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Special Issue Article

Artificial intelligence in health-care: implications for the job design of healthcare professionals

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The adoption of Artificial Intelligence (AI) in the healthcare sector is growing, and AI-based technologies are envisioned to affect not only patient care but also how healthcare professionals work. Nevertheless, the actual impact of various AI applications on healthcare professionals' jobs has not been studied yet. Bringing together a framework to analyse AI applications in health-care and the job design model, we analysed 80 publications from the grey-literature platform 'SingularityHub'. Our findings demonstrate that AI applications in 1) diagnosis and treatment, 2) patient engagement and empowerment and 3) administrative activities have an impact on the various components of healthcare professionals' job design, including job autonomy and control; skill variety and use; job feedback; social and relational aspects; and job demands. Implications for future research and practice are discussed.

Keywords: artificial intelligence, future of work, healthcare, human resource management, job design

Key points

1 Different AI applications can affect different job design components.
2 The implications from AI applications for job design are considered mainly for doctors and patients.
3 AI can not only ensure patient engagement and adherence but also empower patients.
4 The impact of AI applications on job design can depend on contextual factors.
5 More international research on the implications of AI on the job design of healthcare professionals is needed.

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Introduction

Artificial intelligence (AI) refers to using human intelligence in machines through technological innovations (Bohr and Memarzadeh 2020). Health-care is a sector in which AI is promising to have a major impact (Forbes Insights Team 2019). Indeed, healthcare organisations – facing unprecedented challenges related to changing demographics, administrative requirements, increasing morbidity and changes in information technology demand as well as workforce shortages and aging (Reddy, Fox and Purohit 2019) – also utilise AI to realise affordable medical interventions and positive patient outcomes. For example, the technology already assists surgeons in enhancing their surgical outcomes in AI-assisted robotic surgery (Hashimoto et al. 2018). Doctors reportedly use AI to diagnose diseases earlier, especially chronic illnesses such as cancer (Davenport and Kalakota 2019).

This rise of AI is projected to influence the role of healthcare professionals, especially those working with digital data such as radiologists (Chen et al. 2021) or pathologists (Davenport and Kalakota 2019), because of the potential for large-scale automation. The 'father' of deep learning, Geoffrey Hinton (2016), suggested that we should already stop training radiologists. The dominance of AI in health-care is predicted to take over some of the activities currently performed by clinicians or healthcare administrators (Reddy, Fox and Purohit 2019) or replace those not using the technology (Meskó, Hetényi and Győrffy 2018), thereby potentially threatening their job security. For example, a recent study conducted among Korean doctors reported that 35% of their respondents agreed that AI could replace them, while only 6% of them had a good familiarity with AI (Oh et al. 2019). On the other hand, there are also reassurances that although AI technologies may be used to automate certain tasks (e.g. Topol 2019) and augment clinical decision-making (e.g. He et al. 2019), doctors are not projected to be replaced by AI (Davenport and Kalakota 2019) because of the current limits of AI (Reddy, Fox and Purohit 2019) as well as critical global workforce shortages (Britnell 2019).

The fears associated with AI and its impact on the future of work have been observed also in other industries, heated up by the seminal scholarly works of Frey and Osborne (2017) or Brynjolfsson, Mitchell and Rock (2018) on the future of employment, as well as relevant consultancy reports (e.g. Manyika et al. 2017) triggering scholarly investigations (e.g. Parent-Rocheleau and Parker 2021; Parker and Grote 2020). Meanwhile, despite the double-sized projections and claims around AI, and despite the growing research interest in the application of AI to health-care (demonstrated in Figure 1 by the increasing number of publications on this topic during the last 20 years), the actual impact of AI on healthcare professionals' jobs has not been investigated comprehensively except in some high-level perspectives on this topic (e.g. Reddy, Fox and Purohit 2019).

Therefore, the motivation for this research was to conduct a study that goes beyond the discussion on whether AI will automate, replace or augment healthcare professionals' jobs (e.g. Brynjolfsson, Mitchell and Rock 2018; Frey and Osborne 2017). Specifically, this research aims to analyse how the jobs of healthcare professionals have been or will be affected because of the application of AI in healthcare practices. The study integrates two

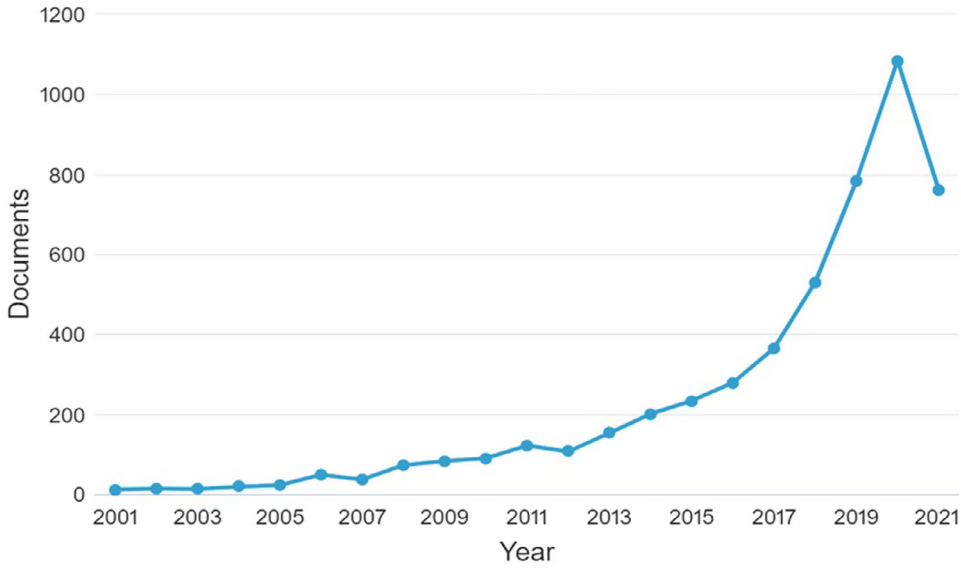

Figure 1 Number of publications from 2000 to 2021 in Scopus literature database

frameworks: the framework of AI applications in health-care (i.e. Davenport and Kalakota 2019) and the technology-oriented job design theory framework of Parker and Grote (2020) extended to the healthcare context. The method adopted in this study is a scoping literature review, inspired by Arksey and O'Malley (2005), of a unique source of knowledge accumulated in innovation and practice. This includes grey-literature publications from SingularityHub (www.singularityhub.com) that since 2008 has 'offer[ed] daily news coverage, feature articles, analysis and insights on key breakthroughs and future trends in exponential technologies as well as highlighting how they're being leveraged for social impact and utilized to tackle the world's grand challenges' (SingularityHub 2021). Our study provides qualitative insights into the Future of Work debate (Huysman 2020) and the better design of AI-enabled jobs of healthcare professionals.

In what follows, we briefly introduce the concepts used in this research, recognise the efforts of other scholars on AI in health-care, and explain how the integration of the two frameworks can provide new insights into the effects of AI on healthcare professionals' jobs. We then describe the methodology, followed by a presentation of the findings. The article concludes with the discussion of our grey-literature findings alongside the relevant scholarly literature and offers recommendations for future research.

Theoretical framework

Different types of AI are separately and jointly (e.g. robots with AI-based 'brains') revolutionising how the healthcare sector works, both to reduce spending and to improve

patient care (Forbes Insights Team 2019). This may be explained by the growing amount of digital data and technical developments as well as important investments in the application of AI in health-care by technology companies and governments. Various frameworks have been proposed for interpreting applications of AI to health-care (e.g. Davenport and Kalakota 2019; Reddy, Fox and Purohit 2019). Among them, the one of Davenport and Kalakota (2019) is particularly notable as it considers clinical (i.e. *Diagnosis and Treatment applications*) and administrative (i.e. *Administrative applications*) components of healthcare professionals' work, as well as taking into account the potential impact of AI on patients (i.e. *Patient engagement and adherence applications*). Categories of this framework have been echoed in other relevant models (e.g. He et al. 2019). It is envisioned that such AI applications can significantly change the jobs of healthcare professionals, defined by the World Health Organization (2013, 57) as those who 'maintain health in humans [such as doctors and nurses] through the application of the principles and procedures of evidence-based medicine and caring'. However, the limitation of this framework is that by itself it does not reveal how these AI applications can potentially affect the job design of healthcare professionals specifically.

The generic research into the effects of technology on job design (e.g. Parent-Rocheleau and Parker 2021; Parker and Grote 2020) suggests that jobs can have multiple dimensions that AI can affect. We can expect that AI influences multiple dimensions of the jobs of healthcare professionals, as they use this technology both positively (e.g. increasing their autonomy and skills usage) and negatively (e.g. increasing work pressure and control).

Therefore, to analyse the ways in which such job components of healthcare professionals can change, we complement the framework of AI applications of Davenport and Kalakota (2019) with the technology-oriented job design theory framework of Parker and Grote (2020), comprising job autonomy and control, skill variety and use, job feedback, social and relational aspects of work and job demands. This was selected because we believe that the job design model is a valuable starting point to analyse the influences of AI on the jobs of healthcare professionals. The model of Parker and Grote (2020) – validated by diverse follow-up studies (e.g. Parent-Rocheleau and Parker 2021) – integrates critical components of multiple pre-existing frameworks such as job-demands resources perspectives (Bakker and Demerouti 2007) with the job-characteristics model (Hackman and Oldham 1976) to specifically study the impact of technology.

To date, several studies have investigated the impact of AI on the future of work in health-care (e.g. He et al. 2019; Oh et al. 2019). Though they provided valuable insights, they have mostly neglected an in-depth analysis of job design aspects to the best of our knowledge. Other theoretically informed studies that focused on job design have not looked specifically at the healthcare sector, which is characterised by the complexity of its governance, including issues regarding technological and workforce structures and reactive attitudes toward innovation (Tursunbayeva 2018).

Consequently, we believe that by integrating the fields of job design and healthcare AI applications, we can build on the strength of each of these individual frameworks and the

disciplines behind them. By doing this, we also contextualise the former generic framework for the specific healthcare sector, while also comprehensively examining the impact of AI by drawing on categories of job design that consider the technicalities, complexity and multidimensional nature of healthcare professionals' jobs (see Figure 2). Finally, with our integrated framework, we contribute to the corpus of research about the AI impact on job design in general, as well as on the job design of a specific group of workers (i.e. healthcare professionals) in particular.

In the following sections, we discuss the dimensions of the frameworks adopted and also provide illustrative examples of AI applications in health-care from previous relevant research.

Categories of AI applications in health-care

AI has been applied to *Diagnosis and Treatment* since the 1970s, though it is still not fully incorporated into healthcare professionals' workflows or medical records systems. The latter in particular remains a challenge, and it has been reported that AI is used for diagnosis and treatment mostly in 'research labs and in tech firms, rather than in clinical practice' (Davenport and Kalakota 2019, 95). These firms and labs claim that they can diagnose or treat diseases with accuracy equal to or greater than that of human doctors by drawing on, for example, data from radiological image analysis, retinal scanning or genomic-based precision medicine (Davenport and Kalakota 2019). Such claims are starting to be supported by scholarly studies. For example, Komorowski et al. (2018) claimed that the treatment selection by an AI clinician is more reliable than that of a human clinician. There are already reported cases of the use of AI for 'population health', particularly for predicting the populations at risk of developing specific diseases or hospital readmissions (Davenport and Kalakota 2019).

The more patients are engaged in their own care and overall well-being, the better their health outcomes should be. For example, the carefully developed care plan aimed at

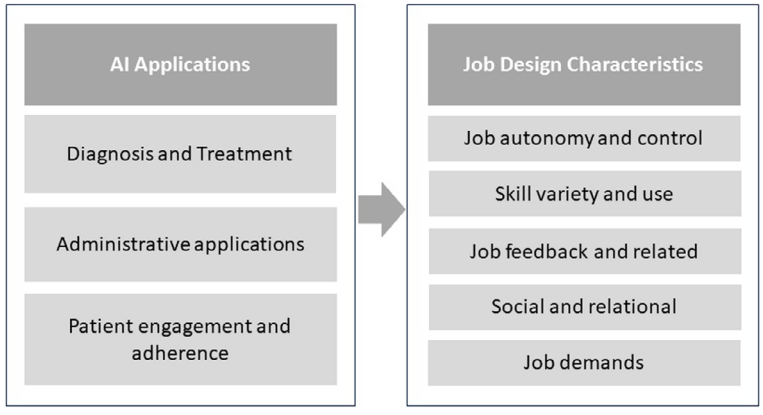

Figure 2 Research model

improving a patient's chronic or acute health could be useless without the actual patient's compliance with it. Thus, *patient engagement and adherence* has been for a long time the final barrier between ineffective and good health outcomes, and there is a growing emphasis on using AI (e.g. machine learning) to drive nuanced interventions (e.g. messaging alerts and other relevant targeted content) along the care path (Davenport and Kalakota 2019).

AI is also projected to make an impact on *healthcare administration*, though to a much lesser extent in comparison with patient care. Considering that the average nurse dedicates a quarter of their work hours to administrative activities related to clinical documentation, medical records management or claims processing, any potential impact on efficiency is valuable. Moreover, healthcare organisations are experimenting with AI-driven chatbots for simple transactions such as refilling prescriptions or making appointments (Davenport and Kalakota 2019), while algorithms also seem to improve the scheduling of hospital workers and thereby reduce costs (Apornak et al. 2021).

Categories of job design dimensions

Job autonomy and control

Job autonomy is an important aspect of job design as it is linked to higher employee motivation and lower turnover (Parker, Morgeson and Johns 2017). Job autonomy involves the freedom to make decisions about job processes and methods, plus the freedom to choose when (e.g. the timing of work) and where to work (Parker and Grote 2020). Based on earlier work (e.g. Grote and Baitsch 1991), Parker and Grote (2020) argue that novel technologies can be both beneficial and detrimental to job autonomy and control – depending on the type of technology and its application and use. AI applications, for example, had consequences for the freedom in decision-making as part of job processes and in terms of timing of work tasks. Thus, AI applications could support healthcare professionals and give them more opportunities to make their own decisions, as well as inform those decisions. However, Parker and Grote (2020) also highlighted the case when iPads were introduced into nursing homes and reduced the perception of autonomy due to the constant surveillance of job activities (Moore and Hayes 2018). Such excessive supervision in healthcare organisations may lead to a lower level of job satisfaction, and therefore healthcare professionals' autonomy, which is important to improve their motivation and offer quality healthcare services (Jiang et al. 2020). Overall, AI tools seem to be already widely used to keep track of the timing and completion of a variety of tasks of professionals in health-care, as illustrated by the examples of Klick Health (Kellogg, Valentine and Christin 2020) and reported by Lebovitz, Lifshitz-Assaf and Levina (2019), who have shown that radiologists have to deal with increased ambiguity and doubt and can often overrule the introduced AI diagnostics system. Lastly, decision-support systems are also threatening the professional autonomy of healthcare professionals by codifying knowledge needed for clinical decision-making previously held exclusively by physicians (Walter and Lopez 2008).

Skill variety and use

Parker and Grote (2020) combined the task identity, skill variety and task-significant components of the original job characteristics model (Hackman and Oldham 1980) with the idea that jobs that involve a wide variety of skills are more interesting and meaningful for workers (Humphrey, Nahrgang and Morgeson 2007).

AI-based systems can take over the more routine jobs, facilitate job enrichment by leaving the more skilled and meaningful tasks to human workers, or facilitate job simplification (Parker and Grote 2020), thereby improving task significance and overall job motivation. A recent study by Chen et al. (2021) highlighted that radiologists believe that AI can take over their more repetitive tasks and allow them to focus on the more interesting and challenging work, though radiographers were more concerned about the potential of AI to change their roles. However, in general, it was underlined that healthcare professionals could outsource some tasks to AI technology to improve their clinical performance only when they acquire new skills to adapt and use AI applications (Talby 2019).

Job feedback

Job feedback refers to the knowledge that employees have about the results of their work, which is important for mastering a task or skill and thus for learning (Parker and Grote 2020). When workers receive direct and clear information, this leads to increased motivation and effectiveness (Hackman and Oldham 1976).

Healthcare professionals also require feedback about their work to realise positive patient outcomes. They used to rely on such feedback on medical interventions from their peers, supervisors, juniors or patients (Hardavella et al. 2017). AI systems are envisioned to become an addition to these sources of job feedback. Nevertheless, there are also multiple examples of decreased feedback and fewer learning opportunities due to the introduction of AI systems (Parker and Grote 2020). For example, Beane (2019) showed that robots in health-care could lead to lower levels of feedback to trainees: on-the-job learning was decreased through the deployment of robots, as tasks were more divided between senior and junior healthcare workers. In addition, when this more instant job feedback is placed in the hands of managers, it may lead to excessive monitoring of healthcare professionals (e.g. Kellogg, Valentine and Christin 2020).

Social and relational

This category was not initially part of the job characteristics model, but considering the importance of social relations at work for positive worker outcomes and motivation (e.g. Humphrey, Nahrgang and Morgeson 2007), it was also included in the Parker and Grote (2020) framework.

AI-based systems can change the tasks that workers perform and thereby redesign the social relations between the individuals and groups involved. For example, Barrett et al. (2012) demonstrated that the introduction of a robot in hospital pharmacies changed the work relations between pharmacists and technicians, enabling pharmacists to maintain their privileged position while technicians took on a new role. Relations with clients or

patients can also change because of the application of AI in health-care. For example, AI systems can be made available for patients to upload their pictures and use diagnostic algorithms themselves (Hwang et al., 2019) without the involvement of healthcare professionals.

Job demands

AI applications are expected to change those job demands of healthcare workers that impose physical and/or psychological strains on them – such as high work pressure and interactions with clients (Bakker and Demerouti 2007).

Examples from the introduction of technology and automation highlight that some of these can actually lead to increased workload, though intended to improve the workflow (e.g. Parker and Grote 2020). It is likely that novel AI systems can also make the jobs of healthcare professionals more difficult, because of the ethical, legal and moral responsibilities related to applying predictive models (Wiens et al. 2019). Thus, healthcare professionals need to be educated about AI to grasp its benefits and limitations, which can add to their job demands at the same time (Demerouti 2020; He et al. 2019). Job demands can change in a beneficial way for workers when the number of tedious and repetitive diagnostics or administrative tasks is decreased due to automation. They can also grow because of the increasing interaction of healthcare professionals with their patients (Van Oort 2019). The results of a recent literature review about how algorithmic management affects job design Parent-Rocheleau and Parker (2021) concluded that the impact of these technologies on job demands (and resources) is highly variable and therefore most likely influenced by several contextual factors, including organisational culture and the labour market.

Methodology

In this study, we have adopted a scoping review method inspired by Arksey and O'Malley (2005), which is frequently used to explore emerging areas of innovation in which relevant formal research may still be sparse or accumulating outside academia. Such reviews are intended to promptly analyse the scope, key considerations and maturity of a specific area, typically to inform policy or propose an agenda for future research (e.g. Tursunbayeva and Di Lauro 2018). Since AI in health-care, and specifically its consequences for job design, is an emerging topic, we adopted this broad approach rather than focusing on narrow and unrepresentative scholarly research. This approach also helps to overcome the difficulties with accessing organisations developing, implementing or using AI, or relevant vendors often bound by confidentiality norms or agreements (Huysman 2020), while providing helpful contextual information and real-world examples of the uses of AI in healthcare (Adams et al. 2016).

Scoping reviews are conducted in five steps, which are described in detail below.

Step 1: Identifying the research question

The motive for this research was to perform a scoping review investigating the impact of AI applications in health-care that is informed by well-established theoretical frameworks. The specific research question set for this study was what is known about how the jobs of healthcare professionals have been or will be affected because of the application of AI in healthcare practices.

Step 2: Identifying relevant studies

A specific grey-literature source – SingularityHub – was used in this research as a source for articles about AI in health-care. The term 'Singularity' refers to the idea that intelligent machines fully surpass human intelligence (Walsh 2017). This data source was selected because the Hub publishes articles and insights daily on key existing and future breakthroughs in exponential technologies that are widely disseminated internationally. For example, the Hub website has around 600K visitors per day, 113K people follow it on Twitter, 146K on Facebook and 22K on Instagram (see Figure 3).

It is not uncommon to draw on magazine articles or blog posts (e.g. Tsitsi Chikandiwa, Contogiannis and Jembere 2013) in academic reviews. To the best of our knowledge, though, we will be the first ones to use this impactful evidence source in scholarly research.

Step 3: Study selection

The articles published by the Hub are clustered on its website into six primary categories of exponential technology including AI, Blockchain, Robotics, Neuroscience, Computing and Biotechnology. In this research, we reviewed all Hub articles published between 2008 and January 2021 under the AI category (around n = 912 out of n = 3781 total articles). The titles of these articles, their authors and dates of publication were extracted into an Excel spreadsheet. These titles were then screened independently twice by two authors, which has been recommended to increase the reliability of article selection (Edwards et al. 2002), to determine if they were related to health-care. One hundred forty-eight of these titles were included in the full-text analysis where both authors independently verified whether the articles matched specific criteria and could thus be included in the final analysis. We selected articles for our synthesis when they 1) were healthcare-related and 2) involved the work of healthcare professionals. We did not include articles that did not

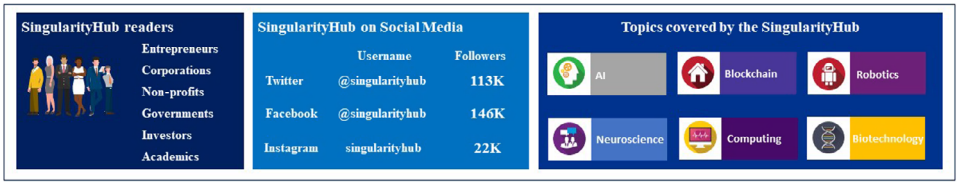

Figure 3 Overview of SingularityHub

specifically mention AI or algorithms and were focused primarily on pharmaceutics (i.e. drug discovery or design), genetics or biology. The first round of the screening found 101 relevant articles, and the second round resulted in 80 papers (most of which were published after 2015), which then were included in the final analysis. The table listing the qualifying articles is presented in Appendix 1.

Step 4: Charting the data

The data extracted from the qualifying articles included applications of AI, job design and healthcare professionals. These data were first extracted into an Excel spreadsheet, where we included article titles, healthcare professionals, job design and AI applications (Appendix 1). Afterwards, we started analysing the articles for key themes and issues with the help of both inductive and deductive coding (Miles and Huberman 1994) to elicit interpretations that matched the job categories of Parker and Grote (2020) and the categories of AI applications of Davenport and Kalakota (2019) (see Figure 2 for the categories used for the coding). The countries mentioned in the qualifying articles were also classified according to the World Bank's Country and Lending Groups (2021). These categories were then grouped into broader macro-categories of regions (e.g. East Asia with Asia Pacific) to facilitate analysis.

This charting (or coding) was performed independently by two authors, who each coded half of the qualifying articles, following mutual agreement on the approach to coding. After the coding was complete, considering the limitations of Excel for performing co-occurrence analysis, we continued the analysis with the help of the ATLAS qualitative research tool. We uploaded all of the articles to ATLAS and individually analysed and coded the other half of the articles, ensuring that in this round we analysed the articles previously coded in Excel by the other author. If the codes were ambiguous, this was resolved through a discussion between the two authors and through examining the wider context in which that code was situated (Palas and Bunduchi 2021). At the end of the coding, the authors verified each other's coding, ensuring that each job design category of Parker and Grote (2020) was associated with the AI applications category of Davenport and Kalakota (2019) where possible.

Although both coding frameworks (on AI applications and job design) structured the data, the inductive coding approach ensured that no important additional emerging theme was missed or neglected. For example, we observed the emergence of the theme on contextual factors of influence (facilitators and barriers) from the data. These factors were open-coded and grouped into the appropriate emerging categories.

Step 5: Collating, summarising and reporting the results

After 'charting' information from the qualifying articles, we first present a descriptive analysis of the studies included, such as geographical distribution and categories of healthcare professionals. Second, we summarise and present our findings according to the developed analytical template derived from job design characteristics categories as outlined by Parker and Grote (2020). Within these themes, we outline and describe how AI changes

these job components of healthcare professionals, taking into consideration the types of AI applications of Davenport and Kalakota (2019). Next, we present our findings in a narrative account and link them to the exemplary articles where we identified these findings (the numbers of the relevant articles listed in Appendix 1 are placed in the text in square brackets: [ ]). In Appendix 2 we also provide a table with the exemplary quotes that support our findings.

Findings

The majority of documents referred to the North America (n = 42), Asia and the Pacific (n = 22), Europe (n = 20), Africa and Middle East (n = 9) and Latin America and Caribbean (n = 2) regions. In the analysis, we also observed that almost all papers mentioned the role of specific categories of healthcare professionals in relation to AI (e.g. physicians [69], clinicians [33], neuroscientists [13], radiologists [14], cardiologists [3], oncologists [3], embryologists [18], surgeons [22], dermatologists [22], epidemiologists [34] or pathologists [22]). Several papers also used doctors [71] or medical experts [6] more broadly or even labelled healthcare professionals as human doctors [26]. The articles also frequently referred to the AI-supported or -substituted future healthcare professionals as robotic doctors (e.g. surgeons [26]) or AI doctors (e.g. physicians [11]) [57]. Some articles also specifically considered the roles of nurses [71] or robot nurses [59], though to a lesser extent.

Job autonomy and control (decision-making)

In terms of diagnosis and treatment, it is projected that in the future, doctors will pair with AI to research more quickly and comprehensively, intelligently diagnose and prescribe optimal treatment plans [57]. This was mentioned as possible thanks to the early detection of disease [18], proactive rather than reactive treatment plans [64] and personalised approaches that consider the patients' needs, goals or potentially health-threatening reactions [69]. AI is also promising to build on the collective experience of clinicians [37], as well as extract and turn large amounts of relevant scientific literature or patients' clinical information (e.g. medicines taken, family history, etc.) [58] into short synopses to aid symptom research and patient assessment. The former can provide doctors with the experience of millions of similar cases when making informed decisions, and non-specialists with the knowledge of specialists (or specialists working in healthcare centres of excellence). The latter diagnostic algorithms are designed to inform doctors about how confident they are (or are not) in their decision in addition to providing an end result. Finally, AI is promising to assist with the diagnosis of diseases that are hard to evaluate (e.g. Parkinson's disease) by providing additional opportunities for diagnostics, for instance by analysing vocal recordings for characteristic anomalies in an individual's voice brought on by the disease [46] or by analysing movement patterns that might indicate conditions like cerebral palsy in newborns [18]. Interestingly, our analysis revealed that some even consider it risky for doctors not to use AI for diagnosis or treatment as they could, for

example, miss some crucial diagnostic signal [5]. The articles analysed almost unanimously agreed that AI is here to assist humans, to optimise their performance, to provide them with alternative assessments or guidance (that may have otherwise been missed) and augment their judgement, not replace it [48; 63]. Several articles compared the performance of AI with that of healthcare professionals and concluded that AI can be better in recognising images [75], can outperform junior (paediatric) doctors, and can be as reliable as more senior ones, thus opening the door for 'building a doctor' versus 'training a doctor' [63]. Other articles discussed the accuracy of computer decisions [57] and ownership/responsibility for those decisions [49] in AI-enabled diagnosis and treatment.

The capability of AI to analyse large amounts of data was also found to be useful for administrative decision-making. Here, for instance, insurance giant WellPoint teamed up with IBM to help their nurses make informed decisions while reviewing patient cases and treatment requests [32].

Job autonomy and control (where and when)

AI enables doctors, nurses and patients to be connected across geographic and time zone boundaries, thus enabling diagnostics and administration of care remotely [44], and where and when both healthcare professionals and patients can or want to do it. This could connect communities in remote areas with experienced consultants and bring progressive medical diagnosis or treatment practices to remote areas or other countries [79], as well as potentially speeding them up. For example, many radiological tests performed in Australia are already being read by radiologists in other countries (e.g. the UK) [22]. Allowing healthcare professionals to check the data or prescribe treatment online or over the phone is also seen as a triage that could limit the patients' visits to those times when they are truly needed [80].

The rise of AI-enabled telemedicine promises many benefits for patients also [8]. For example, 'poorer' patients could benefit from access to quality care. Continuous (24/7) remote monitoring of health parameters with sensors (e.g. heart rate or blood glucose) performed previously only in hospitals [50] could empower patients to carry out personal health monitoring and point-of-care diagnostics, as well as more broadly increase their autonomy. For example, the elderly could now have a choice to continue living in their homes, being assisted by virtual doctors and nurses, or moving to nursing homes [8].

Skill variety and use

According to the Hub articles reviewed, doctors will likely be augmented by AI instead of being replaced. The automation of specific activities will support doctors and give them more time for their patients. Repetitive tasks can be performed by AI, such as diagnosing diseases and certain administrative activities (e.g. patient registration and updating patient records). The more complex tasks become more important, such as interpretation of results and communication with patients [8]. This will allow doctors to focus on caring for patients and applying their communication skills and emotional intelligence [41, 48].

At the same time, patients will have a lot more information about their personal health condition because of several tracking devices. While these technologies are developing, healthcare professionals have an important role in providing insights into how these AI systems should work and be helpful for their profession. Doctors will need to be trained in understanding the technologies of the future and learn computer skills at medical school [49].

In terms of patient empowerment, the data show that healthcare professionals will find patients coming prepared for a hospital visit, with health data available at hand. This could imply that doctors take on an advisory role, rather than a leading role. Hence, the skills healthcare professionals need to engage with both AI and better-informed patients will change significantly.

Social and relational

Medicine has long been segmented into many specialisations, but the healthcare professionals have been expected to accompany the patients through their full treatment journey, as the social and relational aspects form a large component of their work. In our dataset, AI was mentioned as affecting the administrative part of healthcare professionals' work, as well as their diagnosis and treatment-related activities. For the former, AI improved workflows and reduced paperwork, thus improving efficiency and enabling professionals to spend more time on building trust relationships with their patients [33, 49]. For the latter, AI provided doctors with the opportunity to be more productive in their relationships with patients, for example, contacting them with some preventative diagnosis or treatment advice [69]. A report by Gartner indicated that by 2025, half of the population will rely on AI-powered 'virtual personal health assistants' (i.e. chat-operated assistants) for their primary care needs [60]. It was acknowledged that many social and relational aspects with patients and their family members would continue to be done by doctors, as good doctors have emotional intelligence that can help them to have difficult discussions, for example, in the case of terminal illnesses [48].

Job feedback

AI systems are expected to provide more information to doctors about the quality of diagnoses and treatment of patients – or in other words, how well they perform this part of their job. These applications can speed up the diagnosis of diseases and increase the diagnostic success rate [3, 06, 10], thereby also improving the performance of healthcare professionals and potentially alleviating the problem of misdiagnosis [57]. Through improved monitoring and extensive use of wearables, healthcare professionals are provided with an increased amount of data [12]. Based on these data, doctors can get more and better information about their patients' health situation. AI can assist doctors with recommending diagnoses, highlighting conditions that doctors tend to forget [57]. This in turn facilitates feedback and learning [50].

As stated before, AI systems are expected to augment healthcare professionals, not replace them. Augmentation partly takes place through the increased feedback that

doctors get from these AI systems. For example, doctors could check the system to find alternative diagnoses or guidance once they have developed their own judgment about a patient – somewhat similar to a second opinion [8].

On the other hand, there is also the risk that when certain tasks are taken over by AI – such as diagnostics and treatment – healthcare professionals will not be able to interpret and understand how the algorithm comes to its conclusions [8, 41]. By introducing these so-called black boxes, doctors may get feedback only about the outcome and not about the process anymore, and thereby the number of learning possibilities will decrease [7].

Job demands

Doctors are spending many hours on administrative activities, which can be reduced by AI, thereby decreasing their job demands. As one exemplary item describes it, AI technologies could help doctors to spend more time with patients, instead of dealing with burdensome administrative tasks [33].

With the advent of digitalisation and novel technologies, doctors and nurses must process much more information about patients and scientific publications, thereby both increasing and decreasing their job demands. Keeping up with such medical information, which is doubling every 5 years, is an example of an increased job demand [37]. On the other hand, algorithms can also help healthcare professionals to stay updated with such medical information, thus lowering that job demand [37]. For instance, the WAVE algorithm was reported to help doctors to parse through millions of medical papers published annually to stay updated about medical breakthroughs [6].

However, whether the job demands increase or decrease has to do with the choices to be made regarding how the time saved by AI is spent on other activities. In principle, the articles seem to suggest that more time will become available, but this could also mean that doctors can just see more patients, which will increase their stress levels even more [71].

Facilitators and barriers to the application of AI in health-care

In our sample of articles, different contextual factors were described that could facilitate or constrain the adoption and use of AI in health-care and its effects on job design (see Figure 4). Whereas healthcare data availability and quality were mentioned as one of those *barriers* [5, 14, 19, 33], the increasing development and use of data seem to be facilitating AI developments [6, 11, 20, 27], especially when data and software algorithms are openly available [16]. Meanwhile, the current focus on 'sick care' and 'simple' diseases, instead of prevention, may hinder further advances [12, 13]. Another important barrier depicted in the sample was related to ethical aspects; balancing privacy and access to data [4], the safety of data [16, 27], transparency of AI [41] and responsibility of AI decisions [40] and relevant regulatory aspects [4].

AI systems create black boxes that cannot be easily grasped by healthcare professionals [8, 16], causing difficulties in explaining underlying logics and dynamics of diagnosis and treatment [41] and potentially limiting the acceptance of recommendations [33]. Doctors

need to know how predictions and decisions are made [8, 33]. In fact, their trust in AI [23] and acceptance are mentioned as important factors [25, 27, 41].

Several *facilitators* were also identified to advance AI applications in health-care. Many of these facilitators were related to progress in technology, including converging technologies such as computing power, sensors and robotics [12, 24, 27, 33]. Public attention is growing, for example through AI awards [21]. Coinciding with the above are the increasing investments and ambitious strategies developed by large companies and governments [5, 13]. Lastly, we noted that the standardisation of AI applications [8, 10, 13, 41] and the availability of evidence of the benefits from AI were seen as important in advancing AI in health-care [8], while dependence on one system can also be a downside [32].

Discussion and conclusions

Summary

Drawing on the technology-oriented job design framework of Parker and Grote (2020), the framework of AI applications in health-care (Davenport and Kalakota 2019) and a unique data source popular among health and technology innovators (SingularityHub), our scoping review analysed how the jobs of healthcare professionals are being affected due to the application of AI in health practices.

The results of our research demonstrated the emergence of relevant articles in the areas of health and technology innovators since around 2015 (see Appendix 1), which is aligned with the uptake of the scholarly literature (see Figure 1). These articles had a wide international coverage, though most represented regions such as North America, Asia and the Pacific and Europe. Almost all of the sampled articles reported on cases of AI applications or on recent relevant academic publications, or more broadly described the current and future benefits of AI applications in health-care. The tone of most of the articles was

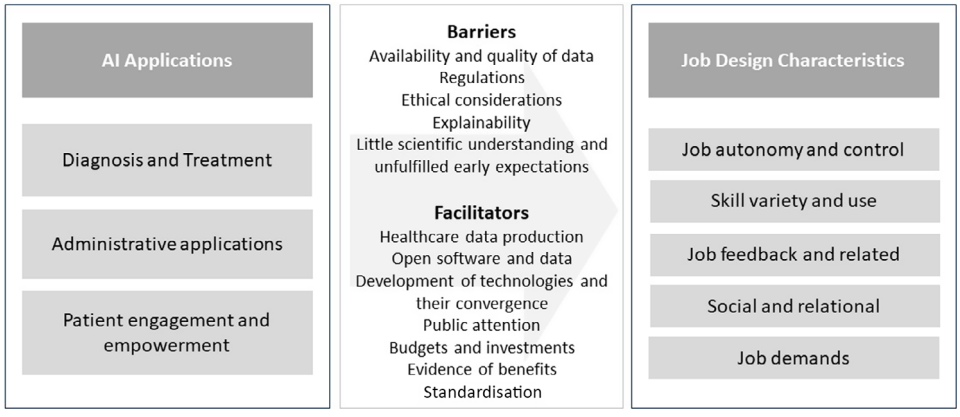

Figure 4 Adapted model of the influence of AI applications on job design characteristics considering the facilitators and barriers

relatively deterministic and techno-optimistic, while part of the recent academic literature is more critical of the role of AI in health-care (e.g. Kellogg, Valentine and Christin 2020) and specifically the attitudes and behaviours of healthcare workers (e.g. Abdullah and Fakieh 2020; Chen et al. 2021).

AI impact on job design in health-care

Our analysis revealed the applicability of the job design theory of Parker and Grote (2020) to the specific healthcare context and empirically validated our integrated framework, which was based on the work by Parker and Grote (2020) and Davenport and Kalakota (2019). We have identified the presence of all the categories of the former theory, including job autonomy and control; skills variety and use; job feedback; social and relational aspects; and job demands. The articles dedicated little attention to the actual impact of AI applications on the jobs of healthcare professionals, while they usually described in detail the types of AI applications. In our analysis, we also observed that different AI applications were discussed as affecting different job design categories (see Figure 5), thus supporting the propositions of Parker and Grote (2020) that AI applications do not affect job design components in isolation. As such, our scoping review informs future systematic reviews that can expand on the job design of healthcare professionals and AI.

Our review highlighted the fact that one of the most important themes is AI's *diagnosis and treatment* application related to the job autonomy of healthcare professionals. Less attention was devoted to how professionals perceive these consequences, for example, potentially threatening their professional autonomy (Walter and Lopez 2008). This finding echoes the one from the broader literature on AI and job design prioritising the focus on job autonomy and highlighting the need to renegotiate the roles of humans and autonomous technology (Parent-Rocheleau and Parker 2021; Parker and Grote 2020).

We noted that AI is changing some pre-existing approaches to the AI-enabled patient diagnosis and treatment processes, as well as the relationship between patients and healthcare professionals. For example, the former is becoming more proactive and focused on prevention, while patients are becoming more engaged and responsible in each AI application, which as a result could also affect the role of healthcare professionals. Considering the empowerment potential of AI, we propose that the patient engagement and adherence category of Davenport and Kalakota (2019) should become *patient engagement and empowerment*.

The implications for job design were frequently discussed for doctors and patients but only seldomly for 1) nurses, 2) managers and 3) organisations (Appendix 1). The first is surprising as nurses provide about 80% of care and are described as a link between patients and processes (Britnell 2019). In many contexts, nurses represent the category of healthcare professional that would be affected the most by the global health workforce shortages (Britnell 2019). The implications for the relations between different types of healthcare professionals were also neglected, which often change with the introduction of new technologies (Barrett et al. 2012; Parker and Grote 2020). These are crucial in health-

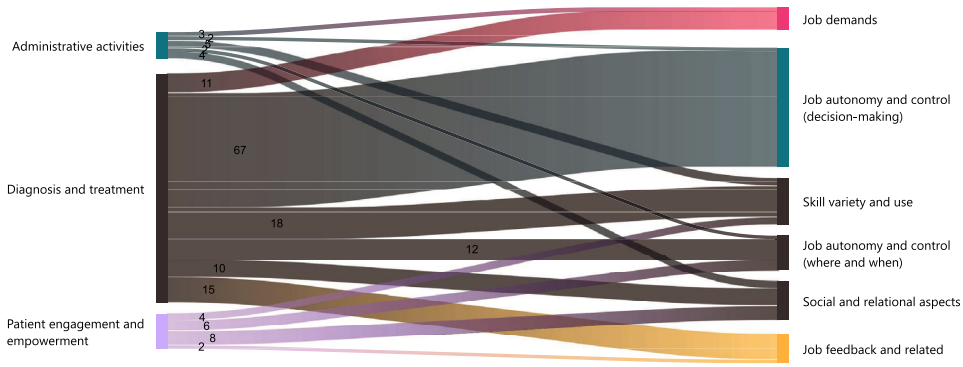

Figure 5 Sankey diagram

care, as care in many cases is provided by care teams of professionals from a variety of specialties (Mayo and Woolley 2016).

Second, we also noted that the implications from AI applications were overlooked for healthcare managers, administrators, non-medical staff or healthcare organisations in general. This is striking given the fact that there is already evidence in the broader jobs and automation literature (e.g. Manyika et al. 2017), as well as the relevant AI and healthcare literature, that some of the activities currently performed by healthcare administrators would also be affected by AI (Reddy, Fox and Purohit 2019). This literature has also called on managers to take an active role (Demerouti 2020; Parker and Grote 2020) in facilitating the transition to the adoption and implementation of AI.

Third, the implications were also missing for organisations, though the impact of technology on jobs could consequently also affect them (e.g. organisational design). Indeed, some organisations from other industries have already adopted more agile hierarchies that can adapt to volatile environments, which has been recommended for the healthcare sector as well (Britnell 2019).

Meanwhile, the implications were frequently considered for patients, which is aligned with the dominant service and medical professionalism logic – that can co-exist in healthcare – both of which are focused on providing high-quality care to patients (Bunduchi, Tursunbayeva and Pagliari 2020).

Contextual factors

It also emerged from our findings that the impact of AI applications was not so direct or deterministic; it frequently depended on accompanying contextual factors which we grouped into potential barriers and facilitators in Figure 4. Frequently, in generic information systems and management research, such factors are grouped under the technology (e.g. specific features of technology), organisational (e.g. characteristics and nature of the adopting organisation), environmental (e.g. characteristics of the macro level at which the technology is adopted) (i.e. the TOE framework of DePietro, Wiarda and Fleischer

(1990)) and individual (Tursunbayeva 2018) macro-categories. Considering such taxonomies, it can be observed that the factors that influenced the impact of AI applications on the job design of healthcare professionals (both barriers and facilitators) were related to the technology (e.g. development of technologies), environmental (e.g. regulation) and individual (e.g. explainability) ones, while none of them were related to the organisational level (e.g. structure, strategy and HRM policies). The presence of all these factors and their effects on job design links our findings to the discussion of sociotechnical thinking and its importance in job design discussed in the broader AI and job design literature (e.g. Parker and Grote 2020). It warrants paying more attention to the organisational-level choices and implementation processes that influence to what extent and how AI applications affect the work of healthcare professionals and the strong agency of the medical professional to decide on the type of technology with which to work (e.g. Lebovitz, Lifshitz-Assaf and Levina 2019) as well as approaches to its application (Bunduchi, Tursunbayeva and Pagliari 2020).

Limitations and future research

Like any study, our research has some limitations. We did not focus on exploring whether AI applications will assist, augment or replace healthcare professionals. Similarly to Nagendran et al. (2020), we noted that several articles discussed this and compared the performance of a human doctor with that of an AI doctor, frequently mentioning that the former could potentially be replaced (though without providing concrete examples of such cases). Interestingly, none of the articles compared the performance of the human doctor with that of the AI-empowered doctor, though the latter was frequently claimed in the earlier literature to substitute for the ones not using AI (e.g. Meskó, Hetényi and Győrffy 2018). We also analysed job design using a specific framework (Parker and Grote 2020). Future studies might like to draw on other job design frameworks which potentially consider work outcomes as well (e.g. Humphrey, Nahrgang and Morgeson 2007), thus triangulating and enriching our findings.

We also refer to AI in a broader sense instead of subclassifying the term into specific types of technology such as machine learning, deep learning or natural language processing, as well as narrower categories of AI applications (e.g. Socha-Dietrich 2020). Similarly, we present our findings often broadly for healthcare professionals instead of detailing them for doctors or nurses, as the latter were very seldom mentioned in qualifying studies. Future scholars might like to draw on more detailed relevant frameworks of AI and categorisations of healthcare professionals, thus enriching our knowledge of how such subdimensions could potentially affect job design, or how their job design is affected for these categories, respectively. Lastly, we focused on only one component of the HR function (i.e. job design). Future research could examine the effects of AI on other HR functions in health-care as well.

Theoretical and practical implications

Despite this, we believe that our findings have important implications for both theory and practice. From a scholarly perspective, they address the need for more qualitative studies on the Future of Work (Huysman 2020) and on the design of technology-enabled jobs in general (Parker and Grote 2020), as well as for more relevant studies specific to the health-care sector (Cavanagh, Pariona-Cabrera and Halvorsen 2021). For example, this research analysed the impact of technology on the actual job design of healthcare professionals instead of only quantifying the jobs that could potentially be affected by AI in health-care. This study also contextualises the generic framework on job design (Parker and Grote 2020) to the healthcare sector and links specific AI applications described in the health literature (Davenport and Kalakota 2019) to job design implications from the management corpus of research. This enriches the current frameworks on AI applications in health-care (Davenport and Kalakota 2019) by providing indications of the most developed or the most expected areas of potential AI applications and directions for how the impact of AI applications can be studied in other sectors.

From a practical perspective, this research revealed insights into the better design of AI-enabled jobs of healthcare professionals that could contribute to rather than reduce their productivity and job satisfaction (Britnell 2019) and generally supports the adoption of fit for beneficial AI applications that was identified as the biggest challenge for AI in health-care (Davenport and Kalakota 2019). For healthcare professionals, this research provides insights into the potential implications of AI adoption for their jobs, so they can prepare themselves for the future (e.g. types of skills important in the future – social skills). This can potentially improve their awareness of the threats and opportunities of smart technologies (e.g. Brougham and Haar 2017). Healthcare managers can start preparing their workforce to collaborate with AI systems and adjust the job design of healthcare professionals. They need to invest in understanding and designing how highly educated workers such as healthcare professionals can effectively and efficiently work with AI systems and introduce programs to facilitate the transition.

In summary, the findings of this research are of interest to broad categories of stakeholders, ranging from policy-makers to healthcare professionals. They also reveal an agenda for future interdisciplinary research.

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Appendix 1

Analysed SingularityHub articles

No.	Article title (year)	Health professionals	Job design effects	AI applications
1	10 Tech Trends That Made the World Better in 2016 (2017)	Doctors	N/A	Diagnosis and treatment
2	3 Exciting Biotech Trends to Watch Closely in 2017 (2017)	Doctors	Job feedback; Job autonomy and control (decision-making)	Diagnosis and treatment
3	5 AI Breakthroughs We'll Likely See in the Next 5 Years (2019)	Doctors	Job autonomy and control (decision-making)	Diagnosis and treatment
4	8 Ways AI Will Transform Our Cities by 2030 (2017)	Doctors	Job autonomy and control (decision-making); Social and relational aspects; Skill variety and use	Diagnosis and treatment
5	A Look at IBM_s Watson 5 Years after Its Breathtaking Jeopardy Debut (2016)	Doctors	Job autonomy and control (decision-making)	Diagnosis and treatment
6	AI Is Rapidly Augmenting Healthcare and Longevity (2019)	Doctors; Nurses; Patients	Job demands; Job autonomy and control (decision-making); Job feedback	Diagnosis and treatment; Patient engagement and empowerment; Administrative applications
7	AI Uses Titan Supercomputer to Create Deep Neural Nets in Less Than a Day (2018)	N/A	N/A	Diagnosis and treatment

1 (*continued*)

No.	Article title (year)	Health professionals	Job design effects	AI applications
8	AI Won't Replace Doctors, It Will Augment Them (2018)	Doctors; Patients	Job autonomy and control (decision-making); Job feedback; Skill variety	Diagnosis and treatment
9	Algorithm Hunts Rare Genetic Disorders from Facial Features in Photos (2014)	Doctors	Job autonomy and control (choice over where and when to work); Job autonomy and control (decision-making); Job feedback	Diagnosis and treatment
10	AI Can Diagnose Like Doctors. But for Continued Progress, Research Standards Must Improve (2019)	Doctors	Job feedback	Diagnosis and treatment
11	An AI Physician on Every Smartphone (2010)	Doctors; Nurses	Job autonomy and control (where and when)	Diagnosis and treatment
12	Apple Isn't Just Satisfied Reinventing Health Care, It's Targeting Clinical Trials as Well (2015)	Doctors	Job autonomy and control (decision-making); Job feedback	Diagnosis and treatment; Patient empowerment
13	Are Artificial Neural Networks the Key to Unravelling the Mysteries of Autism? (2015)	Doctors	Job autonomy and control (decision-making)	Diagnosis and treatment

1 (*continued*)

No.	Article title (year)	Health professionals	Job design effects	AI applications
14	Artificial Intelligence Predicts Death to Help Us Live Longer (2017)	Doctors; Nurses	Job autonomy and control (decision-making); Job feedback; Social and relational	Diagnosis and treatment
15	Bionic Limbs with Artificial Intelligence (2009)	Doctors	N/A	Patient engagement and empowerment
16	Can We Trust AI Doctors? Google Health and Academics Battle It Out (2020)	Doctors	Job autonomy and control (decision-making)	Diagnosis and treatment
17	China and AI: What the World Can Learn and What It Should Be Wary of (2020)	Doctors	Job autonomy and control (decision-making); Job autonomy and control (where and when); Job demands; Social and relational	Administrative activities; Diagnosis and treatment
18	Coming of Age in the Age of AI: The First Fully Digital Generation (2019)	Doctors	Job autonomy and control (decision-making); Job demands	Diagnosis and treatment; Patient engagement and empowerment
19	DeepMind's Protein Folding AI Is Going After Coronavirus (2020)	Doctors	Job autonomy and control (decision-making); Job demands	Diagnosis and treatment

1 (*continued*)

No.	Article title (year)	Health professionals	Job design effects	AI applications
20	Designer Babies, and Their Babies: How AI and Genomics Will Impact Reproduction (2018)	Doctors	Job autonomy and control (decision-making)	N/A
21	Diamandis: Tricorder X Prize Offers $10 Million to Build Star Trek Inspired Health Scanner (2013)	Doctors	Job autonomy and control (where and when); Job feedback; Social and relational	Diagnosis and treatment; Patient engagement and empowerment
22	Digital Diagnosis: Intelligent Machines Do a Better Job Than Humans (2016)	Doctors	Job autonomy and control (decision-making); Job autonomy and control (where and when); Skill variety and use; Job demands	Diagnosis and treatment
23	Drug Discovery AI to Scour a Universe of Molecules for Wonder Drugs (2017)	N/A	Job demands; Skill variety	Diagnosis and treatment
24	Exponential Medicine: Craig Venter Estimates 5 Million Complete Human Genomes Sequenced by 2020 (2014)	N/A	Job autonomy and control (decision-making)	Diagnosis and treatment
25	Exponential Medicine: Data Deluge to Disrupt Healthcare This Decade (2014)	Doctors	Job autonomy and control (decision-making); Job demands; Skill variety	Diagnosis and treatment

1 (*continued*)

No.	Article title (year)	Health professionals	Job design effects	AI applications
26	Exponential Medicine: Healthcare Is Broken, Here's How We're Going Fix It (2015)	Doctors	Job autonomy and control (decision-making); Job autonomy and control (where and when); Social and relational	Diagnosis and treatment
27	Exponential Medicine: The Most Detailed Snapshot of Human Health in History (2015)	Doctors	Job autonomy and control (decision-making)	Diagnosis and treatment
28	Exponential Medicine: This Virtual Assistant Tells You When To Put Down the Bacon (2015)	Doctors	N/A	Patient engagement and empowerment
29	Exponential Medicine" Deep Learning AI Better Than Your Doctor at Finding Cancer (2015)	Doctors	Job autonomy and control (decision-making); Job feedback	Diagnosis and treatment
30	Families Finally Hear from Completely Paralyzed Patients Via New Mind (2017)	Doctors	Job feedback	Patient engagement and empowerment
31	Fighting Developing World Disease with AI (2016)	N/A	Job demands	Administrative activities; Diagnosis and treatment
32	From Jeopardy to Insurance: IBM's Watson AI Hired by WellPoint for Medical Expertise (2011)	Doctors; Nurses	Job autonomy and control (decision-making); Job demands; Skill variety	Administrative activities; Diagnosis and treatment; Patient engagement and empowerment

1 (*continued*)

No.	Article title (year)	Health professionals	Job design effects	AI applications
33	How AI Can Tap into the Collective Mind to Transform Healthcare (2019)	Doctors	Job autonomy and control (decision-making); Job demands; Skill variety; Social and relational	Administrative activities; Diagnosis and treatment; Patient engagement and empowerment
34	How AI Helped Predict the Coronavirus Outbreak Before It Happened (2020)	Doctors	Job autonomy and control (decision-making)	Diagnosis and treatment
35	IBM Markets Watson as Potential Solution to Africa (2014)	N/A	N/A	Diagnosis and treatment
36	IBM Still Slogging Away to Market Watson's AI Smarts (2014)	Doctors	Job autonomy and control (decision-making); Skill variety	Diagnosis and treatment
37	IBM's Watson Expands Commercial Applications (2012)	Doctors	Job autonomy and control (decision-making); Job demands; Job feedback	Diagnosis and treatment
38	iRobot CEO Discusses Their New Robot AVA (2012)	Doctors; Nurses; (patients)	Social and relational	Patient engagement and empowerment

1 (*continued*)

No.	Article title (year)	Health professionals	Job design effects	AI applications
39	Its a Powerful Time to Reshape Healthcare Across the Planet (2016)	Doctors; Nurses; (patients)	Job autonomy and control (decision-making); Job demands; Social and relational	Diagnosis and treatment; Patient engagement and empowerment
40	Just a Few of the Amazing Things AI Is Doing in Healthcare (2018)	N/A	Job autonomy and control (decision-making)	Diagnosis and treatment
41	Life-or-Death Algorithms: Avoiding the Black Box of AI in Medicine (2018)	Doctors	Job demands; Skill variety and use; Social and relational; Job feedback and related	Administrative applications; Diagnosis and treatment
42	Machines Teach Humans How to Feel Using Neurofeedback (2014)	Health provider	Job autonomy and control (decision-making as part of work processes)	Diagnosis and treatment
43	Meet the Engineer Bringing Wearable Sensors and AI to Autism Therapy (2015)	Doctors; Patients	Job autonomy and control (choice over where and when to work); Job feedback and related; Social and relational	Diagnosis and treatment; Patient engagement and empowerment

1 (*continued*)

No.	Article title (year)	Health professionals	Job design effects	AI applications
44	Mobile Health Takes On a New Challenge (2017)	Doctors	Job demands; Job autonomy and control (choice over where and when to work)	Diagnosis and treatment
45	New AI Mental Health Tools Beat Human Doctors at Assessing Patients (2016)	N/A	Job autonomy and control (decision-making as part of work processes); Social and relational	Diagnosis and treatment; Patient engagement and empowerment
46	New Software Can Diagnose Parkinson's Disease Simply by Listening to Your Voice (2012)	Doctors	Job autonomy and control (decision-making as part of work processes); Skill variety and use; Social and relational	Diagnosis and treatment; Patient engagement and empowerment
47	Our Health Data Can Save Lives, but We Have to Be Willing to Share (2017)	Patients	Job autonomy and control (decision-making as part of work processes); Social and relational	Diagnosis and treatment; Patient engagement and empowerment

1 (*continued*)

No.	Article title (year)	Health professionals	Job design effects	AI applications
48	Paging Dr. Watson: AI Jeopardy! Soon to Be Physician's Assistant (2011)	Doctors; Nurses	Job autonomy and control (decision-making as part of work processes); Job demands; Job feedback and related; Skill variety and use; Social and relational	Diagnosis and treatment
49	Robots in Health Care Could Lead to a Doctorless Hospital (2016)	Doctors; Patients	Social and relational; Skill variety and use; Job autonomy and control (decision-making as part of work processes)	Administrative activities; Diagnosis and treatment
50	Sensor Sensibility: New Information from Toumaz CEO (2009)	Doctors; Patients	Job feedback and related; Social and relational; Job autonomy and control (choice over where and when to work)	Diagnosis and treatment; Patient engagement and empowerment
51	Singularity Summit 2011 Part II – Artificial Intelligence and the Brain (2011)	Doctors	Job autonomy and control (decision-making as part of work processes)	Diagnosis and treatment

1 (*continued*)

No.	Article title (year)	Health professionals	Job design effects	AI applications
52	Six Technologies That Hit Their Tipping Points in 2015 (2015)	Doctors; Patients	Job autonomy and control (choice over where and when to work)	Patient engagement and empowerment; Diagnosis and treatment
53	Talking to a Computer May Soon Be Enough to Diagnose Illness (2017)	N/A	Job autonomy and control (decision-making as part of work processes)	Diagnosis and treatment
54	Technology Will Erase Jobs – But Also Make Everything Cheap or Free (2017)	N/A	Job autonomy and control (decision-making as part of work processes)	Diagnosis and treatment
55	The 10 Grand Challenges Facing Robotics in the Next Decade (2018)	N/A	Skill variety and use; Job autonomy and control (decision-making as part of work processes)	Diagnosis and treatment
56	The 3 Major Industries AI and Big Data Will Reshape This Decade (2015)	Doctors; Patients	Job autonomy and control (choice over where and when to work) Skill variety and use; Job autonomy and control (choice over where and when to work)	Diagnosis and treatment; Patient engagement and empowerment; Administrative activities

1 (*continued*)

No.	Article title (year)	Health professionals	Job design effects	AI applications
57	The AI Doctor Is Ready to See You (2010)	Doctors	Job autonomy and control (decision-making as part of work processes); Job feedback and related; Job autonomy and control (choice over where and when to work); Social and relational	Administrative activities; Diagnosis and treatment
58	The Astonishing Healthcare Tech of the Future Is Arriving (2016)	Doctors; Patients	Job autonomy and control (decision-making as part of work processes); Job autonomy and control (choice over where and when to work)	Diagnosis and treatment; Patient engagement and empowerment; Administrative activities
59	The Day You'll Prefer Robots to Humans (2014)	Nurses	Skill variety and use	Diagnosis and treatment; Administrative activities

1 (*continued*)

No.	Article title (year)	Health professionals	Job design effects	AI applications
60	The Doctor in the Machine: How AI Is Saving Lives in Healthcare (2017)	Doctors; Patients	Skill variety and use; Job autonomy and control (decision-making as part of work processes); Job demands; Social and relational	Diagnosis and treatment
61	The Hidden Human Workforce Powering Machine Intelligence (2017)	N/A	Job autonomy and control (decision-making as part of work processes)	Diagnosis and treatment
62	The Massive Project That's Building a 'Google Earth for Human Health' (2018)	Doctors; Patients	Skill variety and use; Social and relational	Patient engagement and empowerment; Diagnosis and treatment
63	The Pediatric AI That Outperformed Junior Doctors (2019)	Doctors	Job autonomy and control (decision-making as part of work processes); Skill variety and use	Diagnosis and treatment
64	The Struggle to Make AI Less Biased Than Its Creators (2017)	N/A	Job autonomy and control (decision-making as part of work processes)	Diagnosis and treatment
65	The Top 100 AI Startups Out There Now, and What They're Working On (2020)	N/A	N/A	Diagnosis and treatment
66	The World's Most Valuable AI Companies, and What They're Working On (2019)	N/A	Social and relational	Diagnosis and treatment

1 (*continued*)

No.	Article title (year)	Health professionals	Job design effects	AI applications
67	This AI Predicts Obesity Prevalence – All the Way from Space (2018)	N/A	N/A	Diagnosis and treatment
68	Tomorrow's Healthcare Is Here Today: Exponential Medicine Begins in San Diego (2016)	N/A	N/A	Diagnosis and treatment; Patient engagement and empowerment
69	Using Big Data to Give Patients Control of Their Own Health (2018)	Doctors	Job autonomy and control (decision-making as part of work processes); Skill variety and use	Diagnosis and treatment; Patient engagement and empowerment
70	Watson Is Now Commercially Available, Set to Help Doctors Treat Cancer (2013)	Doctors	Job autonomy and control (decision-making as part of work processes)	Diagnosis and treatment
71	We Should Use AI to Rescue Modern Medicine From Itself (2019)	Doctors	Social and relational; Skill variety and use; Job demands	Diagnosis and treatment; Patient engagement and empowerment; Administrative activities
72	We'll Soon Trust AI More Than Doctors to Diagnose Disease (2016)	Doctors; Nurses	Job autonomy and control (decision-making as part of work processes)	Diagnosis and treatment
73	What Would It Mean for AI to Become Conscious? (2019)	Doctors	Job autonomy and control (decision-making as part of work processes)	Diagnosis and treatment

1 (*continued*)

No.	Article title (year)	Health professionals	Job design effects	AI applications
74	When It Comes To Jobs, Automation Can Be a Force For Good (2015)	Doctors	Job autonomy and control (decision-making as part of work processes); Skill variety and use	Diagnosis and treatment
75	Where Artificial Intelligence Is Now and What's Just Around the Corner (2016)	N/A	Job autonomy and control (decision-making as part of work processes)	Diagnosis and treatment
76	Where Should AI Ethics Come From? Not Medicine, New Study Says (2019)	Doctors	N/A	Patient engagement and empowerment
			Job autonomy and control (decision-making as part of work processes)	Diagnosis and treatment
77	Why AI Will Be the Best Tool for Extending Our Longevity (2019)	N/A	N/A	Diagnosis and treatment
			Job autonomy and control (choice over where and when to work)	Patient engagement and empowerment
78	Why the Cost of Living Is Poised to Plummet in the Next 20 Years (2016)	Doctors	Skill variety and use	Diagnosis and treatment
79	Why the World Is Better Than Ever – and Will Get Better Still (2016)	Doctors	Job autonomy and control (choice over where and when to work)	Diagnosis and treatment

1 (*continued*)

No.	Article title (year)	Health professionals	Job design effects	AI applications
80	With Latest Tech, Can Doctors Treat Us Before We Fall Sick? (2013)	Doctors	Job autonomy and control (choice over where and when to work); Job autonomy and control (decision-making as part of work processes); Job feedback and related	Diagnosis and treatment

Appendix 2

	Diagnosis and treatment	Administrative applications	Patient engagement and empowerment
Job autonomy (decision-making)	'Machines are helping to design drugs faster and detect disease earlier. And AI may soon influence not only how we diagnose and treat illness in children, but perhaps how we choose which children will be born in the first place.' (P18)	'In a historic step towards modernizing healthcare, insurance giant WellPoint is teaming up with IBM so that the Watson AI can help their staff make informed decisions. The amount of medical literature is staggering – doubling in size about every five years. No human can possibly hope to keep up. Watson, however, is able to process 200 million pages of content in just three seconds. In early 2012, some WellPoint nurses will be able to access Watson to assist them in reviewing patient cases and treatment requests. Later, WellPoint expects to roll out the service to a few oncology practices and eventually this technology could be helping medical professionals all over the world.' (P32)	N/A

2 (*continued*)

	Diagnosis and treatment	Administrative applications	Patient engagement and empowerment
Job autonomy and control (choice over where and when to work)	'Currently, many radiological tests performed in Australia are being read by radiologists in other countries, such as the UK. Rather than having an expert in Australia get out of bed at 3 AM to read a brain scan of an injured patient, the image can be digitally sent to a doctor in any appropriate time zone and be reported on almost instantly.' (P22)	'China's approach to AI development and implementation is fast-paced and pragmatic, oriented towards finding applications which can help solve real-world problems. Rapid progress is being made in the field of healthcare, for example, as China grapples with providing easy access to affordable and high-quality services for its aging population.Applications include "AI doctor" chatbots, which help to connect communities in remote areas with experienced consultants via telemedicine.' (P17)	'In this vision of healthcare, people would be able to monitor their health 24-7, with sensors attuned to various biomarkers that could indicate the onset of everything from the flu to diabetes. AI would be instrumental in not just ingesting the billions of data points required to develop such a system, but also what therapies, treatments, or micro-doses of a drug or supplement would be required to maintain homeostasis.' (P77)

2 (*continued*)

	Diagnosis and treatment	Administrative applications	Patient engagement and empowerment
Skill variety and use	'The hospital of the future may not require many doctors, but the numbers employed are unlikely to change at first.Doctors in the near future are going to need many different skills than the doctors of today. An understanding of technology will be imperative. They will need to learn programming and computer skills well before the start of medical school. Programming will become the fourth literacy along with reading, writing (which may vanish) and arithmetic.' [49]'So the radiologists may end up doing procedures that are currently done by vascular and cardiac surgeons. The increased use of robotic assisted surgery will mean this is more likely than not.' [22]'The goal of AI is not to replace doctors, stressed Karthikesalingam. Rather, it is to optimize physician performance, releasing them from menial tasks, and providing alternative assessments or guidance that may have otherwise slipped their notice.' [48]	'What some hospitals have done in the past 10 years is recognize the potential to be more factory-like, and hence more efficient. The term "focused factories" has been used to describe some of these new hospitals that specialize in a few key procedures and that organize the workflow in a more streamlined and industrial way.They have even tried "lean processing" methods borrowed from the car manufacturing industry. One idea is to free up the humans in hospitals so that they can carry out more complex cases.' [49]	'The technology can scale easily as patients can do the tests themselves in minutes and are as cheap as making a local phone call. This could not only help screen people for early stages of the disease, but it could also allow doctor's to track the disease progression in patients and therapists to monitor the effectiveness of voice therapies without patients having to come into the clinic. This could save valuable resources and allow healthcare workers to have more frequent checkups on patient health remotely.' [46]

2 (*continued*)

	Diagnosis and treatment	Administrative applications	Patient engagement and empowerment
Job feedback and related	'Imagine, having a doctor open her PDA and have access to each of her patients' vital signs. Or, that same PDA could have a program that alerts her to changes in a condition. No more paging doctors when something goes wrong. The doctor could see when things were about to go wrong and get there before they do.' (P50)	N/A	'We measure the three leading physiological indicators of anxiety – sweat, heart rate, and skin temperature – and we track them in real time. Based on how they change over time, we can notify a parent or caregiver. . .the caregivers can then give feedback to the systems saying, "Yes. This was a meltdown," and track the antecedent, the behavior, and then what the consequence was.' (P43)
Social and relational	'If these hurdles can be cleared, AI could automate the legwork of diagnostics by mining patient records and the scientific literature. This kind of digital assistant could allow doctors to focus on the human dimensions of care while using their intuition and experience to guide the process.' (P8)	'We shouldn't downplay that particular impact, the authors stressed. Doctors are drowning in paperwork, which hogs their precious time with patients. Educating the current physician workforce on AI technologies that increase efficiency and improve workflow could cut burnout rate. What's more, the data can in turn feedback to train machine learning models to further optimize care for patients in a virtuous circle.' (P33)	'The technology can scale easily as patients can do the tests themselves in minutes and are as cheap as making a local phone call. This could not only help screen people for early stages of the disease, but it could also allow doctor's to track the disease progression in patients and therapists to monitor the effectiveness of voice therapies without patients having to come into the clinic. This could save valuable resources and allow healthcare workers to have more frequent checkups on patient health remotely.' (P46)

2 (*continued*)

	Diagnosis and treatment	Administrative applications	Patient engagement and empowerment
Job demands	'"We are facing the greatest opportunity in healthcare and medicine in many generations, which is the gift of time, afforded by being able to rely much more on machines to process data," Topol said. "But if physicians don't band together to support the changes they want, the extra time they get from implementing tech solutions will end up being used by healthcare administrators to increase throughput and make doctors' day-to-day jobs even more stressful and less human-centered."' [71]	'"Doctors are spending an hour on the computer for every hour we spend with patients," Verghese said. "Electronic medical records have been the source of more distress than any other invention that's happened in modern medicine. It's like physicians have been demoted to data clerks."' [71]'Doctors are drowning in paperwork, which hogs their precious time with patients. Educating the current physician workforce on AI technologies that increase efficiency and improve workflow could cut burnout rate.' [33]	N/A