

Figure 2. Images captured for a subject: (Top) Sample frames from Peek video, (Bottom) Left: Pictor Plus, Right: Topcon.

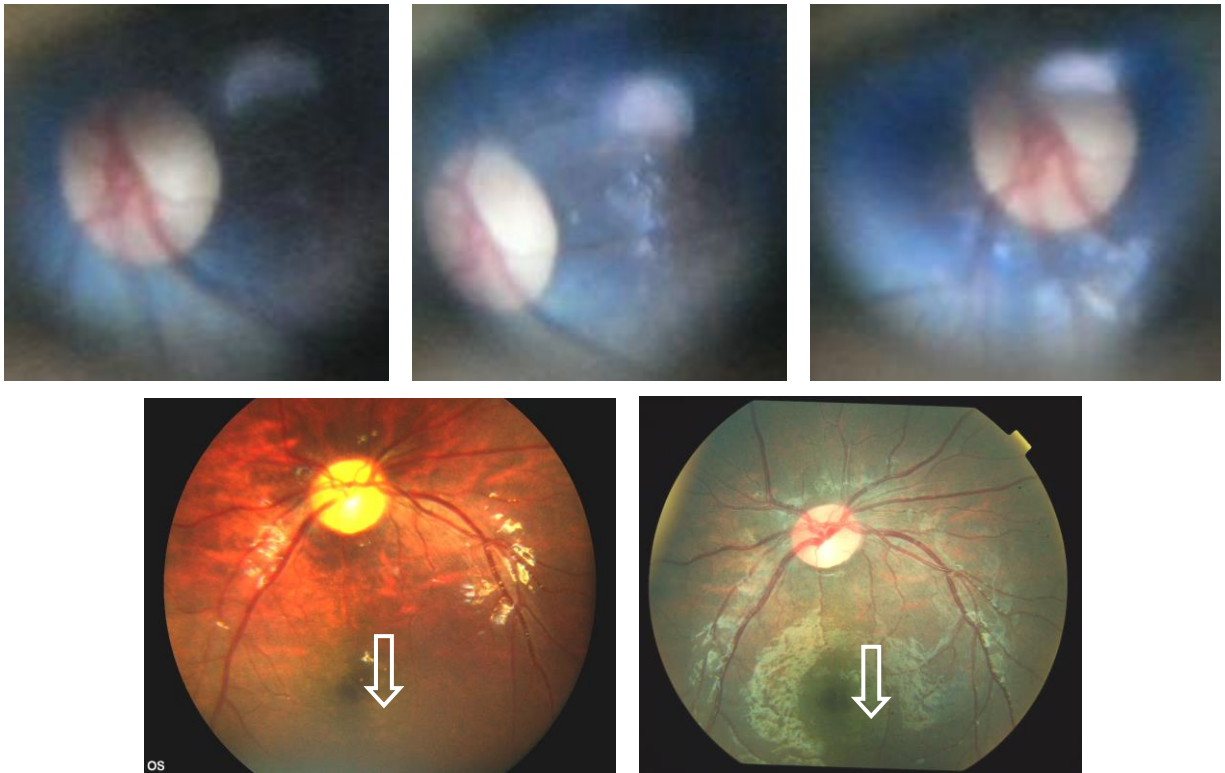


Figure 3. Images showing retinal whitening: (Top) Sample frames from Peek video. (Bottom) Left: Pictor Plus, Right: Topcon. Whitening was not evident in the Peek image which led to incorrect evaluation of the subject.

the hands of an ophthalmologist experienced with this device and when used for immediate diagnosis, but it is more challenging to master than the Pictor Plus or Topcon for a non-ophthalmic technician.

Table 3 shows that the Pictor Plus produced images with quality and resolution to allow the best overall performance, sensitivity of 100% in detecting integrated signs of MR, with a specificity of 87%. Hemorrhages and whitening were all detected in the Pictor Plus images. These results for the Pictor Plus were all superior to the other two cameras. None of the cameras were able to detect the vessel discoloration seen in the BIO examination by the ophthalmologist. This is likely to be a result of the lesions being in the periphery where none of the cameras collected imagery.

Table 3. Sensitivity and specificity for detecting MR, hemorrhages, and whitening using the three cameras.

Category	Peek		Pictor Plus		Topcon	
	Sensitivity	Specificity	Sensitivity	Specificity	Sensitivity	Specificity
Malaria Retinopathy	87%	75%	100%	87%	100%	75%
Hemorrhages	80%	100%	100%	100%	100%	87%
Whitening	82%	87%	100%	100%	100%	67%

Apart from determining the accuracy of each camera in detecting MR lesions, the cameras were also evaluated by the user (ophthalmologist) in terms of usability, ergonomics and relevant factors, as described in table 4.

Table 4: Factors evaluating the camera usability

Factor	Peek	Pictor Plus	Topcon
Set-up	Cellphone	Handheld	Desktop
Field of view	20°	45°	50°
Ergonomic	Handy	Handy	Bulky
Size, weight	Small, light	Portable	Cumbersome
Imaging stability	Highly unstable	Stable	Stable
Image quality	Poor, artifacts	Adequate	Adequate
Cost	\$500	\$10,000	>\$25,000

4. DISCUSSION

Although BIO has been the reference standard for identifying MR, it is important to recognize that may not necessarily be optimum for locations where ophthalmic expertise is not readily available. Fundus photography has the advantage of enabling a telemedicine environment and allowing the grader to study an area more closely and can provide higher magnification than BIO. The table top cameras such as the Topcon pose a significant challenge to the imager when trying to maneuver the camera and perform alignment when the subject is comatose and in a supine position as shown in Figure 4. This was the major disadvantage of the Topcon. The handheld and easy-to-use retinal imaging systems such as the Pictor Plus and the Peek do provide portability and usability advantages, but produce varying quality color fundus images or videos. As demonstrated in Table 3, all of these cameras do provide some capability for MR screening.

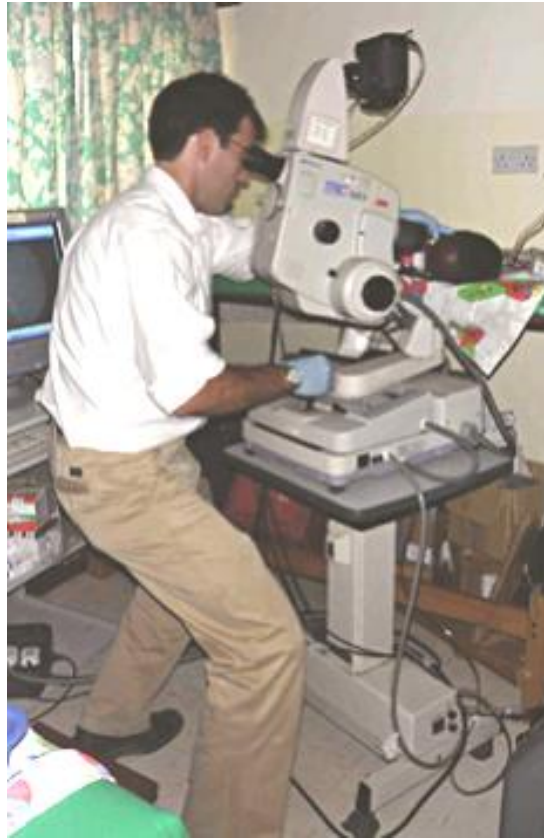


Figure 4. Imaging malarial retinopathy in an infant using Topcon camera.

Although these cameras allow the collection of images from comatose children diagnosed for CM, all three of them have design or capability shortfalls for MR examination. The Topcon's design becomes a cumbersome attribute for the MR application given the state and position of the typical malaria patient (Figure 4). None of the three cameras offer real-time image quality feedback to the user. In these resource limited application, the imager will likely be a minimally trained healthcare worker who may not recognize an inadequate image prior to transmitting the image to the specialist who will make the diagnosis. In a rapidly progressing disease like cerebral malaria, the time taken to re-image the patient could significantly impact the outcome of the patient's recovery.

The lack of single shot wide field ($\geq 120^\circ$) limits the utility given that some MR lesions occur in the periphery where multiple images would be required to capture the full area of the posterior pole. Finally, an automatic MR screening device is needed in these regions where immediate care is required, but accurate diagnosis by a specialist is not easily available.

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