Institution: University of Strathclyde

Unit of Assessment: B12 - Engineering

Title of case study: Innovative technologies for field ophthalmology improve access to healthcare in low- and middle-income countries and in the UK

Period when the underpinning research was undertaken: 2013-2020

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Mario E Giardini	Senior Lecturer	01/09/2013 – present
Nigel Bolster	Research Associate	22/07/2013 – 01/02/2017
Kirsty Jordan	Research Associate	07/01/2019 – 30/06/2019
Matteo Menolotto	Research Assistant	04/01/2018 – 03/01/2019

Period when the claimed impact occurred: 2015 – December 2020

Is this case study continued from a case study submitted in 2014? No

1. Summary of the impact

Researchers at the University of Strathclyde developed a low-cost smartphone add-on to be used by community operators for the imaging of the back of the eye. The device was trialled in African countries (2013-14) and made available commercially through a spin out company from 2016. The innovation has been described as exemplary in World Health Organization guidelines. Research led to further innovations in technology for telemedicine, rolled out in several Scottish NHS boards, where it has reduced the need for travel to and wait for appointments, reduced costs, improved the service to patients, with earlier identification of urgent cases. Stimulated by the COVID-19 response, the technology has been introduced into national policy and in platforms with global distribution.

2. Underpinning research

In 2019, the World Health Organisation (WHO) reported that globally at least 2.2 billion people have a vision impairment or blindness, of whom at least 1 billion have a vision impairment that could have been prevented or has yet to be addressed. This is more prevalent in low- and middle-income countries, in older people and in rural communities. The rapidly increasing demand mandates shifting eye care from secondary care to the community, especially in low-resource settings. Retinal imaging is frequently used in the diagnosis and monitoring of eye disease, such as diabetic retinopathy, glaucoma and age-related macular degeneration, retinopathy of prematurity, and systemic diseases, such as hypertension and malaria. Researchers at the University of Strathclyde, in collaboration with an NHS ophthalmologist, designed a method of adapting a smartphone into a low-cost retinal imaging device. The aim was that such a device could be used with minimal training and in locations with limited diagnostic resources.

A series of these devices were designed and fabricated in Strathclyde in 2014 and sent to academic collaborators at the London School of Hygiene and Tropical Medicine for field trials in Kenya, Tanzania and Mali. Strathclyde researchers performed the necessary adaptations to the field conditions, operating both from Scotland and in the field. Through this process of lab based design and field trials, the researchers developed an ophthalmoscopy adapter, composed of a plastic shell which attaches to the back of a smartphone, and provides a high-resolution view of the retina through an un-dilated pupil. [**R1**]. The phone camera is held close to the front of the eye, and the phone camera flash, or an auxiliary light source, is deflected through the optical assembly to provide images of the retina. These retinal images can then be transmitted to remote evaluation centres for diagnosis. A validation study compared the grading of optic nerves from smartphone images taken by a lay photographer with those of a digital retinal camera taken by an ophthalmic assistant [**R2**].

Participants were recruited from Jan 2013 to Mar 2014 in the follow-up phase of a population-based cohort study on eye disease in Kenya. 2152 images from both devices were sent to Moorfields Eye Hospital, London, where a masked grader graded the images, including providing a vertical optic disk to cup ratio (VCDR; the measure used to diagnose glaucoma). No statistically significant difference in grading or VCDR was found between the digital retinal camera and the

smart-phone acquired images. This showed that the device could record accurate footage of the back of the eye for remote diagnosis and that the autofocussing properties of a smartphone camera can be harnessed to increase ease of use and reduce the need for specialist imaging training.

This technology was subsequently enhanced to suit the context of Accident and Emergency (A&E) and Minor Injuries units in hospitals, where non-specialists often need to refer patients to specialist secondary care [**R3**]. This system was further developed and complemented by a slit-lamp microscope fitted with a low cost camera to the eyepiece. Using a 3D printed mount to maintain stability, the system can be adapted to suit the smartphone or tablet of choice. The technology has been deployed as part of the COVID-19 response, and data has been collected and in the process of being analysed, demonstrating sufficient advantages to inform national policy [**R4**].

3. References to the research (Strathclyde affiliated authors in **bold**)

R1 **Giardini ME**, Livingstone IAT, Jordan S, **Bolster NM**, Peto T, Burton M, Bastawrous A. (2014) A smartphone based ophthalmoscope. *2014 36th Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, Chicago, IL, pp. 2177-2180. https://doi.org/10.1109/EMBC.2014.6944049 [REF2]

R2 Bastawrous A, **Giardini ME**, **Bolster NM**, Peto T, Shah N, Livingstone IAT, Weiss H, Rono H, Kuper H, Burton M. (2016) Clinical Validation of a Smartphone-Based Adapter for Optic Disc Imaging in Kenya. *JAMA Ophthalmology, 134(2),* pp. 151–158.

https://doi.org/10.1001/jamaophthalmol.2015.4625 [REF2]

R3 **Giardini ME**, Livingstone IAT (2020) Extending the reach and task-shifting ophthalmology diagnostics through remote visualisation. Section 9.4.1 In: *REA PM (ed.) Biomedical Visualisation 8*, Ch. 9 pp. 161-174. https://doi.org/10.1007/978-3-030-47483-6_9

R4 Ghazala, FR, Hamilton, R, **Giardini, ME**, Livingstone, IAT. Teleophthalmology techniques increase ophthalmic examination distance. *Eye* (2020). https://doi.org/10.1038/s41433-020-1085-8

Notes on the quality of research: Key research outputs were published following peer review, and supported by several peer-reviewed grants, including:

- Giardini ME. Queen Elizabeth Diamond Jubilee Trust. Technology for eye health, 01/02/2014-31/05/2019, GBP251,400.
- Giardini ME. National Eye Research Centre. Next-generation ophthalmic diagnostics, 01/10/17-30/09/18, GBP7,163.
- Giardini ME. Teresa Rosenbaum Golden Charitable Trust. Next-generation amblyopia diagnostics, 04/01/2020-05/07/2021, GBP67,823.
- Giardini ME. The Scottish Government via NHS Forth Valley. Delivering virtual consultations for emergency eye care. 07/01//2019 – 06/07//2020, GBP11,011.

4. Details of the impact

Innovative ophthalmology technology was developed by researchers at the University of Strathclyde. The initial development of the technology was trialled, and performance verified in African countries, in collaboration with London School of Hygiene and Tropical Medicine. The 'Peek Retina' device was then commercialised and sold through a spin out company. Further advances were made at Strathclyde in collaboration with an NHS consultant ophthalmologist, to develop a system which would be suitable for remote diagnosis of eye problems in NHS or other primary care settings. Remote consultation and diagnosis were found to be of particular benefit to patients and practitioners during the COVID-19 pandemic, reducing the need for travel and personal interaction. Specifically this research has:

- **Informed the design, development and delivery of innovative diagnostic technology for low- and middle-income countries**, leading to economic benefits for a spin-out company and improved eye care provision.
- **Improved the efficiency and quality of eye care within NHS healthcare contexts**, with use in three NHS Scotland Health Boards.

- **Supported effective eye care provision during the COVID-19 pandemic**, reducing travel requirements for patients and ensuring patient and practitioner safety.
- **Informed national policy and planning for teleophthalmology services** in Scotland and England

Informing the design, development and delivery of innovative diagnostic technology for low- and middle-income countries

Retinal cameras remain impractical as a diagnostic tool in many low-income countries and remote primary care settings throughout the world because of high cost, large size, low portability, lack of infrastructure (e.g. electricity and road access), and the need for trained staff. The smartphone-based adapter designed at Strathclyde aimed to overcome these barriers. A plastic clip covers the telephone camera and flash with a prism assembly, which deflects light from the flash to match the illumination path with the field of view of the camera to acquire images of the retina. The phone camera and clip are held in front of and close to the eye, which allows the camera to capture images of the back of the eye. In 2014, the smartphone adapter, named Peek Retina, was awarded Digital Design of the Year by the Design Museum, London, with judges stating: '*It's a great example of how digital design can make a difference in remote healthcare. It uses high design and high technology for a really fundamental purpose, which is ideally to make people's lives better.*' [**S1**] In 2015, the device won an Index "Design to Improve Life" award specifically dedicated to projects with paradigm-shifting global societal impact, alongside Tesla and Duolingo as other category winners [**S1**]. The International Agency for the Prevention of Blindness lists the device in its list of validated diagnostic equipment and the World Health Organisation cites the device as an exemplary case study in its 2016 report on global diffusion of eHealth, highlighting that '*the potential for task shifting and the detection of avoidable causes of blindness in the most at-risk communities makes this an attractive public health intervention*' [**S1**].

In 2016, Peek Vision Ltd. was set up to transfer the technology to commercial availability, as a spin-off from the London School of Hygiene and Tropical Medicine, with research-based expertise from Strathclyde and Strathclyde co-authors then employed at the company to support research and development. This translated Peek Retina into a commercial tool for screening eye disease, initially aimed at solving problems of eye disease in low- and middle-income countries. Peek Retina became commercially available in 2017 and has been distributed to 72 countries [**S2**] including Tanzania, Botswana, Malawi, Madagascar and Mali. Between 2017 and 2020, Peek Vision Ltd received over GBP100,000 in sales of Peek Retina [**S2**]. In late 2018, Peek Vision entered into a multinational partnership with CBM, a leading disability charity which works with eye health implementers worldwide, and in 2019, CBM, Peek Vision and implementing partners launched community eye health programmes in Zimbabwe and Pakistan [**S2**, **S3**]. In September 2020, Peek Vision Ltd closed sales of Peek Retina to focus on other smartphone apps and technology to support eye health programmes, but Peek Retina continues to be used in community healthcare settings globally.

Improving the efficiency and quality of eye care within NHS healthcare contexts

In partnership with NHS Forth Valley, Strathclyde researchers made further advances to the Peek Retina system to allow remote consultation with an eye specialist in NHS settings. The first examination for an eye problem in the UK is likely to be made by an optometrist or General Practitioner, and even in Accident & Emergency (A&E) Departments, eye emergencies are first seen by a non-specialist and then referred to a consultant for follow-up.

In 2018, the initial design was augmented with a 3D printed modification of a slit-lamp microscope which emits an intense beam of light to examine the eye [**R3**]. The addition of teleconferencing software with audio feed enabled person-to-person conversations, and relay of images from diagnostic instruments in real time. Both ophthalmoscope and slit lamp provided images through an iPad. These innovative system and service aspects were interfaced to the Near Me Video Consultation Platform of NHS Scotland, providing a live feed between the patient, the on-site clinician and the remote ophthalmologist [**S4**]. Following consultation, actions can be taken as required, for example an urgent appointment or surgery can be arranged, or prescriptions can be sent directly to the GP, by the specialist clinician.

A trial of the technology in NHS settings in Stirling and Forth Valley began in April 2018, resulting in faster treatment times and significant reductions in the need for follow up hospital appointments.

As a result, by August 2019 the technology was embedded in practice in A&E at Forth Valley Royal Hospital, in the Minor Injuries Unit at Stirling Health and Care Village, and was used by all seven on-call consultants within NHS Forth Valley [**S4**]. NHS Forth Valley received more than 80 video referrals for urgent eye problems in this one year period, with the need for a second appointment removed in an estimated 50 per cent of cases [**S4**]. In 2019, the trial was expanded to A&E at Glasgow's Queen Elizabeth University Hospital, one of Scotland's busiest A&E departments, and to NHS Grampian. There have been many advantages for both patients and practitioners, with clinicians and optometrists stating [**S4**]:

- '*When a colleague needs a steer on what to do, we can have a live view through their equipment, and connect them with a more nuanced plan, often preventing a trek to the eye clinic, and hours of waiting in a second waiting room.*'
- '*The system means that emergency cases are identified earlier and theatre teams can be mobilised more quickly, with treatment starting immediately when needed*.'
- *'Instead of having to transport the patients to hospital, it allows remote areas to access emergency eye care, thus promoting healthcare equality.'*
- '*Patients can get quite anxious, but if they can get a face to face consultation with an ophthalmologist and get things explained to them it can help put their mind at rest. If they do need hospital treatment, they get put into the appropriate clinic more quickly*.'

Supporting effective eye care provision during the COVID-19 pandemic

Scottish Government made GBP3,000,000 available to support emergency eye care measures during the COVID-19 pandemic and reduce the need for patients to attend hospital [**S5**]. The roll out of the slit-lamp microscope and teleconferencing software was part of this response. The NHS Consultant Ophthalmologist who collaborated with Giardini in the research projects was appointed by the Scottish Government as National Lead for Teleophthalmology in March 2020 and called as a member of the Expert Working Committee writing the NHS Scotland National Eye Health Framework for the Coronavirus (COVID-19) Pandemic [**S6**]. This policy framework recommends the innovations co-developed with Strathclyde as part of its national framework for care, noting that '*the gold standard of assessment is via video slit lamp. Teleophthalmology is also invaluable for more remote parts of the country to avoid unnecessary travel. Evidence suggests that most patients will be given advice and treatment without the need for a face-to-face examination*.' [**S6**]

The National Lead for Teleophthalmology confirms that: '*In close collaboration with Dr Giardini, we rapidly adapted local services in April 2020, activating optometric practices matched to population density across NHS Forth Valley, Grampian, and also to rural settings, reaching NHS Highland, NHS Shetland and the Western Isles'* [**S7**]. This implementation during the pandemic decreased necessity for patient travel, lowered pressure on hospital services and reduced crowding in waiting rooms [**S7**]. It enabled diagnosis with greater safety for patient and specialist, by eliminating the need for close proximity in an examination [**S7**]. By 31st December 2020, the technology had been adopted in 12 emergency eye treatment centres across 4 Health Boards in Scotland, matching a population density of 1 centre per 100,000 population on average. Extrapolating from the survey data available, this avoided in excess of 60% of consultation escalations to secondary care pre-lockdown, which increased to an excess of 80% during the first lockdown in 2020, setting a precedent for full national implementation [**S7**].

NHS Scotland received a request during the pandemic to share the slit lamp technology with oDocs, a company from New Zealand which promotes accessible and affordable eye care. The technology was made freely available via the oDocs website during the COVID-19 response [**S7**]. Through this company, the technology was widely available in New Zealand and Australia by end December 2020 [**S7**].

Development of the teleophthalmology system for use in the NHS was facilitated by the Near Me software, developed by an Australian company called Attend Anywhere. This is the video calling platform for NHS Scotland, areas of NHS England and in Australian healthcare. Due to the clear benefits for service provision and patients during the pandemic, Attend Anywhere continues to liaise closely with the NHS to ensure effective implementation and is in ongoing discussion with Giardini and colleagues to further integrate his research into developments of the platform in Australia and the UK [**S7**].

During 2020, the Strathclyde technology also influenced the design of OpenEyes™, the leading electronic patient record platform for eye care in England and Wales, by enabling asynchronous teleophthalmology decision support. OpenEyes™ is an open-source ophthalmology and optometry patient record platform with global reach, which has now been procured for national rollout to every optometric practice and hospital eye service in NHS Scotland [**S7**].

Informing national policy and planning for teleophthalmology services

The successful implementation of the slit-lamp microscope adaptations and teleconferencing technology has inspired further teleophthalmology development at national level. Efficiencies achieved by remote diagnosis are set to persist in the post-COVID NHS, and are being replicated across NHS England, as acknowledged in NHS England/NHS Improvement recommendations (May 2020) which include video slit lamps, mobile phones and tablets as screen-share systems so ophthalmologists in secondary care can provide advice and guidance support to optometrists [**S8**]. Increased efficiency of screening and a reduction in unnecessary travel by doctors and patients will help to reduce carbon emissions associated with healthcare, particularly in remote areas. These issues are all addressed in the NHS Long Term Plan (2019) which includes a commitment to use technology to reduce outpatient appointments by up to 30 million and reduce unnecessary trips to and from hospital as part of a drive to make over GBP1,000,000,000 in efficiency savings [**S9**].

NHS England and Scotland are actively planning to invest more in remote monitoring and diagnostics; an example is the Small Business Research Initiative (SBRI) competition to pioneer remote vision testing, funded by NHS Scotland and Innovate UK. This opened in September 2020 and attracted 25 industrial applicants [**S7**]. The area will open up more commercial opportunities. IDCP, a Dutch company group, opened a subsidiary in Scotland in July 2020 to explore commercialisation of the eye care technologies developed by Giardini's research team [**S10**] and submitted a tender to participate in the SBRI competition. CEO of IDCP confirms that the choice to open a subsidiary in Scotland was aimed at a close liaison with Strathclyde [**S10**].

Attesting to the significance of Giardini's research on ophthalmology policy and practice, the National Teleophthalmology Lead for Scottish Government stated that this work is '*influencing service deployment and influencing policy, with ongoing international outreach. This is important because at service level, with an aging population juxtaposed against dwindling ophthalmology training post numbers, there is an urgent need to decrease pressure on eye care services, reducing the number of emergency referrals that are escalated to secondary care. The teleophthalmology technology addresses this need.'* [**S7**]

5. Sources to corroborate the impact

S1 Collated acknowledgements of the Peek Retina device:
   a. BBC News. *In Pictures: Designs of the Year 2014*. 23 April 2014. https://bbc.in/3lgK9fR
   b. Designboom. *INDEX: award 2015 winners revealed*. https://bit.ly/3liVdJe
   c. WHO (2016). Global diffusion of eHealth. https://bit.ly/3bMcx6e (p. 70-73)

S2 Collated Peek Vision Foundation Annual Reports and Financial Statements, 2017-2019.

S3 Peek Vision. *Peek – the story so far*. 3 January 2020. https://bit.ly/3vrH8Op

S4 NHS Forth Valley. *Researchers say pioneering emergency eye care trial leads to quicker treatment times*. 8 August 2019. https://bit.ly/35ltv8j

S5 Scottish Government (2020). Emergency eye care provision. https://bit.ly/3eTgwxN

S6 NHS Scotland (2020). The National Eye Health Framework for the Coronavirus (COVID-19) Pandemic. Saving Sight, Saving Lives. https://bit.ly/36uYHS9

S7 Corroborating statement from NHS Forth Valley Consultant Ophthalmologist and National teleophthalmology Lead for Scottish Government, dated 24 February 2021.

S8 NHS England. Digital Communication between Primary and Secondary Care and Patients For Eye Care Services in London during COVID-19 Pandemic. May 2020. https://bit.ly/38H1kCi

S9 The NHS Long Term Plan. https://bit.ly/3n9RpcU (2019)

S10 Corroborating statement from CEO of IDCP Group BV, Netherlands, dated 25 November 2020.