The ongoing emergence of technology in healthcare to enhance patient outcomes

13

The Ongoing Emergence of Technology in Healthcare to Enhance Patient Outcomes

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Abstract

Technology, in all aspects, forms a core part of modern life, with a huge proportion of our daily activities having at least some reliance on a technological system for one or many purposes. Healthcare is not exempt from this and, indeed, is arguably one of the areas of our lives within which technology has the most influence – from access to healthcare systems, through to the identification and management of disease states and even the monitoring of our physical status in the absence of ill health. The ongoing emergence of technology in healthcare is accelerating in line with that of technology more generally, offering the potential for even greater developments in how we manage our populations' health and, ultimately, enhance patient outcomes. This chapter seeks to explore key aspects of the emergence of technology within healthcare in recent times, as well as addressing key challenges, opportunities for overcoming these and to consider the future shape of our healthcare systems as a result of more recently emerging technologies.

13.1 Emerging Technologies in Healthcare – How Did We Get Here?

Over the last few decades, technology, particularly that related to telecommunications, has developed at an accelerated pace. Innovations, improved manufacturing processes and design improvements have all led to an exponential increase in the public's use and acceptance of technology in their daily lives. Indeed, the current ubiquity of technology within the lives of many is unparalleled and appears to be increasing (Edwards 2021). One need to only look at the current worldwide use of smartphones to appreciate the exceptionally commonplace nature of technology – at present, the number of smartphone subscriptions alone is reaching parity with global population, with the total number of devices in use set to rise to almost eight billion within the next 5 years (Statista 2022; Ramalingam et al. 2021). Likewise, the capability of such devices is increasing at a remarkable rate, due to a burgeoning software and application development market. For example, the number of applications available for use within the Android mobile device operating system alone has increased approximately 200-fold in just over 10 years (Li et al. 2022), illustrating the enormous potential which is offered by these technologies.

The rationale for the application of technology within healthcare more broadly, whilst multifactorial, is also clear. Above all else, the assistance which technology provides with respect to the handling of large volumes of data, patients' or otherwise, is massively advantageous, and whilst not a panacea, certainly provides opportunity for the lessening of strain on healthcare systems which are currently overburdened by ageing populations, the increased prevalence of multimorbidity, polypharmacy and ongoing threats and realisation of global pandemic. Moreover, the use of technology provides the opportunity for more effective provision of healthcare within low and low-middle income countries, enabling lifespan and quality of life improvements (Pan and Xu 2014). Whilst the impact of technology within more wide-ranging and operational aspects of healthcare provision is significant, the emergence of technology within healthcare is set to continue to offer a great deal of benefit at an individual end-user level. Again, this is the result of a range of contributing factors in addition to the immediate access which patients now have to useful technology, including cultural changes across populations which have seen patients wishing to take a greater level of responsibility for their own health and well-being, reflecting the manner in which modern medicine is practiced (Pipich 2018).

These drivers, and others related and in addition to them, have led to the development, growth and expansion of healthcare technology, which the World Health Organization has defined as the "application of organized knowledge and skills in the form of devices, medicines, vaccines, procedures, and systems developed to solve a health problem and improve quality of lives" (Keestra 2021), and which goes further to indicate both the breadth of the area, and ongoing and potential impacts that these technologies, if used correctly, can have on population health. The parallels which can be drawn between the unprecedented rate of innovation within the digital space and that which is taking place within the many areas of healthcare go further still to reinforce the role that technology has to play, and the synergistic effects to be gained from the concurrent development of these areas. A counterpoint to this, however, is the need to understand that the relationship between technology and the provision of healthcare is *truly* synergistic, and that these technologies alone will not lead to the enhancement of patient outcomes – thus, it is crucial that the role that these resources play in this arena is acutely understood, such that full benefit can be derived, and that the employment of these aspects to the detriment of outcome is avoided.

13.2 The Application of Technologies to Enhance Outcomes

To better understand the value which can be derived from the use of emerging technologies within healthcare, it is useful to consider several key areas within which the use of technology has provided benefit, or indeed, which has led to the development of entirely new approaches for healthcare management. Areas such as telemedicine, and the sophisticated use of smart devices alone or in conjunction with wearable devices, offer significant insight into how technology can be leveraged to these ends, while also illustrating limitations and considerations which should be made to allow the potential benefits of these technologies to be realised.

13.2.1 Telemedicine

Telemedicine, as a wider term, and which is synonymous with terms including "telehealth", "e-health" and "online health", and which is derived from the Greek term *tēle*, meaning "far off" or "from a distance", describes the use of digital communication technologies to facilitate clinical interactions between healthcare providers and end users, complementing or often replacing those which would have traditionally taken place in person (Wootton 2001). It should be noted, perhaps because of some linguistic ambiguity of the encapsulating term, that telemedicine is by no means restricted to the use of a telephone and, indeed, is facilitated by a range of telecommunications technologies. The advantage offered by such approaches are clear and are of benefit to patient and practitioner alike – access to healthcare is facilitated, particularly to those who may find it difficult to attend physical appointments for a range of reasons, including the lack of transport or availability during times when such consultations would traditionally take place, or indeed, as a result of suffering from conditions where mobilisation to clinical primary and secondary care settings may be challenging and potentially detrimental to the patient's health state. Moreover, the leveraging of telemedicine permits healthcare providers to be more efficient with their time, enhancing overall effectiveness of service delivery.

In current times, the value of approaches which allow for the genuine interpersonal interaction between patient and healthcare provider, as well as the effective communication of patient-centric data in a remote way, has been brought into sharp focus as a result of the global COVID-19 pandemic, due to their role in the continuance of function of healthcare systems, including the management of coronavirus-infected patients, while simultaneously reducing or removing the risks which traditional, in-person approaches would present, particularly for those with morbidities which result in elevated risk (Portnoy, Waller, and Elliott 2020). Indeed, whilst the majority of telemedicine activity takes place within high and upper-middle income regions, the literature indicates that there are benefits in relation to the quality of healthcare offerings, providing a clear rationale for the extension of use of telemedicine in a more significant extent to low and low-middle income locales which lack extensive levels of healthcare provision, as it may play a key role in providing access to medicine where none may previously have existed, leading to marked enhancement in population health and development.

The fundamentals of telemedical practice are straightforward, incorporating the transmission of healthcare information across distances digitally, with this information allowing for a full range of medical activities to be delivered, from the creation and maintenance of patient medical records, through to the diagnosis of ailments and the education and training of other healthcare professionals. This transmission of data can occur both in real-time, or in an asynchronous manner, depending on the specific activity being undertaken. Key examples of real-time activities involve those which are mediated by teleconferencing platforms, facilitating conversations between patient and practitioner, or indeed, amongst interprofessional teams

(Koch et al. 2018; Kern et al. 2020); asynchronous approaches involve the transmission of data of some sort which can be used for the purposes of diagnosis or patient monitoring (for example, the provision of test results to another clinician with expertise in a particular clinical area) (Craig and Petterson 2005; Brown et al. 2022; Ross Kerr 2020). Whilst the core activities which define telemedicine would likely be regarded as being rudimentary within the wider span of emerging technologies, the implementation of telemedicine and its impact are still significant areas of research – an interrogation of the MEDLINE database provides approximately 1600 indexed research articles authored over the most recent 5-year period, and indeed, as described earlier, the COVID-19 pandemic has provided added impetus for related research, with approximately 550 of these articles investigating the use of telemedicine-related technologies within this context. In addition, extensive randomised controlled trials supported by major funding bodies have been carried out which investigate the impact that these approaches may have (Salisbury et al. 2017). This significant context may well have acted as a catalyst for the increasingly commonplace use of telemedicine within healthcare settings, and importantly, the acceptance of its use, which is key to its success (Fisk, Livingstone, and Pit 2020; Hu et al. 1999). As such, there is a significant and potentially increasing role for telemedicine to play within healthcare, which in turn has led to an interest in the integration of other emerging technologies, for the purposes of enhancing related outcomes.

13.2.2 The Emergence of Connected Health

As described in the previous section, the activities which constitute telemedicine are multitudinous and involve the transfer of information in relation to the care of patients in a range of modalities. This very nature lends the approach to bring about paradigm shifts in core areas of healthcare practice, which may lead to the introduction of efficiencies within healthcare organisations, whilst simultaneously offering benefit to involved patients. One such approach is that of telemonitoring, which involves a more targeted set of goals, namely to make use of telecommunications for the purposes of monitoring a patient's disease status. Telemonitoring is included within the intermediary grouping of home-telecare, which seeks to support patients, particularly those with chronic conditions, within their own home (Pare, Jaana, and Sicotte 2007). Given the extent of population ageing, and the inter-related increasing prevalence in chronic conditions, with approximately one in every three adults now suffering from multimorbidity (Hajat and Stein 2018), the use of these remote approaches offers a potentially more humanistic and economically efficient way to manage these patient groups.

Whilst telemonitoring itself is arguably an evolved aspect of telemedicine, it also is undergoing its own evolutionary process, influenced by changing attitudes to healthcare, the empowerment of other professions within healthcare to take a larger role in the management of patient populations and, indeed, the development of technologies which can feed reliable clinical information into systems, further potentiating their value and more closely aligning them to orthodox in-person clinical consultations (Caulfield and Donnelly 2013; Frist 2014). This evolution has led to the emergence of *connected health*, which seeks to make use of telemonitoring practices and associated emerging technologies to encourage patients to take greater ownership over the monitoring and management of their conditions, whilst also enabling their collaboration with healthcare professionals to be less point-in-time and more reactive in nature, such that condition worsening can be at best avoided and, at worst, identified as quickly as possible (Caulfield and Donnelly 2013; Burmaoglu et al. 2017).

The characteristics of connected health strongly lend it to the management of chronic disease, and as such, it is unsurprising that its use has been investigated for the management of the most prevalent chronic morbidities including cardiovascular disease and diabetes (Colorafi 2016; Wongvibulsin et al. 2019). This is especially promising given the enormity of the populations who suffer from one or both disease sets, and indeed, the extent of additional morbidities which can be caused by them when control is poor. Telemonitoring enables streamlining of patient interaction and care, and a focus to be placed on those who are experiencing deterioration, whilst those who are experiencing successful disease control can benefit from minimal intervention. Despite the significant potential offered by the effective use of connected health approaches, barriers to more extensive use exist as a result of a combination of issues including the need for a more extensive evidence base, public awareness and acceptance, and the availability of supporting technologies which would allow for full value to be extracted. With respect to the evidence base, meta-analyses do point to the enhanced effectiveness of connected health for the control of major conditions such as hypertension; however, limitations are often reported with respect to the duration or follow up involved in the interventions used to gather this evidence, or in relation to the number of studies available, and/or the population sizes within them (Omboni 2019; Wongvibulsin et al. 2019). Whilst currently to the detriment of further success, the identification of public awareness and acceptance as challenges provides new avenues for the enhancement of rollout of connected health activities, enabling work to be undertaken to address these issues and, indeed, enhance the attractiveness of patients' own ability to play a major role within the management of their health. The extent of these issues should not be undervalued, with general patient awareness of connected health appearing to be low (Barr et al. 2014). This in turn may lead to a lack of engagement or the emergence of concerns around the use of the approach due to a lack of knowledge and related confidence, or indeed with respect to patient comfort in the sharing of their healthcare data electronically (Kuziemsky et al. 2018). Thus, education of student groups is key to the ongoing success and use of connected health and telemedical approaches more widely, which in turn necessitates the involvement of multidisciplinary care teams, who can provide explanations and encourage and reassure patients with respect to the processes themselves and the derived benefits. However, whilst the role of these professionals, particularly those in primary care, such as community pharmacists, would reasonably be expected to provide positive impact, this does appear to be under-investigated (Barr, McElnay, and Hughes 2012).

13.2.3 The Role of Connected Health in Treatment Adherence

Adherence can be very simply defined as the process of patients doing, to the fullest extent, what has been recommended or instructed by their healthcare providers (Vermeire et al. 2001). Achieving successful outcomes for patients depends heavily on their adherence to prescribed treatment or management strategies (Martin et al. 2005), with poor adherence having a clear and obvious link to worsening of patients' disease states, increased rates of co- and multi-morbidities and, ultimately in many cases, worsened mortality rates (Lehane and Mccarthy 2009). Further, if treatment adherence is related only to pharmacotherapy, i.e. the taking of provided medicines in the manner instructed by the prescriber, poor adherence can bring about additional issues including the development of treatment resistance (B. Nachega et al. 2011; Bangsberg, Kroetz, and Deeks 2007) and the heightened risk of suffering from adverse effects where medicines with particular pharmacodynamic characteristics are prescribed (Haddad 2001). Rates of non-adherence in more general terms are high, estimated to be around 25% (DiMatteo 2004) and linked to a myriad of causative factors, including the nature of the condition which is being treated, such as in cases where there is a reduction in cognitive function, or in patient motivation to manage their own care (Smith et al. 2017; Burns et al. 2013).

For the reasons outlined above, adherence is a major concern in public health from broad social and economic perspectives, and thus it is unsurprising that investigations centred on the understanding of adherence, and in relation to the development of technological approaches to improve it, are abundant. From a broader perspective, the core tenets of connected health indicate that its use may be assistive to those who are poorly adherent, and that innovation and the development of new technologies in this area may empower patients and healthcare teams to potentiate outcomes. There are many means by which enhancement of patient adherence can be brought about which fall under the umbrella of connected health, and which also vary in complexity and success. In many cases, the active role of the patient is necessitated, as activities involve the engagement and/or taking of some action or another by the individual, which can be grouped into the categories of “to read”, “to do” or “to connect” (Agher et al. 2020). With reference to these domains, more widely known approaches involve the provision of condition and/or medicine-specific information in the form of training materials which can be accessed by the patient at home via their computer, etc., or indeed, the provision of access to coaching and support groups, which in turn may help them to improve knowledge of their own condition and its management, ultimately understanding the importance of adherence to management strategies (Kvedar, Coye, and Everett 2014). Despite the popularity of these approaches, and the measurable benefits which they appear to provide, there is a need for further optimisation work to be undertaken in order to allow these techniques to be regularly and reliably recommended (Conn et al. 2009).

The use of electronic reminders (which can be grouped within the co-domain of “to read” and “to do”) also form another popular approach in leveraging connected health for the purposes of enhancing adherence. In brief, this technique involves the sending of electronic messages to a patient for the purposes of reminding them to take medications, or otherwise engage in activities related to the management of their condition, which given repeated use, are anticipated to bring about the reduction of non-adherent behaviours. These messages can take the form of short message service (SMS) reminders, those which are sent via an application installed on a mobile device, or indeed, which make use of a dedicated device (Tao et al. 2015). Whilst these approaches do appear to be elegant in their simplicity, and indeed, their use may understandably be automatically assumed to enhance outcomes, the reality appears to be more complex, with variability in outcome of such interventions being brought about by key aspects such as disease type, and the duration over which the intervention is used (Tao et al. 2015). Other approaches which leverage digital communication channels to contact the patient for the purposes of improving adherence, and which appear to offer similar success rates include the use of video-calling technology which can be automated or involve authentic human interaction with a professional – whilst the latter of these two approaches would appear to not introduce as much efficiency as automated approaches, it may offer alternative benefits, in that what is communicated to the patient can be reactively augmented, ultimately allowing the practitioner to focus more on the offering of support, rather than acting in a controlling manner (West et al. 2012).

So far, each of the interventions discussed in relation to the enhancement of patient adherence has required active involvement of the patient with respect to the actioning of the treatment regimen. Further, approaches necessitate manual outcome monitoring to ascertain impact, for example, via the monitoring dose count changes on inhaler devices, or by patient self-reporting (Strandbygaard, Thomsen, and Backer 2010; Cocosila et al. 2009). The latter approach here is of particularly dubious value given the nature of the problem which is being addressed, and as such, the value or accuracy of the data provided by the patient may lead to issues in evaluating the value of the intervention. Thus, opportunities have been identified to harness innovative digital/electronic solutions which may allow for more "true" indications of patient medication adherence to be observed. This may ultimately facilitate the creation of interconnected systems which can actively respond in instances where adherence is poor and, likewise, not engage with patients who are successfully managing their conditions.

Developments in microprocessor technology have undoubtedly played a role in the emergence of the Medication Event Monitoring System (MEMS), constituted of standard medicine containers that contain a sensor and processor within the cap, and which in turn are triggered by, and log, container openings, facilitating patient adherence to be ascertained from both the frequency and timing of package opening (Olivieri et al. 1991). The fundamental purposes of such a technology are to remove the need for patients to record information in relation to their own adherence and prevent the provision of inaccurate data resulting from poor record keeping. These attributes have rendered the use of MEMS particularly attractive in areas of research which focus on levels of patient medication adherence and indeed appear to have proven useful. However, perhaps unexpectedly, more extensive studies into the validity of this technology for adherence monitoring have indicated that the benefits may not be as large as expected, with MEMS-based records correlating moderately well with patients' own manual record keeping (Shi et al. 2010). The rationale for this is multivariate; however, key factors appear to be the lack of consensus or standardisation of the term adherence, and further, the acknowledgement that medication non-adherence comes about as a result of more complex aspects of behaviour (Hartman, Lems, and Boers 2019; Easthall 2019), in turn making the wider comparison and identification of trends across related studies exceptionally complex.

This situation described above provides a well-formed example of how certain healthcare practice areas may not have developed at a comparable rate to the technologies which are emerging within them, which at present may well be preventing the full realisation of the potential which these systems can offer. Thus, to leverage this potential, it is critical that relevant healthcare practices are considered in conjunction with the technologies that are available which could assist with their implementation, and with reference to the direction of travel in those areas, such that those practices can be appropriately future-proofed. This conclusion would indicate that healthcare development in the modern age is perhaps more multidisciplinary than ever and now includes professions such as electrical engineering, software engineering and human factors (Pan and Xu 2014).

13.2.4 Leveraging Mobile Technology for Next-Generation Telemedicine and Health

The introductory section of this chapter discusses the omnipresence of mobile device technology as an allegory for the wider spanning integration of digital technologies throughout healthcare. When considered as its own domain more specifically, it is clear that the ongoing emergence of mobile device technology and capability is set to revolutionise how healthcare professionals deliver their impact. Moreover, as discussed earlier, it will further facilitate individuals' ownership of their health, in the context of condition management. The accessibility of mobile technology, and perhaps more importantly, the rate at which powerful software and applications are being developed for those platforms, have unleashed an entirely new area of potential within healthcare; however, it is crucial that such approaches are designed thoughtfully and in a manner which brings about a real and positive impact on population health.

When mobile devices are considered as a discrete tool for use within healthcare, their potential to deliver significant impact often relates not to the devices themselves, but rather the applications which are developed for use via those devices, and which can effectively harness the inherent usability and connectedness of these devices to facilitate a range of functionality for the purposes of bringing about health-related enhancements. The potential for this resource provision is reflected in the sheer range of health-focused applications available for the two largest mobile device platforms, Alphabet's Android and Apple's iOS, which run into the many tens of thousands, and further to this, the fact that these operating systems themselves are being evolved to contain "baked in" health-related functionality, which in turn are used as key marketing tools to enhance sales of devices to target audiences.

As alluded to previously, technology and mobile apps are also used to support education and professional practice, including enabling the provision of up-to-date, evidence-based information at the point of care and enhancing decision-making in patient management (Hanna and Hall 2018; Keyworth et al. 2018). However, it should be noted that while technology-based interventions may have theoretical benefits for healthcare professionals, this does not mean they will be readily implemented or successful in practice (Keyworth et al. 2018). Barriers preventing the adoption of technology-based interventions by healthcare professionals and patients are discussed later in this chapter.

The burgeoning popularity of mobile devices, coupled with the ongoing development of applications within the healthcare space, has led to the emergence of *mHealth*, which the National Institutes of Health define as "use of mobile and wireless devices … to improve health outcomes, health care services, and health research" (National Institutes of Health 2018). Importantly, and unlike other technological/digital approaches which have been discussed here and elsewhere, mHealth, in many instances, offers the end user a service which is intended to provide enhanced health outcomes in the absence of a healthcare professional. This presents a uniquely dichotomous situation whereby individuals can be effectively empowered to take ownership of their own health, or to be put at risk as a result of the use of resources which are not supported by clinical evidence (Bates, Landman, and Levine 2018). This risk is elevated due to security, safety and privacy issues. Indeed, many applications have been shown to provide inaccurate and potentially life-threatening information (Bates, Landman, and Levine 2018). This landscape has logically led to a requirement for assurance of standards and an ongoing debate around the certification of mHealth approaches, and for standalone health-related applications more specifically. Despite the surface-level sensibility of this approach, difficulties arise due to the fast pace of technological developments in this space, juxtaposed with comparatively sluggish timelines involved in certification processes (Chan and Misra 2014). As such, whilst mHealth has the potential to be exceptionally lucrative from a population health perspective, there is a need for related bureaucratic processes to adapt to match the rate of progress seen within the area which requires this additional regulation. This is reinforced by the time, resource and evidence base required for healthcare academics to assess the value of these software packages via traditional means such as randomised controlled trial. Given the significant challenges in evaluating this area of digital health in terms of impact, here is a need for a new area of research to come to the fore which can track, evaluate and recommend resources robustly and at high speed (Nilsen et al. 2012).

Despite the challenges in mHealth, the area clearly offers multiple strands of opportunity for integration into existing healthcare infrastructures, including via the offering of condition-related data collection, support provision and the optimisation of adherence and management strategies (Becker et al. 2014). Particular value can be extracted in these areas when these opportunities are realised by teams led by those with expertise in the delivery and evaluation of healthcare activities, as previous learnings from related evidence bases can be integrated proactively, enhancing the likelihood of success.

Patient adherence is again an area of interest within the context of mHealth and has been researched extensively, allowing its use as an exemplar of the emergence of these technologies within healthcare. Mobile devices offer significant advantages in comparison to other approaches for the enhancement of adherence, including those which make use of other digital systems. Perhaps the most important of these benefits is the incorporation of multiple hardware components in a form factor, which is easily transportable and which can accompany a patient at all times (Pérez-Jover et al. 2019). For example, the provision of a camera, microphone and multiple connectivity technologies allows for the streamlining of multiple communication types, fully supporting comparatively simple data transfer tasks through to enabling real-time personal interaction at any time. Additionally, the ability for these communication strands to be packaged together via thoughtful application design can enable the provision of intuitive, easy-to-use resources for patients who may have ordinarily struggled with the use of less user-friendly alternatives.

A further potential exploitable benefit of mobile technologies in the domain of patient adherence is the heightened ability to incorporate aspects of social connection between peers, allowing for those within similar situations to support one another, thus removing the need for engagement with healthcare professionals to provide this support and encouragement. This has produced, for example, applications which facilitate the interaction between patients who meet with one another for the purposes of discussing their conditions, but importantly to verify each other's taking of medications via active engagement with the application interface. These verifications create a record which can be transmitted to healthcare professionals at specific points in time, providing them with reliable, yet entirely user-generated data. Such approaches have been shown to have some success in a range of areas, including patients' motivation to take medicines, and improved outlook on their condition due to the ability to discuss it with others, coupled with clinicians indicating that non-adherence issues could be quickly and confidently detected (Fujita et al. 2018). The use of social interaction, and indeed wider social media-type approaches, may well provide a new tool for the enhancement of patient outcomes. While the investigation of this area does appear to be accelerating, it is also currently prototypical, meaning that firm conclusions about its use in more general terms cannot be drawn. Initial reports do appear to be promising, but should be viewed with caution, given concerns over aspects such as data privacy and the quality and accuracy of information which can be provided both actively and passively via social interactions with non-experts. These challenges must be addressed to engender user confidence and widespread implementation of these approaches (Elnaggar et al. 2020).

Whilst the discussion here around the use of mobile technologies is far from exhaustive, the selected examples do clearly communicate that the wider area of mHealth offers enormous potential in bringing about improvement of individual and population health outcomes. Challenges exist with respect to identifying the most effective and clinically sound approaches within the area. This is largely due to the extent of baseline noise, which is increasing at a remarkably fast pace as a result of accelerated technology development, and which currently prevents such technologies from being confidently recommended, due to the availability of full understanding of related benefits and risks (Backes et al. 2021). This does, however, support the need for healthcare professionals to ensure that they have their place in the development and evaluation of new and reliable resources in healthcare technology within those cross-cutting and widening multidisciplinary teams discussed previously.

13.2.5 Combinatorial Approaches: The Emergence of Connected Health Devices

The ability for mobile devices, and more specifically, smartphones, to connect to the internet wirelessly via WiFi and/or cellular connection is a key advantage in their use within healthcare. Data, of all forms, can be efficiently transferred to patients or between patient and practitioner, with barriers relating to distance and the need for physical transfer almost being removed. This connectivity is one of the multiple approaches for wireless networking of which mobile devices are capable, providing enormous opportunities to bring about the connection of multiple peripheral devices to smart devices wirelessly, and by extension, the collection of health-related data, in ways which would have been unimaginable just a few decades ago. While the development and access to these technologies may have been initially slowed by the emergence of competing standards (Bing 2008), in more recent times, there has been the coalescence around several wireless local area network standards which have become a common parlance when mobile devices are discussed. In addition to WiFi standards, Bluetooth and near-field communication (NFC), which make use of their own particular frequency ranges (Cisco Systems 2015), are commonly referred to when the utilisation of wireless communication is discussed, and indeed, this has transferred through to the area of connected health, with these commonplace technological standards being harnessed for the transfer of a range of types of health-related data between devices.

The ongoing emergence of these technologies, particularly when considered together with the exponential increase in sophistication offered by software applications, has enabled the development of devices which can not only capitalise on the ability to connect to mobile devices wirelessly without the need for their own internet connection but can make synergistic use of state-of-the-art sensor technologies, etc. for the collection of data which are to be transferred to the device for a range of purposes. As would be expected, the health sector is catered to in a significant way and has subsequently seen the wider area of connected health being furnished with a range of "connected health devices" (El Amrani et al. 2017). In more general terms, the emergence of these devices often removes the need for manual steps in the reporting of health-related data points, ultimately removing the opportunities for these flows of data to fail or the provision of inaccurate records. Therefore, the necessitation for a patient to measure their blood pressure using a less "intelligent" sphygmomanometer, followed by the input of the produced reading into a software interface of some kind, for example, can be entirely removed, allowing for data collection to be considerably less onerous (Omboni 2019). The value of this is perhaps more clearly elucidated when particular population sets are considered along with the roles which a patient or user must play in order to bring about the success of the process. For example, the seemingly straightforward process of logging a blood glucose measurement requires abilities in psychomotility, device interaction, perception, cognitive interpretation and decision-making. Ironically, this may be a challenging task for those who require the application most, such as older adults (Harte et al. 2014). The enhancement of these approaches via the development of “smarter” systems may effectively remove proficiency requirements in most of these domains, providing a considerable amount of added benefit to the end user.

Given the role that such devices may be able to play in the monitoring of conditions and the exertion of positive effects on patients’ management thereof, there appears to be a surprising paucity of available research which focuses on the use of such devices and the measurement of improvement in patient outcome. It also seems that practitioners have not yet been able, due to resource or choice, to avail of these technologies as part of their patient management plans (El Amrani et al. 2017). Reasons for lack of implementation in practice, and hence a lack of data being generated to ascertain value and impact, include concerns around patients’ use of, and motivation to use, the devices themselves, the potential for technical problems to arise, the nature in which the data are presented and related difficulties in data processing (El Amrani et al. 2017; Haluza et al. 2016). Perhaps most importantly, practitioners have expressed concerns around the use of these technologies being to the detriment of communication and professional relationships with their patients (Nambiar, Reddy, and Dutta 2017)

Significant advances in the area of connected health devices continue to be made. Despite their use not being commonplace (for reasons outlined in the previous few paragraphs), and the likelihood of clinical underuse in the short-to-medium term, connected health devices may eventually form key elements of how next-generation modern healthcare is provided. Of those ongoing advances, the genesis of the Internet of Things (IoT) (Holler et al. 2014) and its substrata of wearable devices are perhaps two of the most notable. They have the potential to make monitoring of healthcare-related data optimally streamlined, as well as bring about full integration of this data collection into an end-user’s day-to-day life, thus normalising a task which currently requires some level of active actioning.

The IoT can be defined as a "set of technologies, systems and design principles, associated with the emerging wave of internet-connected things within the physical environment" (Holler et al. 2014), and as a grouping, provides a range of means by which data can be collected from single or multiple inputs, and subsequently for that information to be shared out to the devices forming part of that interconnected system. The vast range of "things" which can constitute IoT systems further illustrates the potential power of the phenomenon. For example, the breadth of sensor systems and their associated flexibility in application are able to collect massive amounts of data points and types which can then feed processing and recording systems. This can ultimately result in positive outcomes at organisation level through to individual end-user levels. The wide-ranging benefits include enhanced efficiencies within healthcare organisation, improved patient medication adherence, reduction in diagnosis or treatment error and, importantly, the facilitation of activities which relate to preventative medicine (Thangam et al. 2022). Unsurprisingly, the growing usefulness of these technologies within health more widely is reflected in the growth of market size, which exceeded US$100 billion in 2019, and is growing at a rate of 18% (Businesswire 2020). Indeed, the healthcare industry is predicted to solidify its stake as one of the largest users of IoT technologies within the next decade, with over 40% of all IoT devices being used within this area (Moko Smart 2022). Moreover, these developments are not restricted to more basic aspects of health, with the creation of reliable, palm-size IoT systems for clinical tests such as electrocardiogram (ECG) and electroencephalography (EEG) being developed, tested and used currently (Bhagyashri and Hirekodi 2022; Laport et al. 2020). Thus, the IoT is unquestionably on track to become a pillar of modern healthcare.

A major area of value and usefulness of IoT is the home setting. Indeed, the ongoing emergence of truly interconnected connected health devices within the home will facilitate better integration of health monitoring with the user's day-to-day activities, although there is no direct communication with their healthcare team. However, despite the removal of a great deal of user responsibility, the need for active engagement persists, albeit at a low level. As a lack of such engagement may introduce failure at the point of data collection, it should be a key consideration within the design of any such solution.

The developments in IoT and interconnected health devices, in parallel with accomplishments in sensor electronics, etc., have led to the next evolutionary stage within health technology, namely wearable devices. As suggested by the nomenclature, wearable devices are worn on the user's body, allowing for the continual recording, logging and transmission of health-related data via wireless connections, rendering the user's role almost entirely passive, save for the initial wearing and minor maintenance of the device itself (for example, battery charging). The range of data which wearables are currently able to detect and process is impressive, spanning across the physiological, biochemical and spatial (Dunn, Runge, and Snyder 2018). Additionally, devices are available which can provide internal anatomical data via processes such as endoscopy (Alam et al. 2019), although strictly speaking, these probably fall outside of the definition of a wearable device.

In part, the continual emergence of wearable connected health devices is being driven by the consumer health market, consisting of users who, in the main, are in good health, but who wish to be empowered to monitor their own physiological state for a range of reasons, including the enhancement of their well-being (Yetisen et al. 2018). When the consumer wearables market is considered, it is typically in the form of wristwatch-type products. These products typically include Apple Watch, Samsung Gear and Garmin and Fitbit devices. Whilst these brands possess an enormity of the market, their devices also are noteworthy due to the wealth and sophistication of data which they can produce (Mück et al. 2019), the useability of the device themselves and their companion mobile applications and, thus, the ease of use of the systems overall for the end user. The projected ability for these devices to shape the future landscape of IoT-supported connected health is underpinned by ongoing research into the validity of the data that they collect and process, which may support their use as off-the-shelf solutions to enhance access to, and the successful collection of important patient diagnostic data.

Interest in the use of consumer-level wearable health devices has translated to greater levels of explorative investigation by healthcare researchers and shown promising results in many cases. For example, smartwatches offer potential in helping with the detection of conditions such as atrial fibrillation (AF) and could well offer significant value in patient management post-diagnosis and after treatment initiation (Inui et al. 2020; Pantelopoulos et al. 2017). Indeed, the use of these devices in the management of AF is currently under investigation through a large-scale clinical trial involving over 450,000 participants (Lubitz et al. 2021). Smartwatches have also shown promise in the monitoring of other markers of cardiovascular function; devices equipped with pulse oximeters show close parity with medical-grade equipment when used in non-extreme conditions (Lauterbach et al. 2021; Hermand et al. 2021; Schiefer et al. 2021). These examples are particularly encouraging given the extent of the global population affected by cardiovascular conditions and illuminate the role that these devices can play more generally within the management of complex conditions.

In line with what has been discussed elsewhere in relation to the use of health technologies, wearables are not excluded from regulatory requirements when there is an intention to use them medically. The need for this is clear, both from more straightforward aspects of medical relevance and acceptable levels of functional accuracy, and the bringing about of patient benefit in comparison to control, among other reasons. As such, it is important that regulatory processes are introduced which can be afforded to these devices. This necessitates regulators ensuring there is ongoing modernisation and adaptability of their processes to permit beneficial developments at a rate which mirrors that of the base technologies themselves. Regulators do appear to be taking appropriate action, having issued guidance and implemented approval workflows for these devices, which draw many parallels to processes undertaken for the approval of more rudimentary devices and medicines. These will continue to be of importance to device manufacturers, particularly in cases where diagnostic data are collected which offer particular risk (Jiang, Mück, and Yetisen 2020). The implementation of these processes has already seen many wearable devices receiving approval in territories including the United States for the detection of clinical data related to conditions such as diabetes (Dunn, Runge, and Snyder 2018); however, many of these appear to relate to devices which carry out that monitoring as their exclusive task, rather than being integrated into a consumer appliance which offers a plethora of health and non-health functionality. This suggests it will be some time before these devices become reliable resources for the clinically relevant management of patients' health.

The future of wearables, and by extension, connected health devices, is a promising one for healthcare, with next-generation devices already emerging which may offer value in the areas of neurology, respiratory health, ophthalmology and even mental health (Avenga 2020). However, the pathway to their success is rugose and reliant on the progression of other areas in addition to those which relate exclusively to technological development. There is no doubt that a greater assimilation of expertise from the key loci in the overall area of connected health is fundamental to our ability to move forward and, ultimately, bring about marked enhancements in healthcare.

13.3 Barriers to the Emergence of Healthcare Technologies

For many reasons, the rate and quantity of developments in the arena of healthcare technologies, and more specifically, in relation to connected health, would invariably bring about a renaissance in healthcare, were the requirements for such reliant only on technological advancement. However, the reality of bringing about step-change within the area of health is multifaceted and reliant on the satisfaction of many requirements, including those which are intrinsically related to regulation, as discussed elsewhere in this chapter.

As is the case with any element of healthcare development, economic considerations are crucial to the success of connected health. At a base level, technology, regardless of how unsophisticated, costs money, including that which is needed to pay for the assets which form the physical part of the system(s), and the associated requirements for implementation, including the design of new data handling architectures and the training of users at all points of data flow. These fiscal considerations are especially acute when a key motivating factor for the enhanced implementation of digital health is its ability to bring about bettered access to healthcare for those within LMICs and become a priority when testing feasibility (Chen and Liu 2020). The absence of financial support for the hardware and supporting infrastructure represents a significant barrier for technological advancements to bring about their intended effect. Thus, further to regulatory and certification requirements, governments must consider how a greater use of such technologies may bring about more affordable and accessible services and make necessary budgetary changes which will enable these advances to produce more resilient healthcare systems (O'Leary et al. 2015).

Regardless of the ability of technology to deliver desired requirements and the availability of funding to enable its use, the success of healthcare technologies is dependent on their acceptance by those individuals directly implicated in their use, namely patients and healthcare practitioners.

The non-use of healthcare technologies is an area which is keenly investigated (Keyworth et al. 2018), highlighting key and perhaps oft-ignored barriers which commonly affect the very individuals targeted to benefit from these technologies. A considerable number of barriers to the use of healthcare technologies appear to be linked to a lack of education or digital skills, particularly within older adults. Such barriers can include a lack of awareness of the benefits that technology can bring, insufficient education in the area or proficiency in the use of the resources which are provided, and anxieties regarding the correct use of those systems (Rogers and Mead 2004; Delemere and Maguire 2021; Chen and Chan 2013). In addition, a literature review (2018) of 69 studies investigating what maximises the effectiveness and implementation of technology-based interventions to support healthcare professional practice revealed various facilitators and barriers. Facilitators included ensuring senior peer endorsement and integration into clinical workload. Barriers to implementation included organisational challenges and also the design, content and technical issues with the technology-based intervention (Keyworth et al. 2018). Further information in relation to the behavioural aspects of non-use may be gleaned from reference to work in salient areas which overlap with connected health technologies. These include the use of assistive technologies, further illustrating the diversity in the rationale for non-use, including those which are more obvious, such as the incompatibility of the technology with users' disabilities. Non-use of these technologies can also be related to their removal of concealment of an individual's health status, which is perceived to draw unwanted attention towards their health-related issues from family members and others (Söderström and Ytterhus 2010). Indeed, non-use of certain technologies has been linked to the improvement in patients' health which have been brought about in part *by that* technology, with the user erroneously believing that they no longer need to engage with that device/technology after a certain point in order to maintain their improved health state (Dijcks et al. 2006). This fallacy appears to be commonplace wherever long-term management strategies for the maintenance of positive health states are employed (Ulrik et al. 2006; Ashoorkhani et al. 2018).

The barriers outlined here are important but far from exhaustive; they, and others, must be key considerations of successfully designed healthcare technologies at large and in the field of connected health technologies of all kinds. Full credence of these barriers is necessary to produce successful interventions which result in tangible patient benefit, and whilst addressing these may lead to the reduction of what may idealistically be provided by related technologies, this is a compromise which will inarguably allow for maximum benefit to be extracted.

To end this section on a positive note, a brief overview of some potential solutions to the aforementioned key barriers has been included. As previously mentioned, a large part of the success of connected health technologies hinges on the perceptions of the end user, and their acceptance and desire to make use of those technologies. Whilst it is unlikely that any device or system could be designed which would satisfy all users, the consideration of certain characteristics may significantly enhance uptake. One such approach which has been widely employed in the consideration of how technologies can be more widely adopted is the technology acceptance model (TAM), introduced more than 30 years ago. This addresses the key components of ease of use and perceived usefulness, and their influence in users' technology-centric behaviours (Davis 1989; Marangunić and Granić 2015). The TAM has seen both adoption and modification for use in the design of various technologies, allowing it to address environments and user groups effectively, including professionals and patients. In doing so, it allows for both the evaluation and more considered design of systems which are thus more likely to bring about positive outcome on implementation (Attié and Meyer-Waarden 2022).

Unfortunately, the divergence of more recently emerging acceptance models from the "original" TAM prevents the provision of a single model which is transferable in its application, and as such, the criteria used when designing and evaluating such technologies for acceptance require careful consideration by system designers (Rahimi et al. 2018; Orruño et al. 2011).

13.4 Future Directions

The domain of healthcare technology benefits from its intrinsic link to the rich vein of technological developments at large, given that the healthcare industry, and the global community of healthcare professionals, continually strive to work at the cutting edge and to capitalise wherever possible on developments which may translate effectively to patient care. The emergence of technologies in other areas and disciplines provide considerable levels of insight into the shape of healthcare delivery in years to come, and in some instances, breakthroughs are already being made which give a glimpse into the future.

One such technology, virtual reality (VR), currently most linked with applications in entertainment, is now increasingly of interest within healthcare, given its ability to immerse the user in realistic environments for a range of purposes. In short, approaches in VR involve the user entering "into" an environment simply by putting on a headset and ancillary devices which can provide stereoscopic video and 360º audio, and in many cases, also involves the provision of controllers or other functionality which allows the user to interact with and manipulate the environment around them, permitting them to undertake various tasks. The emergence of these technologies was quickly found to be of interest in the area of training for healthcare professionals, allowing practitioners to be brought into challenging, but "safe" environments where they could acquire and practice their own skills, and receive training and guidance, without the need for an equivalent physical space to exist (Mantovani et al. 2003). Additional to this, the use of VR technology enhances training efficiency, by negating resource availability, and related restrictions on the number of individuals who can be trained simultaneously. The ability for VR to offer benefit in patient-facing applications is another defined area of interest, particularly where the placing of a patient into an environment in a safe way can offer therapeutic benefit. This translates perhaps most clearly to the treatment of mental health conditions, where treatment strategies may already involve immersive approaches. To date, preliminary investigations into the use of VR in this way have included the development of treatment strategies for disorders including phobias, post-traumatic stress, addiction and psychosis – however, levels of data and success have varied widely (Gregg and Tarrier 2007; Emmelkamp and Meyerbröker 2021). Thus, further work is required to fully elucidate the role of this emerging technology within these areas of health and others. Ongoing developments within the area of VR include the inclusion of digital avatars driven by artificial intelligence. Digital avatars may allow for more authentic and responsive interactions between the user and the virtual environment in the absence of another "live" participant (O'Connor 2019). Furthermore, approaches which blur the lines between the VR and reality itself via the creation of "digital twins" may facilitate remote management and even surgical procedures (Laaki, Miche, and Tammi 2019).

Perhaps the most exciting avenue to be explored within healthcare in the coming years is that of artificial intelligence (AI), which offers opportunities to generate novel strategies for the management of health and augment those which currently exist, making them more powerful, accurate and significantly more valuable. AI, which incorporates elements such as machine learning and language processing, is a field which has progressed rapidly, and which already constitutes its own industry. AI applications are being created for many aspects of everyday life, with the intention of automating processes and enhancing efficiencies.

Within health, AI approaches can potentiate the use of many of the methods and technologies which have been discussed within this chapter, along with many others, from the diagnostic analysis of data provided by connected health devices, to the ability for advice to be provided to patients in response to the same. The ability for AI to benefit from "learning" from massive data sets, in manner not possible by humans due to the volume of data alone, may lead to these technologies making more accurate clinical decisions than healthcare professionals. Whilst this may seem far-fetched, IBM's "Watson for Oncology" is being used at the present time to make decisions around cancer treatments and has made clinical decisions of striking similarity to those suggested by trained and experienced multidisciplinary oncological treatment teams (Jie, Zhiying, and Li 2021). It is also worth noting that machine learning is increasingly being utlilised in healthcare research, given the manual analysis of text-rich datasets can be error-prone and unscalable. For example, one of the authors of this chapter has demonstrated how machine learning facilitated the examination of over 3000 Fitness to Practise cases involving UK healthcare professionals. These cases were initially converted to text files, with other pre-processing steps implemented, before a topic analysis method (non-negative matrix factorisation; machine learning) was employed for data analysis (Hanna and Hanna 2019).

The potential impact which AI can exert on healthcare is clearly massive and may bring about wide-ranging improvements in outcomes more generally, as well as more granular enhancements in factors such as patients' involvement in their own health, care quality, productivity and medical discovery, etc., and all with greater efficiency and reduced operating costs (Lee and Yoon 2021). However, AI, regardless of its ability to learn, communicate and make decisions, is still a technological system, which will meet the same challenges and barriers that all other technologies face in healthcare, some of which have been outlined in this work, and which may limit adoption. Additionally, whilst outcomes from use cases are encouraging, these are perhaps more blinkered than reports suggest. For example, the ability to predict outcomes, treatment success, etc., in patients is dependent on data sets which have been used to "train" the system, essentially rendering the process useless in circumstances which do not match a well-defined, highly restricted, and even discriminatory set of criteria (Panch, Mattie, and Celi 2019). Conversations around AI are incomplete without some allusion to the ethical implications involved in the use of these systems, given factors such as the amount of data which are shared and the way that data are used (i.e. to potentially allow private enterprises to make use of patient data for the purposes of developing products for profit). There are many other elements which may require sociological and even philosophical consideration to be undertaken before solutions to these ethical concerns can be rolled out at a population level (Smallman 2022). Despite these challenges, and within the scope of the emerging nature of the technology, it would be surprising if AI fails to become a pillar of healthcare systems in years to come.

Notwithstanding the enormity of their projected impact, VR and AI are just two avenues on which we can expect healthcare to travel in years to come and, importantly, in the not-distant future. It is useful to note that many of the technologies which we can expect to see serving diverse roles within health already exist and are being used for other purposes, in various states of maturity. That has also been the case for each of the emerging technologies which have found their way into assisting patients so far. There is appetite to translate useful technologies into the healthcare sphere, with encouragement coming from both those professionals within health who have an awareness of what is being done in other areas and those who are involved in the development of such technologies, given the lucrative and persistent nature of this market.

An educated prediction may include the hypothesis that future directions being added to the healthcare map will be exceptionally combinatorial and may well tie in with technologies which have been discussed elsewhere within this chapter, in addition to others. Drastically enhanced computing power and the ability for systems to handle, process and draw conclusions from extraordinarily large data sets have led to the emergence of “big data”, which in turn can centralise hugely useful information such as patient data sets, treatment outcomes and a host of other useful clinical, management-centric and professional performance data (Dash et al. 2019; Hanna and Hanna 2019) This, combined with technologies such as AI, labs-on-chip-based testing and enhancements in rapid drug and device manufacturing will accelerate the area of personalised medicine (Wu et al. 2018; Jhunjhunwala and Kapil 2022; Katakam, Adiki, and Satapathy 2022), potentially allowing us to move away from population-based empirical models for the treatment of disease and, instead, toward something which is maximally targeted. It is not long ago that the suggestion that someone who had fallen ill could be tested at their bedside, and their diagnostic test results instantly generated and fed into a data set which would allow both the selection of a medication that would cater specifically to that patient’s needs, and its manufacture within hours or minutes within the care setting, would be touted as something straight from a science-fiction novel. However, the technologies which have been discussed here, as well as others within this publication, indicate how the building blocks of such a process are presently being refined. It would be wise to assume that these will soon start to be built together to allow maximal outcomes for those being cared for by the wider healthcare community.

Even with these developments on the horizon, it is already possible to take these suggestions further, which may allow us to see further into the future. 3D printing, considered at length by colleagues elsewhere within this book, is being explored for applications above and beyond the manufacture of medicines. Sophisticated versions of the technique are being used to create tissue scaffolds for the regeneration of cardiovascular tissues and even bone (Lan et al. 2022). Indeed, materials which have been incorporated with mammalian cells have also been produced which may ultimately allow for the regeneration of human tissues and the treatment and cure of conditions which may otherwise have required life-long treatment or permanent synthetic mechanical intervention (Chang et al. 2022). The explosion in the recent popularity of genomics provides another example of the notable impact of technology and utilisation of big data , whereby the ultrafast analysis (again benefitted by the integration of AI) of an individual's genetic material can reveal more about their health in addition to what has been mentioned above, which again benefits from quick processing, comparison against huge data sets, and which will provide practitioners with greater information about optimal disease management (Gulfidan, Beklen, and Arga 2021).

Perhaps ironically, one way in which we might predict health to change in the future does not involve the treatment of patients at all, or at least, may involve the marked increase in the role of preventative medicine within healthcare, and in turn, the treatment of patients for conditions they are yet to experience. The drastic improvement in healthcare over the last decades has seen global increases in life expectancy, and related to this, estimations that levels of disease globally could decrease by 40% by 2040, with over half of these gains in global health coming about as a result of preventative medicine and other contributing factors (McKinsey Global Institute 2020). Of course, many of these preventative measures relate to ones which are currently commonplace, including vaccination. However, the ability to again make use of technologies such as genomics, big data, AI and advanced drug discovery and manufacturing techniques may allow us to routinely identify patients' conditions and undertake highly effective prophylactic action, expanding both life span and quality.

13.3 Conclusions

The delivery of healthcare does not simply coexist with technology, deriving benefit from it where possible. Rather, these two entities are intertwined, serving each other in a range of ways, all of which benefit healthcare practitioners, who are enabled to do their jobs more efficiently and successfully, catering to an increasing and ageing population, and to patients and the population at large, who are experiencing life-enhancing benefits to their care, and to overall health outcomes. A single word which has been mentioned earlier in this chapter efficiently summarises the keystone role which technology plays within healthcare – empowerment – for the reasons noted in the previous sentences, but also for its ability to permit individuals to take greater responsibility for their own health, as it now allows patients to learn more about the workings of their own body and its failings. This empowerment ultimately feeds through to individuals' and populations' education and knowledge about their health and ability to derive synergistic benefit where exogenous action may need to be taken to maintain the status of well-being.

This chapter, whilst a far from the exhaustive account of healthcare technology, is intended to indicate how technology fuels the survival and development of our healthcare systems, and healthcare practices more generally. There is not an action taken by a practitioner or patient which has, or will soon have some input from a technological system, with the hope being that in most cases, significant benefit will result.

This chapter has also reinforced that in many cases, we are not where we need to be yet, and whilst there is a rationale for the use of technologies within health, there is a concurrent need to apply scientific rigour to their use, such that they can be used in a manner which *actually* enacts change, rather than as a result of outcomes which are hypothesised, but never stringently tested. In many cases, this will require not the enhancement of modification of the technology itself, but rather the modernisation of the infrastructure or mode of practice within which it sits – the irony being that the pace of development of technology in healthcare may be slowed by the pace of development of the technology in question.

Few would disagree with the statement that the future role of technology within healthcare is bright, given the ongoing emergence of technologies which allow us to undertake activities at breath-taking levels of speed, accuracy and value. Again, the combination of processes which currently exist in novel ways has significant potential to be one of the most important key developments which we can expect to see within healthcare in the future.

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