Janice Krushner Memorial Lecture
- London -

Studying Blindness, there's an App for that...

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There are thirty-nine million people worldwide who are blind. That's more people suffering with blindness than have HIV and Aids worldwide. Eighty percent of all eye diseases are either curable or preventable, and ninety percent of people living with blindness, are living in low-income countries.

Figure 1. Cartogram showing the prevalence of blindness by World Health Organisation (WHO) region (using WHO region colours)

This density equalising cartogram, (figure 1) shows the globe distorted, based on where blind people live. You can see that they are predominantly living in Africa and South East Asia. In direct opposition to this, is where eye care specialists live, and where care is able to be provided (figure 2). Looking here, the Americas and Europe are incredibly large, with the greatest disparity in Sub-Saharan Africa. In the

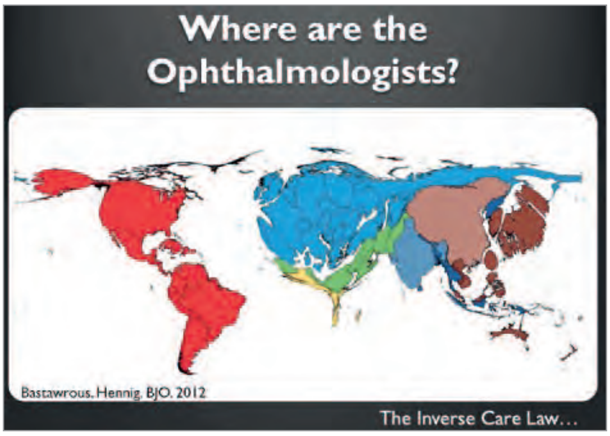

Figure 2. Cartogram showing the number of practising ophthalmologists worldwide by country

United Kingdom there is one ophthalmologist for every twenty thousand people. That's a hundred times more, per person, than in Kenya, where in the least provided areas of Kenya there's one for every two million.

The problem is compounded in that of the eighty-six ophthalmologists in Kenya, half of them reside in Nairobi, the capital city, which serves only eight per cent of the population.

This equates to approximately one ophthalmologist per eighty thousand people. As you go to more remote locations, there's more and more blindness, and fewer and fewer, eye care specialists.

There are several problems: there's a huge lack of human resources; there are very few trained specialists; and those who are there, are focused in areas of relative wealth. There's a lack of infrastructure; only very basic equipment available; infrequent access to electricity and very poor roads. All of these problems ultimately give the result that those who are most in need are least likely to access eye care. Because of the problem with eye disease in Kenya, we established the Nakuru Eye Disease Cohort Study - the first, longitudinal, population-based study of eye disease in Africa. Nakuru is in the Rift Valley in Kenya. It was chosen because it's very representative of the country, having all ethnic groups present, within the area, and having a wide mixture of urban, rural and socioeconomic groups.

Current Technology

We have a team who go around looking for people who were examined six years ago, in a hundred different locations. In each place they examine them for near vision. They consent them; they explain the procedure and they explain where the examination will be taking place. In each place we go, we set up different buildings, and we establish field clinics. Often the places we go, are extremely difficult and remote, although they are quite beautiful.

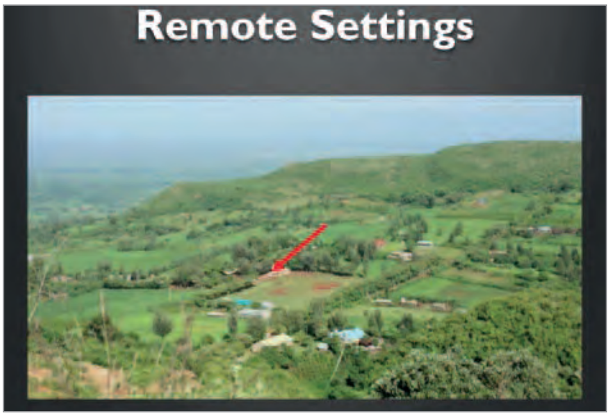

Figure 3

With this clinic (figure 3) the surroundings are stunning, but there is actually no road to it, so we parked a mile and a half away, and spent the next two hours carrying the equipment down to the site.

Once the field clinics are established, the team who saw those participants the day before, register them, go through detailed interviews looking at risk factors, and take their blood pressure. Everyone is measured for spectacle prescription; their vision is measured, and then their corrected visual acuities are also measured with spectacles. There's a lot of waiting around – a lot of expensive equipment; the kind of equipment you'd expect in a high-tech hospital in the UK. Everybody is dilated, and the backs of their eyes are examined, including a detailed assessment by myself with a slit lamp, and pictures taken with a fundus camera. All the data is entered on data entry sheets, and all of these go back to the office, for our data clerks to enter into a database.

The project is expensive; costing us over £100,000 in equipment. The entire project cost over £300,000, when we include staff salaries and consumables, and it requires us to move around in two large vehicles to carry the equipment and the staff. We have a team of twenty staff and there's a huge amount of logistical planning, with a hundred clusters that we're visiting as a part of the project. Sixty-six have no electricity supply and sixty-three have very poor, or no road access.

The lack of infrastructure, has time and time again, been a problem. We're frequently stuck and try and get ourselves out, and in the rainy season, we have huge challenges reaching the more remote locations. Power supply is intermittent. Where electricity is available, it's often dangerous and not easy to use, so we run a lot of our equipment from a petro-powered generator.

Smartphone Technology

Is there another way of reaching those people who are the most difficult to reach? We've developed something called the portable eye examination kit (Peek), which is a smartphone-based tool. It is designed to replace all the standard hospital equipment, in areas

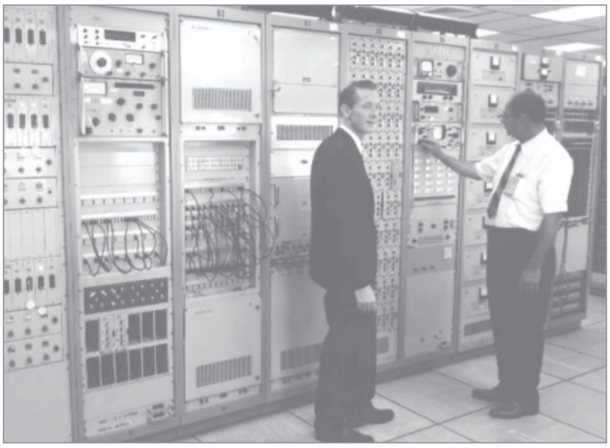

Figure 4

which are difficult to reach and where there's a lack of infrastructure.

This computer (figure 4) which many of you may know, filled a huge room, and was the first computer that was used to power putting man on the moon in 1969. Most of us are now walking around with a smartphone in our pockets; incredibly these smartphones are several orders of magnitude more powerful than that computer.

In 2012, we reached seven billion people on the planet, of which six billion, were connected by a mobile phone, and that's more people that have access to a mobile phone than clean running water. In Kenya, fifty percent of the population do not have access to sanitation services and water; whereas over seventy-five percent have a mobile phone. Mobile phones have evolved hugely over the last few decades; from huge things that required suitcases and satellite dishes, to these powerful, small pocket computers, that we carry around.

Also man has evolved, so in London today, you'll see almost everyone holding a mobile in their hands. Realising this incredible power, we decided to look at all the potential eye applications that were available. We downloaded every single one of them, and tested them, and summarised them in a paper two years ago called 'Eye Phones for Eye Surgeons'. Amazingly, ninety-nine percent of the Apps available for eye disease were in no way validated, tested and proved to work prior to release.

Visual acuity is something that everyone has: it's the measure of what somebody can see. It's hugely important, in terms of determining the levels of sight problems, and what category people go into, and also who requires treatment. Current methods for doing this are both expensive and time consuming, and require one or two trained people to deliver the test. The first application we set about developing, was replacing this, with a visual acuity application in Peek.

Figure 5

You can see the application in action here (figure 5). The patient points in the direction of the letter 'E,' and the tester has just swiped the direction the patient has pointed, without needing to know which way the patient pointed. This way there is a far more objective result and the test is much more rapid. We've used in-the-field feedback to help develop the application. When a patient can't see the results, s/he shakes their hand, and the tester then shakes the phone which records that the patient couldn't see. This result is then attached to that patient record.

What's more, within the application we've developed a sight simulator, because giving people feedback on their vision in the methods that doctors understand, is not necessarily useful to patients. So, for example, a child was tested in a school and was found to have low vision; to show the teacher what this means, you press the 'show me' button, and compare what a normal child sees, with what this child sees (figure 6a and 6b). This will then help the teacher to understand the visual world of that patient.

Figure 6a

Figure 6b

We've also developed a series of applications for children. Testing children's vision is notoriously difficult and requires someone who is highly trained. We've now got a series of games, where the child doesn't even realise they're having their vision tested,

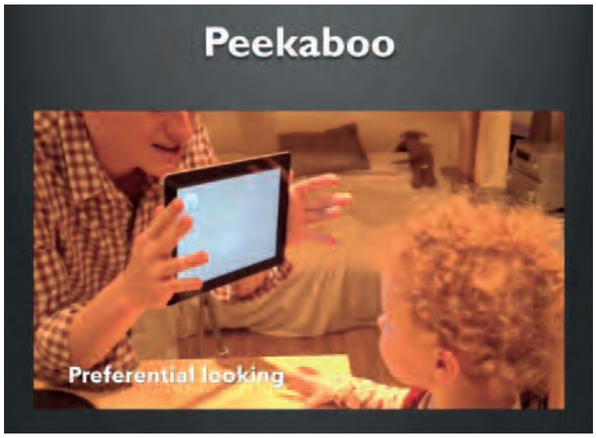

Figure 7

and they feel like they're playing a game. Here the doctor is looking at which corner the patient is looking at (figure 7), and then taps that corner with their finger, to record the answer. The retina is the next major frontier. Being able to view the back of the eye allows us to work out why those people who have low levels of vision are blind. The back of the eye gives us all sorts of information.

Here we have the optic nerve (figure 8), which is a direct extension of the brain.

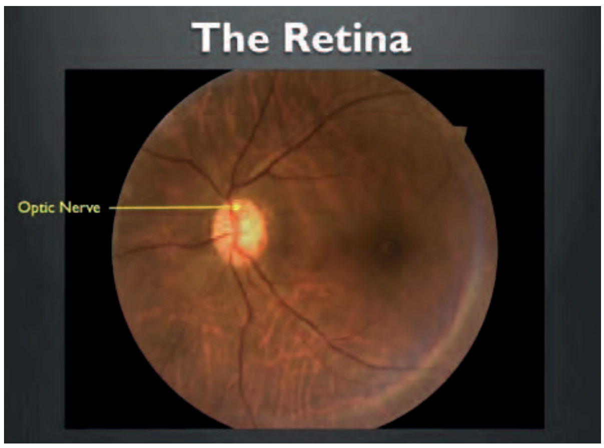

Figure 8

We have the macular, which is responsible for central vision, and there are arteries and veins. All sorts of diseases can be picked up by looking at the back of the eye: from diabetes and glaucoma to malaria, HIV and many, many others.

I've started developing various techniques, and the first thing I started playing with was adapting a technique most ophthalmologists use, called indirect ophthalmoscopy. This way, we replace the expensive headset, and just use the smartphone, holding this condensing lens over a patient's eye.

Here you can see we're getting a view of the back of the eye (figure 9). This is somebody's retina, and all those yellow areas are of laser scarring from treated diabetic retinopathy.

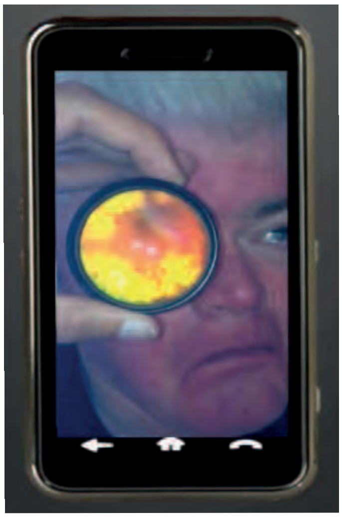

Figure 9

So it works very well, and works well in the hands of ophthalmologists, but the problem is it doesn't work well in the hands of non-ophthalmologists, so I went about developing a new tool altogether. This tool attached a wide field panoptic ophthalmoscope to a Nokia N8, which at the time of development, was the phone with the best camera around. Retro-fitting allowed us to clip it on to the phone, and get really excellent views.

However, as soon as I took it to Kenya, although the views were fantastic, it didn't work well in the hands of the community health care workers; it was too difficult. The rate limiting step was the attachment and not the phone. This, therefore meant, it was not suitable for potential scale up in the future.

So, I went back to the drawing board, and met a very clever person in Scotland, called Mario Giardini, who's experienced in 3D printing. I explained the issues we were having, and the limitations, and how simple the test needs to be if it is to work. Using the latest in 3D printing techniques, we were able to rapidly prototype a new clip-on for the phone, that was small, low-cost and simple to use.

These are the kind of images we were able to obtain (figure 10), using this clip-on, which costs in the region of £1. What made this really stand out, was that for community health care workers, the training time required was less than one minute, and the views

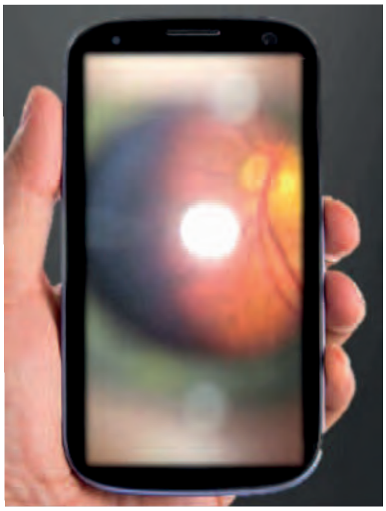

Figure 10

they were able to get were equivalent to those of a much more expensive camera. We were also able to harness the power of smartphones, so this is a panoramic image taken on a smartphone (figure 11).

Many of you will have seen this feature, by sweeping across, it stitches many images together to create a wide field image. So, we're currently working on harnessing this technology that exists in phones, to take wide field images by stitching several photographs together of the retina. This gives us one wide field picture, being the disc, the macula, and further out which can then be

Figure 11

shared in an email, or any other way.

Figure 12

This picture is known as the Eye of God (figure 12). I have a fascination with images that are taken by astronomers. Now I've always wondered, how did they get such high resolution images and it turns out they use a method called 'stacking,' whereby they take lots of images of the same place, and then they remove the background image noise, to leave you with one high quality picture. So we tried doing this with lots of low resolution images of the optic nerve, stacking them together and being left with an image that's really high quality.

When you compare this on Peek, in relation to a hospital desk top camera, for a fraction of the cost we're getting comparable images. We now have the data set on over two thousand optic nerves for comparison.

Figure 13

Visual fields is a test that's commonly done for glaucoma as well as for various neurological diseases. It's difficult to do; this piece of equipment cost £25,000 – it's very large and non-portable (figure 13). We're using the latest in eye tracking technology to make the tests far more intuitive, so by just giving a stimulus for the patient to move to, and then other points for them to look at, we're able to track where they are looking and different points in their visual field. This then, helps us create a map of their visual field.

The slit lamp is the major device all eye care specialists use for getting very high quality images of the eye and being able to diagnose most conditions. These are very rarely available in Africa. So we started building various concepts, for looking at how we could make a miniature version of this piece of equipment, which costs £15,000.

And this is the first prototype (figure 14) where we were able to get excellent images, and we're furthering

Figure 14

this now, to see how close to the standard of slit lamp we're able to get.

The fantastic thing about working and piggy-backing smartphones, is that smartphones are evolving, irrespective of what we do. They're becoming more powerful, more user-friendly, more portable. I noticed recently that the latest iPhone has come up with fingerprint recognition and we've been looking at various ways of using personal identifiers. It's very important to be able to identify somebody in the field, especially when the spelling of names is difficult and they don't have an address. So iris recognition is one method, but the fingerprint is certainly something that we're looking to build on.

Every time an examination takes place, the tester enters who they are; enters the patients' details; and the GPS location of where the examination is taking place. Therefore, every test is trackable to a location. The data that's collected on the phone is integrated into a database which allows us to search, in any given area, by any given parameter. So if you zoom in on the study area here, you can look for people who have cataracts and are blind in both eyes by the numbers of pins (figure 15). You can change the parameter, for example: people blind in one eye as well as those with cataracts, will show a different number of pins (figure 16).

Figure 15

Each one of these red pins is an individual who's identifiable, contactable and locatable. We're then able to use a bulk text messaging service to select a group of people and send them a message, for example saying, 'will you be coming for treatment on any given time? Please respond'. We've also

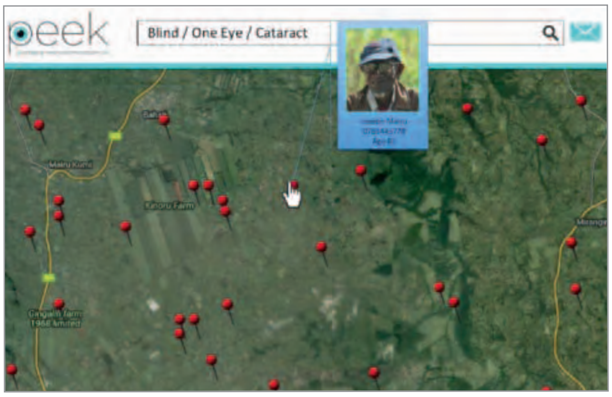

Figure 16

discovered it's very important to have someone in each area that we call a key informant. This is someone who is connected to those people, who can ensure that they come to surgery, and that they get the relevant support that they need, and someone who can co-ordinate activity locally.

And we no longer have to struggle with issues of power. Our health care workers move around with solar-powered backpacks which are always charging through a back-up battery. The phone uses the navigation function to direct them back to the patients' home. We're no longer struggling with issues of poor roads. Health care workers can travel on foot, or on bikes, and go to the patient. Patients are seen in their own homes by health care workers from their own community (figure 17 overleaf).

In areas of suitable bandwidth, it's possible to connect the community health care worker in the most remote

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Figure 17

area, with global experts. This effectively puts global experts in the houses of these people. When comparing the costs of standard hospital equipment against Peek, it comes in at a fraction of the cost and the weight. It requires only one person to operate it and they can move around on foot or on bike.

We are using the Nakuru cohort study mentioned earlier, to validate the smartphone work, so every person who's been included in the eye disease cohort study, is separately examined on the smartphone in their own homes and the results of both are compared.

Future uses of technology

As well as being used on the equator in Kenya, Peek was used at the South Pole, in a recently completed expedition, led by Sir Ranulph Fiennes. It's thought that living and moving around on the South Pole is a good surrogate for life in space, because of the minus seventy degrees temperatures, the altitude and the cold.

Thank you to...

I'd like to thank the fantastic team who've made all this possible: Stewart Jordan the App designer for Peek, Dr Mario Giardini the head of hardware, Dr Iain Livingstone, a fellow ophthalmologist and head of paediatrics, Dr Matthew Burton and Dr Hannah Kuper, my PhD supervisors who've also supported the work going forward, and Dr Tunde Peto, head of the grading centre at Moorfields.

Also, thanks to my wife and son, for being part of the journey in Kenya and for sharing all the struggles and successes, and also thanks to our generous funders and partners who have made this work possible.

Dr Andrew Bastawrous

London School of Hygiene and Tropical Medicine

Q&A

Questions and Answers

Q. You seem to have developed the smartphone application very quickly. Clearly it must have taken a lot more development than what we've seen in your presentation. I'm well aware of the possibilities with 3D printing but, presumably you can't personally print 3D? Presumably that was a mock-up, or are you going to manufacture the actual working version?

A. 3D printing has enabled us to do rapid prototyping so the first version that I developed, I did on my own, in the garage, and it took me several months to get it working. I then met a collaborator at the University of Strathclyde who is a bit of a wizard in terms of hardware. He was able to reproduce what I'd built in a couple of hours, which is both amazing and frustrating, given how long it had taken me to do it in the first place. But this put us in a position where we could make modifications very rapidly, test it, and then tweak it on the computer and print another version. So, this accelerated the process a hundred-fold, to the point now, where we have a device that is one and a half millimetres thick. So, the phone still fits in your pocket and it works equally as well as an ophthalmoscope.

Q. What about the optics? I mean you're not 3D printing the lenses?

A. We're not 3D printing the lenses. Part of the 3D printing basically puts everything in position, so that the lenses are perfectly aligned once they're put in. The whole device in terms of materials is less than £5 and we're not using any fancy lenses or tools, it's more the precision of alignment. Because we're doing everything on a miniature scale, and given how small the camera is on the smartphone, this enables us to create something that is incredibly easy to use.

Q. Is this something you're commercialising?

A. Our plan at the moment is to look at launching something of a social enterprise. Software is very easy to distribute, so we've put it on Google and placed it on the App store. The software is downloaded and is going to be free and open source. However, hardware comes at a cost to us and we have to manufacture and distribute it, and so on. So we're looking at models whereby we can generate revenue in high-income countries, and use that influence to keep it free, or low costing, in low-income settings.

Q. Many congratulations Andrew, this is a superb piece of kit. Can I ask you, in-the-field, what back-up do you have? If you lost the camera, is it automatically saved somewhere else?

A. When any data is collected, whether that be visual acuity data or image data, it's stored locally on the handset.

Q&A

If there is sufficient data coverage, it's automatically uploaded. If there isn't data coverage, as soon as that person moves into an area where they can access data, then the information gets uploaded from the phone to a cloud server where it's encrypted. This can then be accessed by the appropriate people who need whichever level of data. It's all stored securely on the phone. For example, if the phone was stolen, you need to get past the hardware unlock key, through the password protection or face recognition, and then you also need to enter your specific password to get into the Peek camp. So even if the phone was to go missing, or is stolen, it's very hard to get hold of that data.

Q. I'm on the Scottish Intercollegiate Guidance Network working group, drawing up the new protocols for diagnosis of glaucoma and aftercare. Is there any possibility of getting some research done, either in the UK or Scotland? One of the problems we have identified is that many older, or vulnerable people, live in isolated areas and to get to an eye clinic is a long journey, and can take a whole day to get there and back. Of course, they are then stressed and tired, which is not ideal for doing some of the rather unpleasant tests. Have you any thoughts of trying to bring this, even as a research project, into the UK?

A. Great question and the answer is yes, and it happens to be Scotland that we are focussing on. Two of our collaborating institutes are the University of Strathclyde, where we have the lead hardware engineer and hardware team, and then there's the Glasgow Centre for Ophthalmic Research, where Dr Iain Livingstone is based. He's actually, as we speak, on his way to have a discussion with a group from the Highlands about using Peek as a tool for general practitioners assessing people in the community, and then sharing that data with hospitals to see if these people need to come in. As you say, it's the identical problem which we are facing in Kenya. You want to ensure that people are referred in a timely and appropriate fashion. So, in a nutshell, yes and Scotland is our first focus within the UK, and that's where our testing will be taking place.

Q. I'm amazed at the amount you've achieved and I wonder how long it's taken you to get to this stage and what your ultimate objective is?

A. For me, the dream was always to go into ophthalmology and to produce a tool to make a social impact, but that was before the days of smartphones. The idea specifically for Peek came in 2011, when I was awarded a grant from the Medical Research Council to do this PhD in Kenya, a cohort study of eye disease. I was then fortunate, in that the IGA supported me to explore this idea of using smartphones. So, it was just over two years ago, that I started looking at suitable people who could work with me to make this a reality.

In terms of your second question, the ultimate aim is really in line with that of Vision 2020 and eliminating avoidable blindness. We have recently been funded by the Queen Elizabeth Diamond Jubilee Trust, to do five major trials, over the next five years in Kenya, Tanzania, India and Botswana. The final study is culminating in a nationwide mapping in Botswana with a view to finding every single person, in a country of two million, who are blind and then using that as advocacy, to raise the necessary funds to eliminate blindness in that whole country. It may seem like a difficult or impossible vision, but I actually believe it is something that is very achievable. As a ballpark figure, we're looking at something like £20-30m to treat an entire country. There are enough people out there, to dip into their pockets and cover something like this, if there is the potential legacy for them. So all we need to do is to package something which allows it to be possible to reach the World Health Organisation and International Agency for Prevention of Blindness, whose ultimate goal is elimination.

Q. It was some years ago that you applied for this grant I seem to remember. Just in terms of the IGA funding, did you have other funding at the time or were we the first to fund your App?

A. You were the first, and so IGA provided me with funding to buy a visual field analyzer and to provide a salary for a visual field technician in Kenya. It also provided some funding to develop some of the tools specifically for imaging the disc.

Q. It's one thing being able to achieve the diagnosis, and I've been to Kenya a couple of times, so I'm very well aware of the poverty out there. But, how affordable and available is the treatment for the population in Kenya?

A. Although Kenya and other similar countries are very under-resourced, the eye care centres there are mostly running at 40-50 per cent of their capacity. The reason for this is that the patients who have the greatest need of eye care, are the least likely to access it, because they are the furthest away. They are the most difficult to diagnose. There's actually a lot of funding available to provide treatment, and the situation that I have here, is that there are multiple donors who want to provide money for treatment, but the patients can't be found to be treated. And so this [Peek] really bridges that gap, in terms of increasing the throughput of patients to the centres that need it, and by doing so, the quality of those eye care centres improves. As volume goes up, the tendency is that quality goes up with it.

Q&A

Keith Barton – Thank you very much Andrew. I suppose the last question is something that I eluded to earlier, is that the IGA donors like to see research that will actually benefit patients in the UK, as well as overseas. You've mentioned about developing this in Glasgow but do you see this developing as an everyday tool?

A. I would very much like to see this in the UK. There's a recent paper that I was asked to be a reviewer on. The outcome was effectively that only 18% of doctors are comfortable doing fundoscopy. Given the potential for people to start looking inside the eye, we have semi-automated software which helps to assess a disc. I would hope that the opportunities for detecting people with early glaucoma is going to be expanded, because there are going to be far more people who are able to pick them up, and that has huge benefits for those individuals, and their families in the long-term. This is certainly something that we would very much like to see working within the NHS and when I move back to the UK that will be one of our focuses.

Keith Barton – So our sons and daughters won't go out and buy it [Peek] and GPs might finally throw out their ophthalmoscopes?

A. If you have no training in healthcare whatsoever, you are able to view a fundus within one minute of picking this up. That's the key really, that with our study here, we have an ophthalmic medical officer who's graded somewhere between a nurse and doctor. We have somebody who's quite good at mobile phones but has no healthcare training and they've both been doing fundus examinations. I think this will hugely broaden the scope for different calibres of people assessing the eye and linking up people who are able to make appropriate diagnosis and management decisions.

Keith Barton – Andrew, thank you very much. That was fantastic and we are very grateful. We wish you all the best with future research in Kenya.

Andrew Bastawrous – I would like to take this opportunity to say thank you to the IGA for all their support and, as I say, all these things remain ideas unless people get behind and support us so thank you very much, it's nice to see the impact this is having on people I'm working with now.