good alternative.

226

227 Following training, the 24 RCH nurses examined children <5 years who were attending their RCH clinic for growth  
228 monitoring and immunization and had never been examined before. Recruitment took place between February 2017  
229 and June 2017. Children with serious medical conditions or whose carers were unwilling to provide consent were  
230 excluded. The nurses performed the red reflex screening using the Arclight in a dimly lit room. The pupils were not  
231 pharmacologically dilated. The RCH nurses completed a questionnaire about their experience of using the Arclight for  
232 red reflex screening.

233

234 If a child “screened positive” on red reflex examination in one or both eyes in the RCH clinic, they were referred to  
235 the paediatric eye clinic-KCMC an average of five kilometres distance. They were re-examined by a paediatric  
236 ophthalmologist (GF) using a slit lamp and dilated indirect ophthalmoscopy to determine whether or not there was  
237 media opacity or other pathology. Children who screened negative were not referred for examination by the  
238 ophthalmologist in this part of the study.

239

240 **Statistical analysis**

241 Data were double entered and managed in Access (Microsoft). The analysis was performed in STATA Version 14  
242 (StataCorp)

243 For the initial comparison study a sample of 40 positive cases in the whole sample was estimated to provide at least  
244 +/- 15% precision to estimate the sensitivity of the test (based on a sensitivity of 50%). Negatives were also recruited  
245 to ‘mask’ the testers and to estimate the specificity.

246 For the feasibility study, we estimated that 100 Arclight examinations per screener would provide adequate screening  
247 experience and ability to detect cataract in the general population. We based the required sample size on the observed  
248 prevalence rate of cataract 1.18% in the pilot study and estimated that a sample size of **2,400** would detect cases with  
249 +/- 1.05% precision at 95% confidence level. An intraclass correlation coefficient of 0.05 was taken into account to  
250 adjust for cluster variance between nurses.[22]

251 The sensitivity, specificity, and area under the curve (AUC) of each of the four methods were estimated along with  
252 their confidence intervals. A scatter plot of sensitivity against specificity was plotted to compare the four methods. We  
253 used descriptive statistics to report nurse’s learning experiences with Arclight, Peek Retina and CatCam and the  
254 challenges of red reflex screening using Arclight in RCH clinics. In all screened failures, positive predictive values  
255 were determined.

256

#### 257 **Role of the funding source**

258 The funder had no role in study design, data collection, data analysis, data interpretation, or writing of the report. The  
259 corresponding author has full access to all the data and had final responsibility for the decision to submit for  
260 publication.

261

## 262 **RESULTS**

### 263 **Diagnostic accuracy study:**

264 We recruited 101 children who had a mean age of 33.4 (range 2.0 – 60.0 months) and **59** (58.4%) were male. Of the  
265 59 males and 42 females, 26 males and 15 females (total 41) were found to be “true positive” by the reference standard  
266 ophthalmologist’s examination: 37 had cataract and four had retinoblastoma. The remaining 60 children were  
267 designated as “true negative” by the reference examination (20 had mild allergic conjunctivitis, 13 with abnormal red  
268 reflex (eight had refractive error and five had strabismus), seven had nasolacrimal duct obstruction, three had optic  
269 atrophy, three had blepharitis, two had bacterial conjunctivitis, two had sub-conjunctiva haemorrhage and ten were  
270 truly normal).

271

272 The sensitivity and specificity values of the four techniques, relative to the reference standard ophthalmologist’s  
273 examination, are reported in Table 1.



274  
275  
276 The torchlight assessment had a very low sensitivity of 7.3%. The other three tests had high to very high sensitivities  
277 (>90%) and specificities. The CatCam performed the best of the four tests, with only 1/41 “true positive” child not  
278 identified and no false positive results. The estimated sensitivity and specificity were highest for CatCam, followed by  
279 Arclight and Peek Retina, Figure 1.

280  
281 Community nurses screened 2,728 children aged <5 years between February 2017 and June 2017 (Figure2). Their  
282 median age was 9.0 (IQR: 4-17 months) and 1,259 (46.2%) were male. They identified 24 (0.88%, 95% CI: 0.31-  
283 1.48%) children who were considered to have an abnormal red reflex using the Arclight: “screened positive”.

284  
285 All children who “screened positive” were referred to KCMC and examined by the paediatric ophthalmologist. Seven  
286 of these children had the target conditions: six cataracts (four bilateral, two unilateral) and one retinoblastoma. This  
287 gives a prevalence estimate of 1.5/1000 (95% CI: 0.40-3.75/1000) for bilateral cataract and 0.37/1000 (95% CI: 0.00-  
288 2.04/1000) for retinoblastoma. All seven children with target conditions (cataract and retinoblastoma) needed surgery.  
289 Retinoblastoma cases were all group E according to the International Classification of Retinoblastoma (ICRB) and  
290 were all enucleated. Seventeen of 24 (70.8%) “screened positive” children did not have either target condition (29.2%  
291 positive predictive value (95% CI 12.62-51.09)), however, seven had other ocular pathologies (one corneal opacity,  
292 two strabismus, four refractive error)-these can also cause abnormal red reflex. One child underwent strabismus  
293 surgery.

294  
295 After three months of screening using Arclight, the majority of nurses (23/24) completed the questionnaire, and all had  
296 additional comments. They reported that they could differentiate a normal from an abnormal red reflex, 3/23 (13%)  
297 very easily, 9/23 (39%) easily and 11/23 (48%) with some difficulty. Three quarters (74%) of nurses reported that  
298 examining a neonate less than four weeks old was more difficult than an older child. Very quick examination (duration  
299 30 seconds to one minute) was reported by 8/23 (35%) nurses; an average of 2-3 minutes 10/23 (43%) nurses; an  
300 average of 4 to 5 minutes 3/23 (13%) while 2/23 (9%) took longer than 5 minutes to elicit a red reflex. A third of nurses  
301 (35%) reported that learning Arclight needs less than a day, another third (39%) thought a full day was required and  
302 the remainder (26%) thought two or more days were needed. All nurses reported that parents were happy and willing  
303 to let their children be screened. 18/23 (78%) reported that there was a suitable space in their facilities for screening.  
304 However, 9/23 (39%) reported that screening interfered with their day-to-day activities because of staff shortages,  
305 large numbers of children, increased workload, and multiple responsibilities.

## 306 **DISCUSSION**

307 Community screening is not a suitable environment for accurately estimating the sensitivity of a screening test where  
308 the disease is rare (in this case an estimated prevalence of 1-2 per thousand). Therefore, we initially compared the four  
309 diagnostic tests in a hospital based diagnostic accuracy study, using a sample enriched with true positives. The  
310 weakness of that approach is that the screening test may be less sensitive in the community when performed by non-  
311 specialist nurses in a less optimal environment, and on younger patients (the hospital patients are older because we  
312 need true positives and our children present late in the absence of a screening programme). It was not practical to cross  
313 check all the cases in the community phase of the study because it would have involved stationing paediatric  
314 ophthalmologists in several MCH clinics for 3 months. We tried to limit this weakness by 1) selecting ophthalmic  
315 clinic nurses in the comparative study who had no previous training in red reflex testing and 2) ensuring that the RCH  
316 nurses were able to perform red reflex testing after their training during the workshop.

317

318 The comparison study showed that assessment with torchlight was the least sensitive device (7%). Assessment with  
319 CatCam had the highest sensitivity (97.6%; 95% CI: 87.1-99.9), possibly because infrared light does not cause pupil  
320 constriction, so the pupillary diameter is larger in this test. The sensitivity of assessment with Arlight ophthalmoscope  
321 was also very good (92.7%; 95% CI: 80.1-98.5) which agrees closely with the sensitivity of 93.8% reported by Mark  
322 et al in 1987[23] where third-year medical students were given a 30-minute introduction to ophthalmoscope and  
323 retinoscope and then allowed to examine eight children with congenital cataract and eight age-matched controls with  
324 normal findings.

325

326 Although CatCam performed better than Arlight in the comparative study, only one prototype device was available  
327 which meant it could not be used in the prospective RCH clinic study. Arlight had already been demonstrated to have  
328 a sensitivity of (92.7%; 95% CI: 80.1-98.5) and was readily available, so was used in this second phase.

329

330 Both CatCam and Peek Retina prototypes were used for the study. Catcam is a prototype modified smartphone device  
331 which is not commercially available. It does not test the red-reflex but instead images the infrared reflex. Both this and  
332 a separate UK proof-of-concept study have indicated that infrared reflex imaging may make childhood cataract  
333 screening more accurate. A large UK newborn population screening study is proposed to test this hypothesis using the  
334 more recent standalone prototype, Neocam. If superiority is confirmed, the technology may be commercialised. Given  
335 the manufacturing costs it would be expected to retail for under GBP 5000, though might be available for less than this  
336 in developing countries. Peek Retina, a smartphone add on designed for dilated retinal examination, specifically optic

337 disc assessment, is commercially available for GBP180, however the product is frequently shared with partners in  
338 LMICs for free or at a significant discount to further the mission of Peek's work.

339

340 Our data suggest that if 10,000 children are screened using red reflex testing, ninety children are expected to be referred  
341 as screening failures, 22 (0.22%) of whom are expected to have true cataract (15 bilateral); 4 (0.37%) retinoblastoma  
342 and 30 (0.3%) children are expected to have other conditions such as refractive errors and strabismus, and 34 will be  
343 normal.

344

345 Our prevalence figures are higher than previously reported. Published estimates of retinoblastoma incidence (thought  
346 to be globally consistent) are 1 per 15-20,000 live births.[12] However, the lower end of our confidence interval for  
347 prevalence would be consistent with that incidence. Cataract prevalence data for children are scarce and variable; our  
348 prevalence estimate is higher than published estimates from SSA and India i.e., 0.4 to 8.5 per 10,000 children.[2, 24]  
349 Our prevalence figures could be an underestimate, in that sensitivity of Arclight in the eye clinic was 92.7 percent and  
350 may be slightly less in the community because of less than optimal conditions and the number of false negatives was  
351 not established. Conversely, our estimate may be biased upwards if news had circulated in the community that eye  
352 screening was taking place in certain health centres and carers who suspected an eye problem in their child  
353 preferentially sought out these centres. However, it was in the same order of magnitude as the pilot study prevalence  
354 figure from a separate large community sample, suggesting consistency though the same phenomenon could have  
355 happened here too.

356

357 These findings are of public health significance in view of the consequences of delay in diagnoses and adherence to  
358 referral. Attention needs to be given to address the human resource issues identified by the nurses who conducted this  
359 exercise in their own workplaces. Our study shows that more than 50% of non-ophthalmic nurses found Arclight easy  
360 to use although screening infants (with smaller palpebral fissures and pupils as well as limited co-operation) did present  
361 some difficulties. The majority reported feasibly short learning times and subsequent examination times, as has been  
362 found in other studies.[16, 20] This means that Arclight red reflex screening by RCH nurses is feasible as well as being  
363 both sensitive and specific. This method offers the potential for screening for congenital cataract and retinoblastoma  
364 to become an integral component of primary child health activities.

365

366 In summary we recommend a change of advice by WHO from torchlight examination only to red reflex testing at the  
367 primary level. We have shown that screening with CatCam and Arclight are sensitive and specific, and that screening

368 with Arclight is feasible in the community.. Red reflex screening yields significantly higher prevalence estimates of  
369 cataract in children than previously reported in the region, highlighting the public health importance of this  
370 intervention. A potential advantage of a digital imaging system such as CatCam is the facility for telemedicine and,  
371 potentially, automated image analysis, which may decrease the training required for rural screeners in the future. The  
372 disadvantage may be initial cost.

373

374

375

### 376 **Acknowledgements**

377 I would like to acknowledge the Queen Elizabeth Diamond Jubilee Trust for supporting this project. Grant Number  
378 ITCRZC6813 supported the project. The content is solely the responsibility of the authors and does not necessarily  
379 represent the official views of the Queen Elizabeth Diamond Jubilee Trust. Authors do not have actual or potential  
380 conflict of interest in relation to this study.

381

382 **References**

383 1. Kalua K, Patel D, Muhit M, Courtright P. Causes of blindness among children identified through village key  
384 informants in Malawi. *Canadian Journal of Ophthalmology* **2008**; 43:425-7.  
385 2. Shirima S, Lewallen S, Kabona G, Habiyakare C, Massae P, Courtright P. Estimating numbers of blind children for  
386 planning services: findings in Kilimanjaro, Tanzania. *British Journal of Ophthalmology* **2009**; 93:1560-2.  
387 3. Waddell KM. Childhood blindness and low vision in Uganda. *Eye* **1998**; 12:184.  
388 4. Bowman RJ, Kabiru J, Negretti G, Wood ML. Outcomes of bilateral cataract surgery in Tanzanian children.  
389 *Ophthalmology* **2007**; 114:2287-92.  
390 5. Yorston D, Wood M, Foster A. Results of cataract surgery in young children in east Africa. *British journal of*  
391 *ophthalmology* **2001**; 85:267-71.  
392 6. Bowman R. How should blindness in children be managed? *Eye* **2005**; 19:1037.  
393 7. Mwende J, Bronsard A, Mosha M, Bowman R, Geneau R, Courtright P. Delay in presentation to hospital for surgery  
394 for congenital and developmental cataract in Tanzania. *British Journal of Ophthalmology* **2005**; 89:1478-82.  
395 8. Cassidy L, Rahi J, Nischal K, Russell-Eggitt I, Taylor D. Outcome of lens aspiration and intraocular lens  
396 implantation in children aged 5 years and under. *British journal of ophthalmology* **2001**; 85:540-2.  
397 9. Gimbel HV, Basti S, Ferensowicz M, DeBroff BM. Results of bilateral cataract extraction with posterior chamber  
398 intraocular lens implantation in children. *Ophthalmology* **1997**; 104:1737-43.  
399 10. Bowman R, Mafwiri M, Luthert P, Luande J, Wood M. Outcome of retinoblastoma in east Africa. *Pediatric blood*  
400 *& cancer* **2008**; 50:160-2.  
401 11. Nyawira G, Kahaki K, Kariuki-Wanyoike M. Survival among retinoblastoma patients at the Kenyatta National  
402 Hospital, Kenya. *JOECSA* **2013**; 17.  
403 12. Kivelä T. The epidemiological challenge of the most frequent eye cancer: retinoblastoma, an issue of birth and  
404 death: BMJ Publishing Group Ltd, **2009**.  
405 13. MacCarthy A, Draper G, Steliarova-Foucher E, Kingston J. Retinoblastoma incidence and survival in European  
406 children (1978–1997). Report from the Automated Childhood Cancer Information System project. *European Journal*  
407 *of Cancer* **2006**; 42:2092-102.  
408 14. WHO. A five year project for the prevention of childhood blindness:report of a WHO consultation.  
409 15. Blundell R, Roberts D, Fioratou E, et al. Comparative evaluation of a novel solar powered low-cost  
410 ophthalmoscope (Arclight) by eye healthcare workers in Malawi. *BMJ innovations* **2018**; 4:98-102.  
411 16. Lowe J, Cleland CR, Mgaya E, et al. The Arclight ophthalmoscope: a reliable low-cost alternative to the standard  
412 direct ophthalmoscope. *Journal of ophthalmology* **2015**; 2015.  
413 17. UK N. Childhood Cataracts- Diagnosis. Accessed 30th April 2018.  
414 18. Malik ANJ, Mafwiri M, Gilbert C. Integrating primary eye care into global child health policies. *Archives of*  
415 *disease in childhood* **2018**; 103:176-80.  
416 19. Blaikie A, Sandford-Smith J, Tuteja SY, Williams CD, O’Callaghan C. Arclight: a pocket ophthalmoscope for the  
417 21st century. *Bmj* **2016**; 355:i6637.  
418 20. Bastawrous A, Giardini ME, Bolster NM, et al. Clinical validation of a smartphone-based adapter for optic disc  
419 imaging in Kenya. *JAMA ophthalmology* **2016**; 134:151-8.  
420 21. STARD. An Updated List of Essential Items for Reporting Diagnostic Accuracy Studies:.  
421 22. Adams G, Gulliford MC, Ukoumunne OC, Eldridge S, Chinn S, Campbell MJ. Patterns of intra-cluster correlation  
422 from primary care research to inform study design and analysis. *Journal of clinical epidemiology* **2004**; 57:785-94.  
423 23. Ruttum MS, Nelson DB, Wamser MJ, Balliff M. Detection of congenital cataracts and other ocular media opacities.  
424 *Pediatrics* **1987**; 79:814-7.  
425 24. Nirmalan PK, Vijayalakshmi P, Sheeladevi S, Kothari MB, Sundaresan K, Rahmathullah L. The Kariapatti  
426 pediatric eye evaluation project: baseline ophthalmic data of children aged 15 years or younger in Southern India.  
427 *American journal of ophthalmology* **2003**; 136:703-9.  
428

429

430

431

432

433

434 **Figure 1: Sensitivity, specificity and confidence intervals of CatCam, Arclight, Peek Retina and Pentorch**

435

436 **Figure 2: Participants flow chart of children screened by community nurses**

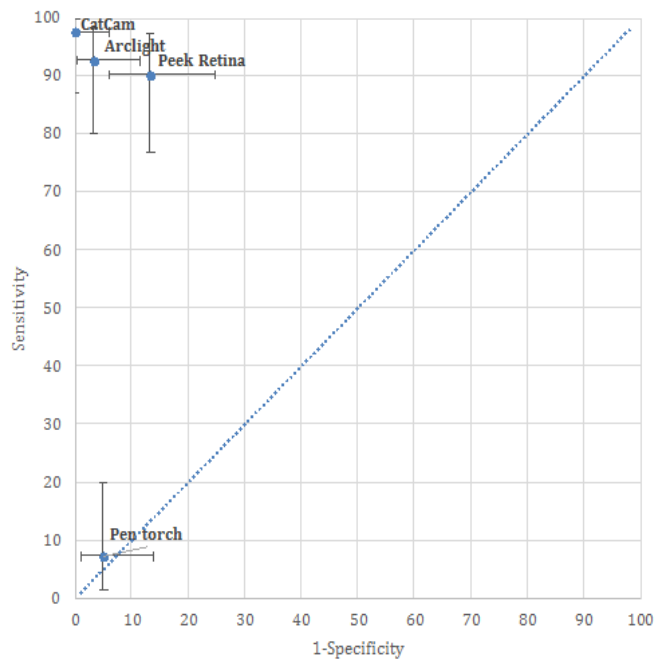
437

**Table 1: Results of screening tests for detection of cataract and retinoblastoma using four different screening methods (torchlight, Arclight, Peek Retina and CatCam)**

Screening test		Reference Examination		Total n/101	Sensitivity (95%CI)	Specificity (95%CI)	AUC (95%CI)
		+(n/41)	-(n/60)				
CatCam	+	40	00	40	97.6 (87.1-99.9)	100.0 (94.0-100.0)	0.99 (0.96-1.00)
	-	01	60	61			
Arclight	+	38	02	40	92.7 (80.1-98.5)	96.7 (88.5-99.6)	0.95 (0.90-0.99)
	-	03	58	61			
Peek retina	+	37	08	45	90.2 (76.9-97.3)	86.7 (75.4-94.1)	0.88 (0.82-0.95)
	-	04	52	56			
Pen torch	+	03	03	06	7.3 (1.5-19.9)	95.0 (86.1-99.0)	0.51 (0.46-0.56)
	-	38	57	95			

AUC - area under the receiver operating characteristic curve.

**Figure 1**



**Figure 2**

