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TECHNOLOGICAL ADVANCES AND MEDICINE: A NARRATIVE REVIEW IN THE LIGHT OF COVID-19

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ABSTRACT

The current global pandemic, known as COVID-19, poses challenges to healthcare systems worldwide. At the same time, it has provoked a collective focus on new and disruptive technology and stimulated the application of such technologies to disease control and containment efforts. Some of the innovations that have played the most significant roles have come from the fields of artificial intelligence, big data analytics, and communications technology. The current situation provides a good opportunity to relook how medical people engage with technological advances. This narrative review attempts to provide a historical context to the adoption of technology and of technical developments in Singapore and discusses the impact of disruptive technology in healthcare.

Keywords
Artificial intelligence; Collaboration; Communications technology; Disruptive technology; Healthcare

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INTRODUCTION

COVID-19[1] burst onto the global healthcare scene in late December 2019 as a reminder that quarantine controls, contact tracing, and barrier methods have not outlived their usefulness. Almost overnight, a new social order has developed, which has impacted medical education, clinical practice, and public health and policy. In the wake of the outbreak, there has been a change in the perception, attitudes, and behaviours of the medical community towards harnessing technology.[2]

In simple terms, technology refers to scientific knowledge that has been applied to practical purposes. One tends to think of machines and engineering applied to various fields, including the medical. However, other types of technologies impact on healthcare as well, including communication technology, data storage and analytics, energy power technologies, construction, manufacturing, transportation, robotics, assistive technologies, and artificial intelligence.

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Technological breakthroughs belong to two distinct types. Sustaining technological developments advance the capabilities of current products. These can be better versions of the old or entirely new products for the same market. Examples include machines delivering sharper image quality, newer surgical techniques, or medications with fewer adverse effects. On the other hand, disruptive technology[3] happens when a new product breaks up the status quo, changes the way people aspire to and achieve a goal, and creates new markets where the existing technology may become superfluous and overpriced. In healthcare, one example is the development of home self-dialysis. Patients who were unable to be admitted to a nephrology ward now self-dialyse in their own homes.[4]

This paper presents a narrative review of disruptive technology and how the medical industry has interacted with and responded to it. In the light of enforced innovations resulting from COVID-19, it will also suggest new ways of engaging with technology.

METHODS

A literature search of the PubMed Central database was performed using the keywords “disruptive technology”, “disruptive innovation”, and the MeSH term “disruptive technology”. Two initial inclusion criteria were defined. The articles must focus on disruptive technologies in their content and must address the healthcare sector. No time limits were set. All potentially relevant article titles were evaluated, and the abstracts of articles deemed relevant were assessed. Full-text versions of selected relevant papers were evaluated. Non-English language articles, those with in-depth technical details (e.g. coding, technical language), and articles discussing non-healthcare related topics were excluded. A search on Google Scholar was also conducted to include the opinions of non-healthcare professionals on the use of disruptive innovation in the healthcare sector. The attached flowcharts provide information on the searches.

For the description of early technology use in the local healthcare scene, previous publications from the Singapore Medical Association (SMA) were reviewed using the search term "healthcare IT journey". The "Patient Master Index" was identified as one of the earliest computer systems in use, and further readings from SMA around it were used to augment our understanding of the implementation of technology in the early phases. Information regarding the introduction of Electronic Medical Records and the National Electronic Health Records were obtained from the Ministry of Health and Integrated Health Information Systems websites, respectively. Local news articles from Channel NewsAsia and Today were referenced for the cyberattacks of 2018 and 2019. The discussion points highlighted in the article regarding the use of technology within the public healthcare sector in Singapore were based on the authors' personal experience as well as readings around the topic.

RESULTS

Disruptive technology and modern healthcare challenges

To the healthcare professional, the most public effect of COVID-19 might be the change in the way things are done, whether scientific research, clinical practice, medical education, or public health policy and regulation. In terms of technology, data storage and analytics, artificial intelligence, and communications technology have had the greatest impact on this.

In China, early in the outbreak, crowdsourced data building on novel data collection and analysis techniques helped to produce early epidemiological insights such as the extent of the outbreak, incubation and infectious periods, and transmission patterns.[5] The synergy across space and time was made possible by the interconnection of common personal computing devices, the Internet of Things.

Machine learning was used in artificial intelligence programs that helped to delineate the features of COVID-19 in lung computed tomogram (CT) imaging. The time taken to review each lung CT scan was minimised, thus reducing the time to reporting and clinical decisions. Artificial intelligence has also been explored to predict transmission patterns and next potential cluster areas.[6]

Communications software is allowing new collaboration strategies that enable the continuation of scientific research, data analysis, and medical education across physically disparate sites. Contact tracing and epidemiology, time-honoured from the cholera outbreak in 1854, are now aided by the ability to gather reams of data and to connect it across multiple domains, as done by the Taiwanese,[7] South Koreans,[8] and elsewhere.[9]

At the time of writing, new applications continue to be developed, as well as new applications of old technologies.

The Impact Of Disruptive Technology

The nature of disruption is such that the established incumbent eventually makes way for a different version. In healthcare, one immediate example is how the internet has disrupted the doctor-patient information asymmetry. Medical information, accurate and otherwise, is widespread and accessible. This has changed the doctor's role. From being an authority, he now has to negotiate a shared decision and guide the patient to an informed consent or refusal.[10-11] For better or for worse, this has forced a paradigm shift to doctors' self-perception and chosen role.[12]

Advanced practice nurses are another disruption. With additional training in defined areas, the advanced practice nurse is empowered to provide clinical consultation and has prescribing privileges in selected settings.[13] As these nurses take over care in areas that used to require doctors, primary care physicians find themselves having to address more complex issues, or to take on the care of patients with more complex problems. This brings its own burden of retraining and recertification.[14]

Telemedicine, with the healthcare provider and patient not physically together in a consultation, is even more disruptive to the doctor-patient dyad. It has evolved to address limitations of space, time, and expertise and may involve specialist or general practitioner (GP) consultations. Tele-stroke[15] or tele-dermatological consultations use technology to overcome limited access to specialist care. As COVID-19 sweeps through communities, tele-GP consultations may help to provide care in the context of social distancing.[16] If tele-GP becomes established, the shape of GP consultations and even the type of doctors and patients can be expected to change. Change begins in small ways, and a final diagnosis of disruption is retrospective.

Adopting an exciting new technology can create problems. Scientific evidence takes time to be accumulated and validated. When the measured pace of medical decision making is speeded up, the price may be that of adverse patient outcomes. This was the case with the use of electronic cigarettes as a "healthier" alternative to smoking or as an aid to smoking cessation. E-cigarettes have now been shown to be not only ineffective in smoking cessation but also detrimental to health by contributing to lung injury.[17]

Another potentially poor outcome is the low reversibility of a bad decision. To reverse a widely diffused technology is difficult even with strong evidence for support, particularly if the technology has become entrenched or is associated with non-clinical benefits. For example, electronic fetal monitoring continues to be a widespread "standard of care" despite inconclusive evidence of its benefits.[18]

Technology can become an issue if used beyond its intended function. The technology that uses Quick Response coding to identify potentially ill citizens in China can also be redirected towards dystopian efforts in social monitoring and discrimination.[19]

Advances in communications technology have allowed near-instantaneous transmission of information within the medical community, and between the medical community and the general public. Unfortunately, the advantage that this confers is balanced by the misinformation that is possible due to the democratic nature of technology and varying levels of health and technology literacy. This adds an unpredictable psychological facet to technological and technical interactions.[20]

In general, however, one can expect that new technology will bring benefits and catalyse further improvements. Additionally, if the new technology is also disruptive, different value networks associated with the disruption will develop. Human resource utilisation can be expected to improve with certain innovations, as when a machine is set to do what a machine does better than a human being, or when practitioners are able to practice at the top of their license with an adjustment to the job architecture. Over time, health literacy is expected to improve with better organisational processes and more equity in access to healthcare and health-related information.[21]

Despite obvious benefits, the uptake of new technology in

healthcare is not straightforward. The cost-effectiveness of harnessing disruptive technology is difficult to define due to intricacies of cost analysis and complexities of the healthcare industry. Infrastructure requirements, data quality, and legal and ethical concerns surrounding data privacy and ownership create challenges for governance and control. The usual economic model to justify change is ill-adapted to Medicine. Healthcare-related drivers of change are often disconnected from profit, and it is difficult to assign a value to patient benefit.[22] New models of governance and of cost-effectiveness analysis are needed to navigate these challenges, and the ethical and judicial challenges need to be deliberated before considering potential benefits.

How the healthcare sector views technology

In Singapore, the Ministry of Health began computerising its systems in 1984, under the Civil Service Computerisation Programme of the National Computer Board.[23-24] The plan then was to link the government hospitals, polyclinics, and ancillary services into various networks. Twenty years later, in 2004, electronic medical records were introduced across public health institutions, and in 2011, the National Electronic Health Records was launched as a nation-wide, nationally accessible resource.[25-26]

Doctors have had a love-hate relationship with technology. Electronic records have made the doctor's handwriting a fondly remembered oddity and illegible prescription errors have become lesser. Information technology has allowed doctors to quickly and simultaneously access accurate information and to reduce repetitive manual form-filling. However, the possibility of remote access may push clinicians to consider patients as collections of parameters to be reviewed. Wards are sometimes filled with collective exasperation at yet another technological breakdown. On a more subconscious level, the greater proficiency of junior doctors with information technology may threaten the sacred senior-junior hierarchy in Medicine.[27]

The data leaks that came to light in late 2018 and early 2019 involving SingHealth, [28] the National Public Health Unit,[29] and Health Sciences Authority[30] were an information technology nightmare and a watershed event in the computerisation and digitisation drive. It resulted in an immediate scramble to implement stricter controls and internet-data separation in public health institutions. Governance and risk management became key to technology implementation.

While having a unified electronic health system helps build a national database that can be mined for health-related purposes, the data leaks are a sober reminder of the price that we pay as a society and as individuals in terms of potential privacy compromise.

In 1984, when Singapore began its computerisation process, a local survey found that ten percent of a thousand clinics used computers, mostly for accounting and word processing purposes.[31] In 1990, over sixty percent of forty-two private clinics had computers.[32]

Adopting technology does not come cheaply or smoothly.[33] Medicine tends to progress incrementally, gathering evidence and formulating guidelines. Technology, by contrast, can move at a blistering pace. Industry standards change quickly while the doctor remains with his equipment that is a generation or two behind. One talks about patient health literacy. Perhaps it is time to address doctors' technology literacy as Medicine and technology intersect more frequently and intricately.

Technology can be used and misused. Patients complain about the disruption of the therapeutic relationship when doctors spend the consultation time looking at the computer screen.[34] Conversely, doctors are concerned that in sieving through the extensive electronic medical record they may miss subtle data points, with legal consequences.[35]

We should be aware of the movement to adopt technology appropriately. This is a concept that emphasises on choosing technologies that are apt to our needs and our context and are people-centred.[36] In a sense, appropriate technology is the counterpoint to disruptive technology. Should doctors switch to using hand-held cardiac ultrasound devices or continue using their stethoscopes? Should we develop complex algorithms to evaluate new patients, or should we take some time to allow them to talk? The response depends on the context and our priorities.

A related dichotomy is that between technology and clinical skills. Do we depend on the chest x-ray, or should we percuss and auscultate more confidently? Does it matter at all what the physical findings are when the patient is going for a pan-CT scan? In our adoption of technology, we need to guard against the temptation to think that given the right code and algorithms, technology can solve all our problems.[37]

The future of Medicine

The interaction between technology and Medicine provides a tantalising glimpse of what the practice of Medicine could be. Countries are making use of big data analytics and other new technologies for case identification and disease containment.[7-8] Collaboration had happened across institutional and national boundaries in pursuit of a common objective, as when GenBank was used to facilitate the SARS-CoV-2 sequencing.[7,38] Premier medical journals have put aside paywalls to allow open access.[39] One is tempted to envision a seamlessly interconnected medical ecosystem enabled by blockchain technology.

A blockchain refers to a growing list of records, called blocks, that are linked together in an encrypted manner. Not surprisingly, blockchain technology is being used to develop electronic medical records and their applications in facilitating medical research. One outcome could be the creation of health records from data collected via commonly held personal devices to build up blockchain-powered medical records.[40]

With the massive amounts of data collected using wearable technology and other consumer held devices, artificial intelligence and machine learning may help create a rapid-learning system that uses data analytics to assist in diagnosis or in individualising treatment. [40-41]

Blockchain technology is also expected to improve biomedical research and education by eliminating data falsification and under-reporting or exclusion of the undesirable results of clinical research, and may make it easier for patients to grant permission for their data to be used for research.[42]

The Human Genome Project was declared complete in 2003. With the genome mapped, nanotechnology is being considered with techniques of gene editing[43] for gene therapy and precision medicine. The science of nano-sized particles is also expected to be applied to tasks such as biomarker-facilitated diagnosis and directed drug delivery.[44]

Three-dimensional printing uses specialised printers equipped with preset raw materials to build up a digital construct. It is a manufacturing technique that has captured the medical imagination[45] and has been applied to creating individualised prosthetics and complex anatomical models for surgery planning.[46] The hope is to use tissue cells as building blocks to print grafts or entire organs for transplantation.[47]

Virtual reality as we know it, allowing perception of a simulated external world via a head-mounted display, was invented in 1968,[48] but its medical uses have been discovered mostly in the last decade. Current uses include medical education, psychotherapy, surgical training,[49] and as an interface for communication.[50]

A robot is a machine that is capable of performing a complex series of tasks and is usually programmable. Robotics have been applied to widening types of surgery and rehabilitation as well as to the more mundane tasks of automation in a pharmacy and cleaning work in contaminated areas.[51]

The list is exciting and incomplete. Technology is poised to drive medical practice in the twenty-first century. Beyond technology, however, is the knowledge economy which forms the basis of innovation, development, and disruption in the post-industrial age. The common thread running through the various disruptions today is the human collaboration that underpins the knowledge base. We caught a glimpse of this with the Human Genome Project, a disruptive global collaboration to achieve an unprecedented objective. Collaboration is premised on the fact that no one group, or nation has a monopoly on knowledge.

While the advantages to doing otherwise may seem obvious, collaboration in the healthcare sector has traditionally been only amongst fellow medical professionals, a phenomenon that has been described as "total internal reflection".[52] To fully capitalise on the latest developments, it is time for medical professionals to collaborate with colleagues from engineering, sociology, and economics. One example of this is the multidisciplinary centres for safety and quality improvement working on climate change.[53]

Those who are technologically ahead need to ensure that the disadvantaged are not left behind. COVID-19 has shown us that richer nations have more resources to be deployed in a crisis. Perhaps the creation of an equal healthcare playing field across societies and countries would be the true disruption of our time. This is an effort that requires the partnership of Medicine, technology, diplomacy and government, and industry.[54]

DISCUSSION

Integrating healthcare needs and technology: lessons from COVID-19

The nature of healthcare is such that we are rightly concerned about governance and regulatory controls, evidence and validation, as well as safety checks. These moderate the pace at which we adopt new technologies. The rapid advancements of technology mean that change is the norm, and technological innovations may appear more quickly than the healthcare industry is comfortable with. COVID-19 has shown us that it may be desirable to engage with technology in a new way.

There is a need for a mechanism that allows for rapid decision making, often in fields that are outside our areas of expertise. This may mean empowering a sub-committee within the traditional procurement committee and allowing them to co-opt relevant expertise. Proper documentation, even with quick responses, will help to ensure there are justifications to a rapid decision. These should be coupled with regulatory requirements that can stay relevant.

The recent widespread adoption of online conferencing platforms is an example of swift decision making and implementation to ensure educational, service, and administrative continuity. When authorities in Singapore implemented movement restrictions affecting large-scale gatherings on February 7, 2020, [55] organisations had to find technology tools for the new order. The College of Family Physicians, Singapore (CFPS) was no different. Through a combination of prescient early adoption and the efforts of the CFPS president and council, individual physician teachers, asset owners, administrative staff, vendors, and physician course participants, the first successful online conference involving 450 people was conducted the next day. [56]

While organisational leadership is crucial, it may also be timely to encourage a bottom-up approach. Linking a portion of employee incentives to system performance may foster changes from multiple perspectives in many issues, including engagement with new technology and even future responses to crises.[57-58]

Adaptation to change is an evolutionary instinct for survival and will be sustained as long as the need for adaptation persists. Over the course of time, if the changes seen remain and become part of new norms with novel value networks, disruption will have occurred.

CONCLUSION

The COVID-19 pandemic has shown us that in a highly interconnected world with blurred geographical divisions, [59] a crisis can appear unannounced and force us into a disruption situation. When this happens, vigilance, swift responsivity, cross-domain nimbleness, and generous collaboration will all be vital to continued viability.

"There is a tide in the affairs of men, which, taken at the flood, leads on to fortune." [60]

Declaration of Conflicts of Interest

The authors declare that they have no conflict of interest in relation to this article.

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LEARNING POINTS

- **Despite their downsides, disruptive technology, in the form of data storage and analytics, artificial intelligence, and communications technology, has had a great impact on the current healthcare landscape.**
- **Collaboration across communities and integration across domains are needed to successfully harness disruption.**
- **The medical profession needs to be able to embrace and deal quickly with technological advances when the need arises without forgetting its duty to evaluate these advances properly.**

Figure 1. PubMed Literature

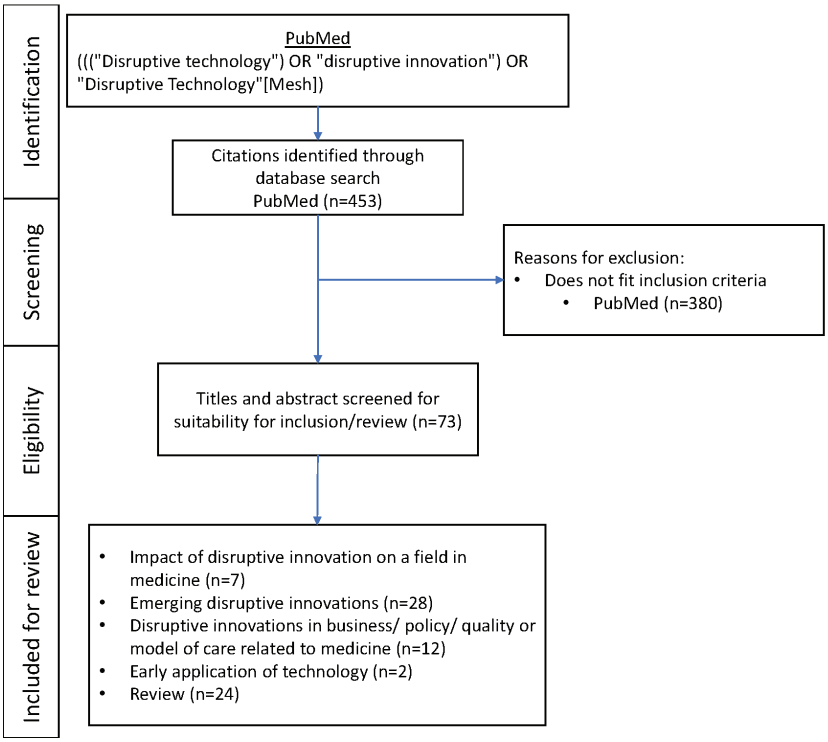

Figure 2. Google Scholar Literature Search