Digital health during COVID-19: lessons from operationalising new models of care in ophthalmology

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The COVID-19 pandemic has resulted in massive disruptions within health care, both directly as a result of the infectious disease outbreak, and indirectly because of public health measures to mitigate against transmission. This disruption has caused rapid dynamic fluctuations in demand, capacity, and even contextual aspects of health care. Therefore, the traditional face-to-face patient-physician care model has had to be re-examined in many countries, with digital technology and new models of care being rapidly deployed to meet the various challenges of the pandemic. This Viewpoint highlights new models in ophthalmology that have adapted to incorporate digital health solutions such as telehealth, artificial intelligence decision support for triaging and clinical care, and home monitoring. These models can be operationalised for different clinical applications based on the technology, clinical need, demand from patients, and manpower availability, ranging from out-of-hospital models including the hub-and-spoke pre-hospital model, to front-line models such as the inflow funnel model and monitoring models such as the so-called lighthouse model for provider-led monitoring. Lessons learnt from operationalising these models for ophthalmology in the context of COVID-19 are discussed, along with their relevance for other specialty domains.

Introduction
The COVID-19 pandemic has created an unprecedented disruption to global economies and health care,1 with extensive lockdowns and travel bans to flatten the curve. However, mounting economic pressures and unmet population needs have forced governments to reopen societies. A reopening has to be balanced with public health safety, including infection control and safe distancing measures. This balance has created an urgent need for digital transformation in many industries, enabling remote work and the continued provision of services while providing adequate safety to people and minimising avoidable human contact.

Health care has been disrupted on two fronts: the direct effect of COVID-19 on health care, and the indirect effects that arise from mitigating efforts. The indirect effects are particularly important now, as many societies reopen at different stages with different amounts of success. Importantly, the traditional face-to-face (F2F) patient-physician care model has to be re-examined to meet new requirements from public health measures to mitigate against COVID-19 transmission. Digital technology and new models of care have been rapidly deployed to meet these challenges.

In this Viewpoint, we review the operationalisation of digital health and new models of care in ophthalmology that have adapted to incorporate a range of digital health innovations. We highlight the main lessons learnt and discuss issues that need to be addressed for long-term sustainable transformation, using a narrative review approach, incorporating additional relevant literature as appropriate.

Effect of COVID-19 on health care
There are several common factors that all health-care systems had to address during the COVID-19 pandemic. In general, health-care systems had to reorganise care for existing patients to reduce F2F clinic appointments, triage cases requiring urgent consultation, postpone non-urgent visits including elective surgeries, and set up new infection control measures. These changes have affected the availability of health-care resources, such as existing physical infrastructure and essential supplies, such as personal protective equipment, which have been stretched to meet these demands.

Health-care systems also had to address the surge in patients at a high risk of COVID-19, including patients with respiratory diseases, while minimising their contact with other patients requiring continued care for non-COVID-19 illnesses. These changes required the reconfiguring of workflows and physical infrastructure to reduce the risk of health-care-associated transmission. In addition, health-care organisations had to reorganise manpower to meet large and sudden fluctuations in clinical need at different geographical regions and settings (front-line and community-based settings) in response to local outbreaks.2 Public health policy responses, such as the quarantine of those returning from travel, or alternate week split-team measures to physically separate health-care workers, further added to manpower disruptions in health care.3

Collectively, these factors contributed to rapid dynamic shifts in demand, capacity, and even contextual aspects of health care. These challenges present the need and thus opportunity for digital innovation, with the overall aims of improving the efficiency of few health-care workers, decentralising care with minimal physical touchpoints, and reducing the time spent in health care premises.3

Current state of digital health and digital ophthalmology
Digital health can improve health care by increasing access to health-care services for individuals, improving population health, and enhancing the experience of receiving or delivering care.4 COVID-19 has encouraged a renewed interest from both patients and health-care
Telehealth

Chief among these technology domains is telehealth and telemedicine. The promise of telehealth is increasing the availability of expertise and access to care, thereby increasing the geographical coverage of health systems. In ophthalmology, classic examples include remote screening for diabetic retinopathy based on imaging of the eye with the use of colour fundus photographs or optical coherence tomography, or both, and teleconsultation between patient and provider with the use of messaging or video conferencing. Asynchronous and synchronous tele-ophthalmology have been deployed in some regions. These include the technology-based eye care services from the US Veteran Affairs health-care system, and the hospital eye services under the UK’s National Health Service, that facilitate remote specialist review of patients within community-based settings and triage to reduce the unnecessary referral of patients from primary to secondary or tertiary care. New and potentially more cost-effective models were piloted just before COVID-19, leveraging technology platforms to enable the shared care of patients with glaucoma between community optometrists and hospital ophthalmologists to reduce unnecessary referrals and facilitate community-based monitoring of patients who were stable. These approaches are useful to project secondary and tertiary eye care services for gap coverage across regions where expertise is not readily available.

AI decision support for triaging and clinical care

However, the increasing global burden of eye diseases necessitates solutions that not only de-centralise services but that can also meet the growing shortage of health-care workers by expanding the capacity of existing services. One solution is AI, which might support the triaging of cases for appropriate clinical care. The automated classification of medical images is a leading AI application, and AI for classifying eye disease in colour fundus photographs and optical coherence tomography images has been shown to be clinically acceptable. In regions without enough sufficiently skilled manpower and eye care, these solutions can be applied to exponentially increase the capacity of existing health systems, infrastructure, and resources. Notably, real-world evaluations of these AI tools reported that they were clinically acceptable. Studies have also shown their cost-effectiveness, particularly for a complementary approach of semi-automated eye screening wherein both human graders and AI algorithms work hand-in-hand. Moreover, new prospective AI applications have been made use of in ophthalmology for predicting the individual risk of future disease progression of common eye diseases such as diabetic retinopathy, age-related macular degeneration, and glaucoma, as well as the likelihood of a successful treatment response to invasive interventions, such as intravitreal injections with anti-vascular endothelial growth factor (anti-VEGF) agents in retinal diseases.

In particular, AI support for treatment decisions for a patient has been applied for the management of age-related macular degeneration, a leading cause of blindness that is often asymptomatic in early stages. Novel AI algorithms have been developed to detect, in ophthalmic imaging, early features or quantify subjective measurements, or both, that drive treatment decisions in a reproducible manner, such as the volume of intraretinal or subretinal fluid. Investigations have further shown the potential of these AI algorithms to predict progression in patients with age-related macular degeneration on the basis of colour fundus photographs or optical coherence tomography images, as well as predict the need for more or less frequent anti-VEGF injections. One study showed improved accuracy for the prediction of age-related macular degeneration progression over 12 years when the use of colour fundus photographs was combined with genotype data. However, investigations have revealed challenges with applying this solution of clinical AI support for treatment decisions on a larger scale, such as maintaining reproducibility across different data capture techniques, or imaging platforms of varying hardware, or software platform maturity, or a combination. In this regard, the advent of transfer learning for the retraining of AI tools reported that they were clinically acceptable. Studies have also shown their cost-effectiveness, particularly for a complementary approach of semi-automated eye screening wherein both human graders and AI algorithms work hand-in-hand. Moreover, new prospective AI applications have been made use of in ophthalmology for predicting the individual risk of future disease progression of common eye diseases such as diabetic retinopathy, age-related macular degeneration, and glaucoma, as well as the likelihood of a successful treatment response to invasive interventions, such as intravitreal injections with anti-vascular endothelial growth factor (anti-VEGF) agents in retinal diseases.

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Figure 1: Illustration of patients’ journeys through different models of care before and during the COVID-19 pandemic

(A) Patients with unstable active retinal disease (~70%) undergo registration and preliminary tests (such as a VA check) from home to minimise touchpoints when they attend their regular appointments at tertiary hospitals.

(B) Patients with stable disease instead undergo home monitoring, whereby any disease progression detected is reviewed in community-based centres. Only patients requiring further assessment are escalated for review in tertiary hospitals.

AMD=age-related macular degeneration. IOP=intraocular pressure. OCT=optical coherence tomography. SNEC=Singapore National Eye Centre. VA=visual acuity.
Home monitoring

Another area that ophthalmology has made substantial progress is in the area of home monitoring, with the use of various technology solutions broadly referred to as IoT.29 Patients can now access a range of IoT devices and mobile phone applications for home monitoring and the early detection of functional vision impairment.30,41,42 Examples of such self-monitoring tools for age-related macular degeneration include the ForeseeHome device by Notal, which measures preferential hyperacuity perimetry, or the MyVisionTrack device for shape discrimination hyperacuity, both of which have been introduced to monitor macular visual function remotely.30,41,42 These tools provide new sources of individualised information that can improve the accuracy of clinical AI support for treatment decisions and enable personalised care or monitoring applications, or both, detailed in the later sections.

Emerging technology domains

These digital solutions (telehealth, AI, and IoT) require substantial new infrastructure for health-care data collection and transmission, presenting challenges of bandwidth and cybersecurity.43 This need is where 5G networks and blockchain will probably play a growing role in coming years. 5G networks can be a major enabler for digital health by improving network bandwidth and stability, overcoming the constraints of current mobile phone networks (3G and 4G).44 In addition, blockchains are distributed databases that link blocks of data with digital signatures (which are called hash) in chains that retain the history of any modifications to the data.45 These provide programmable access controls and permissions to enable tiered data access from multiple devices, while providing enhanced security through cryptography and enhanced accountability through non-repudiation in datasets.

New models of care during COVID-19 in ophthalmology supported by digital technologies

During the COVID-19 pandemic, health-care services had to address the three factors highlighted earlier: reducing F2F appointments, minimising contact among patients, and reorganising manpower on the basis of fluctuations in clinical need. Within ophthalmology, a large group of patients whose condition was stable and did not need active interventions were encouraged to adopt remote care through virtual clinics, while patients at high risk continued to attend F2F visits (figure 1).

Moreover, for specific diseases, the goals of care had to be re-examined for many patients. One main example is in patients with age-related macular degeneration, for whom fixed-dosing and treat-and-extend patterns of anti-VEGF injections were recommended to reduce the frequency of follow-up visits for non-treatment monitoring.46,47 This recommendation creates a situation where all F2F visits for patients are visits for anti-VEGF injection treatment, rather than the traditional monitoring visits.

Against this backdrop, various digital models have gained additional traction in facilitating these new processes for clinical care. Figure 2 summarises several of these models based on existing reports of digital health for ophthalmology. These models are discussed in the context of COVID-19 in the later sections. Many health-care systems apply these digital health solutions independently or in combination, depending on the technology and intended clinical context.

Out-of-hospital operational models

Out-of-hospital or pre-hospital operational models can be applied to cater to patients before they seek care at clinics and hospitals. These digital health solutions include the sorting conveyor and hub-and-spoke models. The sorting conveyor model involves the use of digital solutions to provide telesupport based on a patient’s clinical needs or the triage of patients, or both, to facilitate care transitions between primary, secondary, and tertiary care such as that described within stepped-care mental health services.46 These solutions can be leveraged to provide recommendations for self-management or referrals to seek detailed reviews with providers where relevant expertise are available. This model has also been applied for AI systems classifying eye diseases on the basis of ophthalmic images.47,48 These applications include AI algorithms to augment community screening via tele-ophthalmology.44 This model has been used by eye care providers to scale up responses and reduce unnecessary encounters during COVID-19, such as the virtual internet hospital model applied by the Zhongshan Ophthalmic Centre in China.49 In addition to ophthalmology, various AI-based conversational chatbots have been applied with this model in pilot studies,50 although more robust clinical validation is required.44,45

Conversely, the hub-and-spoke model augments clinical services in geographically remote settings (the so-called spoke) through patient–provider or provider–provider consultations with providers or specialists based in referral centres or tertiary hospitals serving the catchment area (the so-called hub).4 This model has been applied within community-based primary eye care services, including technology-based eye care services and hospital eye services, for both synchronous and asynchronous tele-ophthalmology to enable shared care with tertiary specialists providing triage or follow-up recommendations after patients complete fundus imaging in primary care.51–53 Similar applications of the hub-and-spoke model in other specialties include the administration of thrombolysis by mobile teams supported by neurologists from the Cleveland Clinic (Cleveland, OH, USA),54 and reducing unnecessary emergency room transfers in Houston’s Emergency Telehealth and Navigation programme (Houston, TX, USA).55 The benefits of these
out-of-hospital operational models during the pandemic include the improved right-siting of patients, the optimised flow of patients through health systems, the reduced congregation of patients at tertiary care settings, and reduced unnecessary touchpoints.

**Front-line operational models**

Front-line settings in which patients seek F2F care at clinics or hospitals present unique challenges for the adoption of digital health. These challenges can vary greatly depending on the form of the solution and intended application; and are complicated by varying capacity and willingness to adopt digital health, whereby the stream fishing, inflow funnel, pyramid, and shuffling cards models represent options for clinical services with progressively increasing capacity and willingness to operationalise digital health (figure 2). The operational effect is shown in figure 2 because it relates to the need to reorient in-person services to cater to the new digital service. Services that prioritise the continued provision of care at physical health-care settings but require digital solutions with less operational effect to supplement surge capacity can consider the stream fishing and inflow funnel models. However, clinical services that are willing to adopt a digital-first approach for the follow-up of their patients remotely can consider dedicated service orientation for digital health operationalisation, such as pyramid or shuffling cards models, or both.

The stream fishing model can help to engage services that might have spare capacity after the cancellation of

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**Table:**

| Digital health operational models | Clinical context and model description | Clinical applications | Health system effect | Operational effect | Descriptions of illustrative examples and existing research reports |
|-----------------------------------|---------------------------------------|----------------------|---------------------|-------------------|-------------------------------------------------------------------|
| Out of hospital (pre-hospital)    | Sorting conveyor                      | Triage or risk stratify | +++                 | Low               | AI-based eye screening (eg, Idx-DR, SELENA)20,48                   |
|                                   | Hub-and-spoke                         | Consultation*         | ++                  | Middle            | AI-based chatbots (eg, ZOC digital hospital)9                     |
|                                   | Stream fishing                        | Telosupport†          | +                   | High              | Telehealth outreach services from secondary and tertiary care to primary care (eg, technology-based eye care services, 12 hospital eye services; Emergency Telehealth and Navigation)57 |
|                                   | Inflow funnel                         | ↑Availability of clinical expertise | +++                 | Low               | Single patient channel (eg, emergency room)                      |
|                                   | Pyramid                               | ↑Access to health-care services | +++                 | Middle            | Support from providers on an ad hoc basis52 (eg, surgeons with cancelled electives) |
|                                   | Shuffling cards                       | ↑Capacity and efficiency of health care | +++                 | High              | Multiple patient channels (eg, multiple primary care clinics)      |
|                                   | Catchment net                         | +                     | +                   | +                 | Digital first service before in-person care (eg, SAVED)7         |
|                                   | Lighthouse                            | +                     | +                   | +                 | Digital only health-care services with scheduled chronic cases and ad hoc acute cases (eg, SNEC video consultation)58 |

**Figure 2:** Illustrations of digital health operational models, their clinical applications, and the potential effect on health systems and operations

AI=artificial intelligence. mVT=myVisionTrack application. SELENA=Singapore Eye Lesion Analyser. SNEC=Singapore National Eye Centre. ZOC=Zhongshan Ophthalmic Center. *Consultation is a provision of medical advice or clinical care, or both (eg, diagnosis, prescriptions, or recommended surgery). †Telosupport is the provision of information not amounting to clinical care (eg, generic information about drug interactions, tackling misinformation).
non-essential appointments, such as opportunistic screening or elective surgical services, and was adopted for the Moorfield’s Attend Anywhere virtual eye casualty during COVID-19.31 These providers thereby help to augment front-line services by remotely reviewing patients with non-essential, non-urgent needs seeking to attend or queuing for in-person services to avoid overcrowding in health-care premises. This process requires clinical decision making from a patients history and a restricted examination during the video consultation, which was shown to be useful to avoid more than 70% of potential in-person encounters,32 and was effective for the provision of ophthalmic first-aid or addressing ocular surface-related symptoms during COVID-19.33 However, there are limitations in applying the stream fishing model during a surge in demand from patients with ocular disorders such as glaucoma, because of the need to acquire ophthalmic imaging and functional data for review.34 Nevertheless, the inflow funnel model can apply to services experiencing an increased clinical load with a low willingness to operationalise digital health extensively. Services with overstretched manpower because of split-team working arrangements or staff placed in quarantine are particularly suitable, because remote manpower with relevant expertise is readily available. The inflow funnel model can expand capacity to deal with a surge in medical conditions, whereby remote provider(s) help to triage patients.3 Experts have also described the use of the inflow funnel model as a form of electronic personal protective equipment to reduce the unnecessary exposure of front-line providers.35 This method has great relevance to general ophthalmology clinics as illustrated in Hong Kong, where a dedicated staff does all ophthalmic assessments such as intraocular pressure measurement and targeted slit-lamp photographs, before relaying data to ophthalmologists via telemedicine for the diagnosis and treatment or triage, or both, of patients to reduce physical contact and to conserve personal protective equipment.36

The pyramid model uses a stacked combination of digital or physical services, or both, to differentiate patients who can self-manage from those who require a scheduled teleconsultation or physical consultation. The pyramid model can be applied in ophthalmology by stacking digital technologies, beginning with the sorting conveyor model to triage patients into one of three possible care pathways: (1) self-management or observation; (2) remote video-consultation via hub-and-spoke tele-ophthalmology with the use of approaches such as technology-based eye care services and hospital eye services, which can be augmented by shared care with community optometrists or general practitioners; or (3) referral for in-person secondary or tertiary care.37,38 Technology combinations that have been similarly applied outside ophthalmology include the Babylon conversational AI-chat bots that triage patients and refer those requiring further assessment onwards for a video consultation.39 Hybrid telehealth (the stacked combination of digital and physical clinical services) has also been illustrated in the SAVED trial of text-based asynchronous reviews with synchronous video consultations at emergency services in Singapore,40 highlighting its potential to facilitate early discharge and reduce time in hospitals.

Finally, the shuffling cards model is a complete end-to-end digital service with scheduled asynchronous consultations combined with synchronous on-demand consultations as needed. This procedure is manned by a dedicated provider(s) whose sole responsibility includes attending to inbound patients from digital health solutions. One such example in Singapore is a follow-up video consultation (VidCON) service for patients with stable glaucoma to reduce hospital encounters. Patients first receive investigations in the community with results sent for asynchronous review by glaucoma specialists.38 Patients with no change in management plans are notified asynchronously by mail, and those who require a change receive a synchronous video consultation.

Operational models for the remote monitoring of health status

Digital health solutions are for the continuous monitoring of patients whose condition is stable and requires long-term follow-up, but not active F2F care. These remote monitoring tools can be operationalised with the use of the lighthouse or catchment net models. Lighthouse models are provider-led or state-led, collecting data from mobile phone health applications or IoT, or both.41 Lighthouse monitoring models can aggregate data for clinicians to review via web-based dashboards to identify patients that might require an early consultation.42 Examples of the lighthouse monitoring model applied in ophthalmology include the MyVisionTrack application highlighted earlier, that provides automated once per week reminders for functional vision monitoring.43 Alternatively, solutions such as the ForeseeHome device provide alerts to providers when a deterioration in vision measures is detected in their patients, prompting the provider to initiate a video consultation.44 These solutions can be interlinked with AI in the future to automate insights, triage, and engagement. This model also translates to fields outside of ophthalmology, as illustrated with Diabeo, which provides data-driven insights for diabetic glucose monitoring, to optimise care (insulin regimen) and proactively identify patients needing an early intervention.45 Given the implications of provider-led data access and interventions such as teleconsultations, these applications might require dedicated manpower and patient consent.

Conversely, catchment net models are patient-led services that use solutions to track biophysiological markers and provide patients with recommendations for the right-siting of care for patients to act on.
Patient-reported solutions can also be used to directly provide crucial insight to patients, such as the Alleye self-monitoring application, which is both US Food and Drug Administration-approved and Conformité Européenne-marked for vision monitoring in age-related macular degeneration. Alleye characterises metamorphopsia for the early detection of neovascular age-related macular degeneration and highlights the need for review where relevant. These home vision monitoring tests can play a useful role for patients who miss their follow-up appointments because of the pandemic, by detecting a progression in their disease that might require an urgent review for the consideration of interventions such as an anti-VEGF injection (figure 1B). Although patient privacy can be maximised by restricting remote data access only to the patients’ selected providers who recommended that they use these devices, robust validation is still required to ensure that patients understand recommendations and prompts in the device, particularly if these devices are intended to be distributed through direct-to-consumer channels.

### Challenges limiting the effectiveness of digital health

Despite these promising developments, there are substantial challenges to the effective deployment of digital health, such as tele-ophthalmology, to decentralise care with the complementary application of AI tools to expand capacity. The adoption of digital health has largely been restricted by various systemic barriers to sustained adoption, little consideration of the new intervention’s effect on its supporting clinical system, and little validation for feasible operational models. COVID-19 has aligned the priorities of all stakeholders and little consideration of the new intervention’s effect on its supporting clinical system, and little validation for feasible operational models. COVID-19 has aligned the priorities of all stakeholders and little consideration of the new intervention’s effect on its supporting clinical system, and little validation for feasible operational models. However, long-standing barriers to adoption will continue to dampen the effectiveness of these solutions during the pandemic, and potentially undo progress in adoption once operational demands revert after the crisis. These potential issues have prompted calls for digital health solutions to be evaluated through clinical research in tandem with their deployment to address the crisis. However, apart from the practical considerations highlighted in the previous section, barriers that need to be addressed for research or to drive adoption, or both, are also unclear.

### Barriers to the sustained adoption of digital health technology

There are various potential barriers to the adoption of a new digital health solution. We summarise several overarching considerations to address these barriers in the context of COVID-19 on the basis of existing reports and our collective experience in deploying a national tele-ophthalmology programme, and operationalising telehealth primary care services for individuals at a high risk and quarantined populations during the COVID-19 pandemic.

The table illustrates a system level approach to identifying these barriers, potential ways to address them, and measures to monitor them to increase the adoption of digital health solutions. Studies to evaluate health innovations are typically done in phases beginning with relevant outcomes from the level of the solution, and gradually moving up to the level of the macrosystem. Each layer introduces additional complexity and essential considerations, such as, at the initial level of the solution (table), a patients ability to understand information based on the solution design to use it safely, technology literacy to use it effectively, and acceptance of any additional responsibilities that are required of them.

Even the form of technology can add challenges for adoption, where device compatibility or devices requiring hardware such as the ForeseeHome device for age-related macular degeneration present additional barriers, compared with mobile phone applications that can be

| Potential barriers | Measures to monitor to increase adoption |
|--------------------|-----------------------------------------|
| Solution form (eg, device, technology) | Complicated user interface and experience design for the patient or the provider |
| | Sound scientific basis of the solution needed |
| | Problems with accessibility, material cost, and technology platform (dedicated hardware vs mobile phone-based) |
| | Patient acceptance and willingness to use solution |
| | A review of the problem and solution (performance and strength of the association) |
| | and epidemiology (to establish the potential market size) |
| | Affordability and social determinants of health |
| Microsystem (eg, ward, specialist outpatient service) | Issues from interactions with the existing models of care (either to overlay, augment, replace current models, etc) |
| | Ethics and medicolegal constraints |
| | Provider acceptance (eg, clinicians, nurses) |
| | Pilot validation studies (with a focus on clinical outcomes or performance) |
| | Guidelines for use, liability for negative outcomes, safety net mechanisms |
| Mesosystem (eg, hospital, hub-and-spoke model) | No supporting resources and systems |
| | No feedback loops for sustained adoption or extension (eg, a review of solution performance measures for long-term optimisation) |
| | Good quality of infrastructure (eg, interoperability, access to electricity, internet, and security) |
| | Mechanisms to review and share results (eg, morbidity and mortality meetings, quality improvement projects) |
| Macrosystem (eg, population screening programme) | Absence of a supportive organisational culture, staff availability, nor incentives |
| | Difficulties with policy implementation, financing, and regulatory environment |
| | Create incentives to align human capacity with each other (eg, key providers of service, support staff) to facilitate adoption |
| | Health economic assessment, availability of suitable financial incentives for adoption |
| | Health technology assessment, pre-market approval |

Table: System level approach to address barriers for the adoption of a digital health innovation
easily accessed from Apple or Google stores such as Alleye. Moreover, the transmission of data in a suitable format across the relevant operating systems being used in the target clinical service is another main barrier, because of the absence of interoperability between electronic medical record systems and the various imaging devices that often vary within and between primary and secondary or tertiary care settings, as well as no uniformly accepted standards for data formatting and transfer. When done sequentially, this approach can provide crucial insight to iteratively refine the solution and its operational model on the basis of the outcomes of studies at each system level.

Initiatives to increase the adoption of solutions often meet unanticipated roadblocks if the needs of relevant stakeholders and the health-care context are not considered holistically. Take, for example, new AI solutions for diabetic retinopathy screening, whereby metrics (e.g., sensitivity, specificity) that affect performance might need to be configured for different countries on the basis of cultural factors and the availability of resources. This requires the consideration of a cost structure, the acceptance of false negative results with screening, and the capacity to follow up on referred cases (e.g., availability of ophthalmologists) considering the false positive rate. Identifying these barriers is essential to developing targeted solutions, such as the variation in algorithmic accuracy in real-world application that can be addressed through calibration with local datasets with the use of techniques such as transfer learning, which was highlighted earlier.

Telehealth in the form of video consultations is one example in which global adoption has been restricted by inadequate funding, because its requirements for operationalisation have been grossly underestimated, leading to perverse incentives such as a lower compensation for remote consultations as opposed to in-person care. Many doctors have had a hard time coping with interruptions to existing packed clinics with ad hoc on-demand requests for a teleconsultation from remote patients, some of whom did not connect successfully despite best efforts to troubleshoot technical issues with them. Without established workflow and priorities, the knock-on effects of these interruptions lead to an additional workload and inefficiencies that overwhelm medical services. Therefore, it is necessary for clinicians, administrators, and researchers to evaluate operational considerations and address potential barriers to adoption before attempting deployment at a large scale.

Overall, this proposed system-level approach (table) can be used for evaluating solutions to these barriers to adoption, and to develop suitable operational models. This approach can also be used to map out the relevant stakeholders and their incentives, to develop an engagement strategy to facilitate adoption. This involves addressing concerns in communications, generating capacity, and incentivising primary stakeholders that make the decision for adoption (e.g., end users, the head of the department, the hospital information technology department) and secondary stakeholders that influence decisions (e.g., key opinion leaders, the ward operations manager, the logistics team).

Future and next steps

This Viewpoint has highlighted key considerations to plan for the successful deployment of digital innovations when applying new models of care during and after the COVID-19 pandemic. As countries start various stages of re-opening, health-care organisations can anticipate a surge of accumulated clinical needs as patients return to seek chronic care and elective procedures, as illustrated with the substantial decline in ophthalmology outpatient attendance, particularly by patients with age-related macular degeneration, during the Italian lockdown. Service providers might consider the pyramid model to risk stratify patients, either into self-monitoring in patients with stable conditions, or early outpatient follow-up in patients whose condition is unstable; and to establish which patients should be considered for interventions such as anti-VEGF injections. Organisations might also benefit from a digital presence to engage patients seeking care options online to coordinate management remotely and direct patients to seek care in appropriate settings, thereby minimising unnecessary touchpoints.

In the long run, each intended application of digital health needs to be iteratively and continuously evaluated, because the operational considerations can vary considerably between organisations, and even within them, over time. The ideal models for digital health-enabled services are ones largely driven by the technology, clinical need, demand from patients, and manpower availability. On the basis of the results of initial pilot studies and traction as clinical demand from patients gradually increases, services might transition to models with a greater effect. For instance, these services might move from the stream fishing model, initially relying on spare capacity, to the shuffling cards model, with dedicated manpower.

Choices between models with a low or high operational effect (figure 2) might be driven by mesosystem factors (table), such as culture and financing. As an example, the stream fishing model might work well with a stakeholder alignment through a fee-for-service process, or contextual factors such as a collegial organisational culture. However, increasing the adoption of these services can be a challenge in the absence of these factors within a full employment organisation, if providers do not step forward to help to attend to inbound patients. This situation can happen when providers do not have the capacity for these patients, because of existing responsibilities such as administration. Under those circumstances, any success in adoption will probably be
short-lived and unlikely to be sustained post-pandemic, when priorities revert to what they were before.

Never has extensive operational overhaul been more urgent in health care than in the current climate of the COVID-19 pandemic. Advances in digital health have given medical professionals tools to respond effectively to the challenges posed by COVID-19. However, to ensure sustained adoption, it is necessary to not assume that digital solutions will naturally assimilate into clinical practice, and instead adopt participatory approaches that regularly involve stakeholders. Moreover, the urgency of the pandemic presents new considerations. Providers do not have as much time as they would have under normal circumstances to reorient F2F services while clinical demand for a digital service gradually picks up, because of the sudden surge in patient demand during the pandemic. Operational models such as the pyramid or shuffling cards models, which assign dedicated manpower to operationalise digital health, might be needed instead.

Providers can anticipate that the balance of patient demand and manpower availability will probably change as lockdowns and physical distancing measures are eased at the macrosystem level (table), which would then require operational reorientation. Overall, existing mechanisms and dedicated manpower capacity need to be constantly adjusted and mobilised to enable the sustained adoption of digital health to enhance clinical care. We implore fellow colleagues to critically evaluate frameworks of operational models for digital health solutions in practice.

Search strategy and selection criteria
To identify potentially relevant reports, electronic bibliographic databases of published research in PubMed, including MEDLINE and Institute of Electrical and Electronics Engineers Xplore, were searched on Oct 1, 2020, from Jan 1, 2016, to Sept 1, 2020, with the following search terms: ("Digital health" [All fields]) OR ("Telehealth" [All fields]) OR ("Artificial intelligence" [All fields]) OR ("Mobile health" [All fields]) OR ("mhealth" [All fields]) AND ("Triage" [All fields]) OR ("Screening" [All fields]) OR ("Pre-hospital" [All fields]) OR ("Home-based" [All fields]) OR ("Monitoring" [All fields]) AND ("Ophthalmology" [All fields]) AND (English Language). Full-text English language reports and reference lists were reviewed for studies aligning with the conceptual framework of operational models for digital health solutions in practice.

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