Title
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Journal
The Journal of Arthroplasty, 35(7)

ISSN
0883-5403

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Publication Date
2020-07-01

DOI
10.1016/j.arth.2020.04.048

Peer reviewed

The Journal of Arthroplasty xxx (2020) 1–6

Contents lists available at ScienceDirect

The Journal of Arthroplasty

journal homepage: www.arthroplastyjournal.org

Digital Orthopaedics: A Glimpse Into the Future in the Midst of a Pandemic

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ARTICLE INFO

Article history:
Received 16 April 2020
Received in revised form 17 April 2020
Accepted 17 April 2020
Available online xxx

Keywords:
digital orthopaedics
telehealth
covid-19
digital health
virtual visits
future

ABSTRACT

Background: The response to COVID-19 catalyzed the adoption and integration of digital health tools into the health care delivery model for musculoskeletal patients. The change, suspension, or relaxation of Medicare and federal guidelines enabled the rapid implementation of these technologies. The expansion of payment models for virtual care facilitated its rapid adoption. The authors aim to provide several examples of digital health solutions utilized to manage orthopedic patients during the pandemic and discuss what features of these technologies are likely to continue to provide value to patients and clinicians following its resolution.

Conclusion: The widespread adoption of new technologies enabling providers to care for patients remotely has the potential to permanently change the expectations of all stakeholders about the way care is provided in orthopedics. The new era of Digital Orthopaedics will see a gradual and nondisruptive integration of technologies that support the patient's journey through the successful management of their musculoskeletal disease.

Background

The COVID-19 pandemic is placing a massive strain on the ability to deliver care to patients with musculoskeletal complaints. In the world of hip and knee arthroplasty, which generally cares for an older population with a number of comorbidities, patients are being asked to delay interventions until hospitals are safe for elective surgery.

Care delivery models based on the in-person visit are therefore not able to meet patient needs in the context of "stay-at-home measures" and "social distancing". Conversely, digital health tools have been particularly useful in the response to COVID-19 because they enable care to be delivered at a distance. It is important to note therefore that the class of tools and applications generally termed "Digital Health" may change the paradigm of how we deliver care

One or more of the authors of this paper have disclosed potential or pertinent conflicts of interest, which may include receipt of payment, either direct or indirect, institutional support, or association with an entity in the biomedical field which may be perceived to have potential conflict of interest with this work. For full disclosure statements refer to https://doi.org/10.1016/j.arth.2020.04.048.

Disclosure: The views expressed in this article are those of the authors and do not necessarily reflect the official policy or position of the Department of the Navy, Department of the Army, Department of Defense, nor the US Government. Nothing in the presentation implies any Federal/Department of Defense/Department of the Navy endorsement.

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https://doi.org/10.1016/j.arth.2020.04.048
0883-5403/© 2020 Published by Elsevier Inc.

but does not change the care we deliver. For example, whether an exercise for knee strengthening is proposed by a therapist or an avatar does not change the nature of the exercise itself. This is an important distinction as these technologies are designed to enable and simplify the delivery of care, not to change the actual treatments we provide patients. They are each designed as solving a pain point somewhere along the analog patient journey. Their business models depend on it. Digital health tools can track and backfill surgery cancellations, free doctors from taking notes during virtual visits, identify patients at risk for treatment failure, triage patient questions to decompress human phone banks, refresh surgical skills and procedures virtually, track and manage patient recovery at home, and print equipment that is not otherwise available among a litany of functions that focus on enabling better care delivery. These technologies aim to support patients along their health care journey and help, and not replace, providers.

Contrary to the claims by most startups seeking funding in Silicon Valley, digital adoption does not have to be disruptive. New technologies require new skill sets and, unfortunately, many perceive their adoption as threatening their livelihood or their inherent value to the system. Although such a point of view may be common, it is wide of the mark. In a recent article in Harvard Business Review [1], the authors made several salient points regarding the topic of the perceived disruptive nature of digitalization. They point out that the adoption of new technology does not require the wholesale disruption of the current value proposition of a practice or hospital, but rather the implementation of digital tools enables the same institution to better serve its patients; they emphasize that digital will not replace physical, but rather augment it. They underscore that digitalization does not require a painful overhaul of legacy systems but rather a focus on incremental bridging from one set of technologies to another. We acknowledge at the outset that the wholesale transition to electronic health records (EHRs) was painful and expensive. Many physicians resent the amount of data entry required. On the upside, the EHR adoption in the United States is around 95% and the digital infrastructure that supports it does allow for an ecosystem of products to connect to each other through middleware applications that sit as intermediaries between the EHR and more useful applications. During the pandemic, we have seen how digital solutions can improve patient care by complementing standard analog care models.

Critical to this success was the fact that the federal government and the Center for Medicaid and Medicaid Services quickly implemented new payment models supporting the use of virtual care platforms. Medicare adopted equivalency payment models for tele and in-person care, voided the need for the existence of a prior patient-physician relationship to pay claims for telehealth visits, state medical licensure requirements were waived, and Health Insurance Portability and Accountability Act rules were relaxed allowing televisits to be performed via regular phones and commonly used social media applications. While these restrictions will be relaxed only for the duration of the pandemic, it is likely that many will not be fully reinstated. As a result, Telehealth, Digital Health and mHealth (mobile health) companies have all seen a marked uptick in adoption of their services as health care providers seek to use digital tools to care for patients sheltering at home.

The goal of this communication is therefore to describe technologies that have been particularly helpful in the orthopedic response to COVID-19 and that the authors believe will remain relevant to the musculoskeletal community even after the end of the pandemic.

Telemedicine Platforms

Telemedicine platforms are the backbone of virtual care and quickly became an invaluable resource for health care systems responding to the COVID-19 pandemic. They enabled not only more efficient triage of the increasing volume of possible COVID-19 patients but did so while importantly protecting our health care providers and complying with “social distancing.” In addition, telemedicine served as a tool for specialty providers to help offload primary care providers, urgent care clinics, and emergency departments of other acute and chronic issues that could be managed without their involvement. This allowed primary care and emergency room providers to focus on the higher acuity COVID-19 patients as well as prevent overcrowding of their facilities. The realities that enabled the ease with which the transition to virtual care took place in the United States are multifactorial but can be broadly categorized into three buckets. First, the infrastructure for telemedicine was readily available in the United States as digitized clinical records could be accessed remotely through secure portals. Second, new state and federal regulatory guidelines removed the last enduring barriers to the widespread adoption of telehealth platforms by changing the payment models. Third, the venture capital invested into telemedicine startups over the past decade has enabled a ready, able, and vibrant ecosystem to exist. As reported by Mobile Health News, the amount of capital invested in digital health in the first half of 2019 alone was over $1.5 billion and capped many years of progressively increasing funding for the sector.

Virtual and Digital Scribes

COVID-19 led to the nearly overnight end of clinic visits and a rapid rise in virtual care with many practices going from 1%-2% of all visits being online to nearly 100%. In-person scribe services were already common in clinics where the administrative burden of documentation was perceived to be untenable. Many practices had to quickly pivot from the in-person scribe model to utilizing virtual scribes on telehealth platforms. These virtual scribes, like their in-person counterparts, can document visits in the EHR and free the provider to engage with the patient on the online portal. The virtual scribes log into the visit and have access to everything the clinician sees and hears. Digital scribes are joining the party as well. Virtual digital scribes are software programs that take advantage of the rapid advances in the branch of artificial intelligence (AI) devoted to voice recognition. Coupled to complex ontologies trained on hundreds of thousands of medical articles, these algorithms can listen to a natural conversation between the patient and the clinician and create the equivalent of a clinical note, place it in the chart, and even provide an evaluation of the note for billing. Simpler programs can take and transcribe a dictation.

As virtual digital scribes become further integrated into telehealth platforms, they will be able to support clinicians working from home seeing patients without their support staff. Although randomized control trials have shown that access to scribes can decrease charting time and increase physician satisfaction [2], little is known about the impact of digital scribes on patient or decreasing physician burnout. Their increased adoption in busy clinics and Emergency Departments has, however, been noted by companies in the space and while still in their formative years, the potential of these companies should not be underestimated.

Chatbots

Chatbots can triage calls freeing staff to focus on more complex problems. What makes chatbots different is that they use AI to not only understand the question being posed in “natural” language, but also to select the corresponding answer from a selection of options. For example, if a patient asks about a “headache”, “pain between the ears”, or “throbbing in the head”, the chatbot understands all three to be referring to a headache. It can then ask further questions before providing an appropriate answer, recommend an appointment, or triage the patient to a provider. These tools are excellent for screening patients for symptoms, checking on medication adherence, or to follow up on symptoms, and can be based either on text, voice, or email [3].

At the earliest signs of the current pandemic, the World Health Organization quickly set up a chatbot screener for COVID-19 symptoms. Similar tools were quickly implemented in Seattle to help local government track the spread of the virus. Jefferson Health's telemedicine system successfully used chatbots to triage patients without the need for in-person care. The University of California San Francisco designed and deployed an employee screening chatbot that decreased hospital entrance times from 30 minutes to less than one minute. There are many companies currently offering chatbot services to manage everything from patient scheduling to collecting patient-reported outcomes. The success of chatbots during the COVID-19 response and the fact that many are now active and integrated into numerous health care system's informatics infrastructure, suggests that their use will expand following the resolution of the pandemic.

Virtual Physical Therapy and Telerehabilitation

The COVID-19 pandemic has resulted in the need for "social distancing," avoiding in-person contact and crowded, enclosed places. The traditional care model for recovery after hip and knee arthroplasty involves intensive in-home physical therapy (PT) and/or in-person outpatient therapy. The need to maintain "social distancing" coupled with the previously mentioned payment reforms have led to a surge in the availability of both telehealth PT options from PT providers as well as virtual PT delivered by avatars. For many patients, both of these options provide customized PT in the comfort of a patient's home at a lower cost, thus establishing a more adaptable and equally effective PT pathway than traditional in-person PT.

Bettger et al performed a prospective, randomized trial of an avatar-based virtual PT program for patients after unilateral TKA and compared clinical and economic outcomes for their patients. They found that compared with traditional in-home or clinic-based PT, avatar-based virtual PT significantly decreased 3-month associated health-related costs while providing equivalent clinical outcomes. They stressed the importance of appropriate clinical oversight of any truly virtual PT program to ensure patients progress appropriately. This oversight can be provided by a physical therapist, physician, or physician extender [4].

Fisher et al described a physical therapist–based telehealth navigation platform that included not only telehealth visits with a live physical therapist, but also care navigation with a nurse practitioner that was available to perform real-time assessments in the postoperative period after joint arthroplasty. They noted a significant cost savings associated with this telehealth care navigation platform compared with their standard pathway, the avoidance of in-person evaluations for minor postoperative concerns, and an absence of readmissions in their telerehabilitation group [5].

Data Science

The COVID-19 pandemic has elevated the importance of data, data science, and data-driven decision-making to the forefront of medicine and national policy as leaders have struggled to make important life and death decisions because of a lack of high-quality data to guide them [6]. For those with expertise in data science, the COVID-19 pandemic has been nothing short of humbling. Three anecdotes that bring important data-related learnings to light are listed in the following.

First, COVID-19 has shown that data quality is of supreme importance in the context of predictive analytics. When there is a paucity of reliable data, no amount of technology will provide the insights needed for good decision-making. For example, no piece of data would have been more important or valuable in this pandemic than the accurate, up-to-date number of COVID-19 cases in the country, ideally broken down by geographic region. Yet, an accurate count of COVID-19 cases has not been available making forecasting the spread of the pandemic particularly difficult [7]. The lack of this seemingly rudimentary data point (the number of new cases over time) further made machine learning and AI, both much touted technologies of our day, powerless. This evolving story drives home the point that data is king, and that getting accurate, unbiased data in real time is paramount and that in the absence of accurate and sufficient data predictive models are, at best, an educated guess.

Second, "flattening the curve" is a text-book example of how a data-driven approach from epidemiology can be successfully implemented and translated into effective policies that not only change behavior but, when heeded, can save thousands of lives. Flattening the curve means spreading out new cases over time so that the health system is not overwhelmed, and the affected population buys time to ramp up testing and develop vaccines and treatments. During that window, the system can provide more and better data to optimize the models and inform decisions to fight and manage the pandemic [8]. The elegance of the phrase, "flattening the curve" is difficult to overstate. It has proven to be a life-saving concept that was born in data and then successfully packaged into a simple phrase and infographic that concisely explained what the problem was to decision makers and the general public alike. It lent credence and context to the phrases that explained what to do about the problem (e.g., "social distancing" and "shelter in place") and their impact. The story of this data-derived insight turned public-health meme is still unfolding but may truly go down as one of the great public health triumphs of our day. One moral of the story is the importance of taking our data-derived insights across the "finish line". Data, technology, and a good analysis alone do not go far enough: we must make the data do something by translating insights into effective policies that induce behavior change if we are to achieve the desired outcome. This will be true as we apply data science to orthopedics in the future as well.

Third, there are faint glimmers of the potential impact of machine learning on basic science in the efforts to find treatments and a vaccine for COVID-19. In general, machine learning–based approaches are helping scientists to target their efforts to those areas most likely to meet with success as opposed to squandering time on experiments that are less likely to be fruitful. For example, machine learning has helped scientists predict chemical properties of drugs and proteins [9], predict vaccine immunogenicity [10], identify promising drug targets [11], and even identify existing drugs that have the potential to be repurposed for use against other pathogens [12]. It remains to be seen if these advancements will be successfully applied to the discovery of treatments and a vaccine for SARS-CoV-2, the virus that causes COVID-19. The exciting potential of machine learning is perhaps best exemplified by AlphaFold, a machine learning–based system that has demonstrated a remarkable ability to predict the 3D structure of proteins based solely on genetic sequence [13]. Understanding how these proteins "fold" allows scientists to design drugs that recognize and target those unique antigens. The AlphaFold group has already released the predicted structures of several understudied proteins associated with SARS-CoV-2 in hopes that these structural predictions will contribute to the scientific community's understanding of how the virus functions and serve as a starting point for future experimental work aimed at developing therapeutics [14].

Wearable Sensor Devices

Smartwatches and fitness trackers are receiving a lot of attention in the current COVID-19 pandemic as a consumer-level technology that aids early diagnosis of viral infections. Sensors have been used to track fluctuations in heart rate during sleep and to provide population-level data to determine if measures to contain the novel coronavirus pandemic were effective. In the height of the COVID-19 outbreak in Shanghai, China, and Veneto, Italy, wearable sensors were utilized to monitor COVID-19–positive patients at home to free up scarce hospital resources.

Wearable sensor devices (WSDs) may play a significant role in the emerging age of Digital Orthopaedics. WSDs typically include accelerometer, gyroscope, and global positioning sensors that can track position, movement, acceleration and vital signs such as temperature and heart rate. WSDs have potential to promote a healthy lifestyle and improve patient engagement. Furthermore, they can provide remote postoperative monitoring, help predict postoperative outcomes, collect patient-reported outcome measures, facilitate gait and motion analysis, and inform return–to-sports decisions. In one study, a 1000-step daily goal for ambulation in the early postoperative period was associated with lower probability of prolonged length of stay after major surgery [15].

Smartwatches and fitness trackers increase patient involvement in their care by providing real-time feedback. This has been shown to be effective in obesity/metabolic syndrome management using telemonitoring-supported exercise training with fitness trackers [16]. Innovative tracking devices are available that can be worn around operated or diseased joints to enable continuous monitoring of activity data—including range of motion, ambulation, exercise compliance, and wound-site temperature trends. These noninvasive connected trackers enable the surgeon to remotely evaluate real-time data on a patient's postoperative progress.

Real-time data collection using smartwatches as ecological momentary assessment tools have been used in elderly patients with arthritis to monitor their patient-reported outcomes, pain levels, and postoperative symptoms [17]. In addition, real-time objective physical activity data obtained from WSDs is a more objective measurement than self-reported data for physical activity, which is subject to significant bias. Smartwatches are highly portable and can be leveraged as an excellent medium for continuous data collection.

Sensors in smartwatches can be used to extract the three main parameters of gait: step length, swing time, and stance time [18]. This quantitative gait analysis has important implications in orthopedic practice for the diagnosis of a variety of musculoskeletal issues such as concussion/collision impact and motion analysis in sporting activities such as pitching a baseball and detecting differences in motion that predispose patients for graft rupture following ACL reconstruction [19]. Such data can be utilized for making safe return-to-sports decisions. While data collection and in particular the ability to accurately predict outcomes is still in its infancy, it is clear that, as in COVID-19 response, there are many opportunities to use consumer-grade sensors in orthopedic care.

Surgical Scheduling Applications

Surgical scheduling platforms simplify the complexity of canceling and rebooking procedures. As the "curves begin to flatten" and surgeons are given the green light to proceed with elective surgeries, they may be overwhelmed by the task of rescheduling these procedures. This daunting task may be difficult to tackle with a notebook full of names, an EHR calendar not designed for this purpose, fewer staff due to COVID-19–related requirements or staff reductions, concerned patients, and the complexity of obtaining authorizations. Some surgeons may use the current crisis as an opportunity to implement surgery scheduling platforms to streamline the rescheduling process and modernize their practice with tools that can connect multiple hospitals, implant representatives, preoperative screening clinics, and third-party payers through a single platform that can also provide analytics such as utilization metrics, backlog analysis, and cancellation mitigation tools.

All interested parties are connected to the same scheduling-based platform and the platform can connect to nearly all EHRs, thanks to the wide and government required implementation of Fast HealthCare Interoperability Resource standards to assist with data sharing between EHRs and patients or providers. Some of these platforms can assist in rescheduling by using AI algorithms to identify which patients are available to fill a cancellation or triage patients by level of care to surface the most urgent. All key players are kept informed in real time of the schedule, most notably the patient. The goal is to keep patients engaged in the process through direct communication while minimizing the work burden placed on the surgeon and their support staff.

Integration can be accomplished in as little as a few days to a few weeks depending on the complexity of the EHR integration. Implementation and staff education can be performed and scaled remotely. When surgeons are able to resume elective surgeries, a scheduling-based platform may be invaluable to practices trying to reboot their surgical workflow.

Virtual and Augmented Reality

Virtual reality (VR) is a rapidly growing technology with potential applications across the episode of care for hip and knee arthroplasty. VR provides users with immersive, interactive experiences in computer-generated environments through the use of a headset and body motion sensors and typically, hand controllers, in the current generation of commercially available platforms. VR and AR can deliver sophisticated simulations and immersive environments for remote PT and surgical training. VR has shown benefits in resident training in multiple orthopedic subspecialties. In a recent study, Logishetty et al. demonstrated several benefits of VR for surgical resident training for direct anterior approach total hip arthroplasty on cadaveric specimens. Trainees exposed to VR training demonstrated less need for guidance or intervention, more accurate component orientation, and were faster surgeons than the non-VR group [20]. A follow-up study by the same group demonstrated reduction of surgical errors and improvement in efficiency of movement in the operating room compared with a baseline assessment after only 4-5 hours of VR training [21]. The latest versions of these platforms allow collaborative modes, where surgical teams can practice procedures together online without physically being in the same location. With elective orthopedic surgical procedures on hold during the COVID-19 pandemic, VR may provide trainees, surgeons, and even surgical assistants an avenue to learn and maintain proficient surgical skills, all at an acceptable social distance.

VR may also be utilized for remote delivery of PT in patients with hip and knee arthritis, as well as for perioperative PT. These platforms enable surgeons and physical therapists to remotely prescribe and monitor patient-specific programs for rehab that can be performed in the comfort of the patient's home. A systematic review and meta-analysis demonstrated no difference between traditional PT and VR PT for multiple orthopedic diagnoses in terms of function and pain [22]. Similarly, an RCT focused on the use of VR PT after TKA demonstrated noninferiority of VR PT to traditional PT in terms of pain, strength, and range of motion [23]. Although the cost effectiveness of VR-based PT compared with traditional in-person PT is yet to be determined, VR PT may have an important role in providing hip and knee arthroplasty patients PT remotely during and after the COVID-19 pandemic.

Patient Engagement Platforms

Patient engagement platforms (PEPs) provide both patients and physicians a means to interact and to facilitate longitudinal care. The utility of these software applications is in channeling and engaging a patient's skills, desires, and knowledge to promote positive health outcomes [24].

Patient engagement increases a patient's willingness to participate in care and is associated with improved patient interactions, decreased cost, emergency visits, and hospitalization [24–26]. PEPs have been utilized to facilitate care in various aspects of medicine, including smoking cessation and diabetes management [27,28]. The potential for PEPs in orthopedics to expand during and after the current pandemic is high. Patients whose elective surgeries were postponed are likely to experience an extended period of nonoperative management. PEPs can provide educational resources and targeting at-home therapeutic alternatives proactively updating patients regarding changes in clinic services, surgical schedules, or COVID-19–related policies. PEPs have been shown to provide a meaningful connection between the patients and the provider's team [29,30], have demonstrated utility in collecting patient-reported outcome measures, and save time for providers during telemedicine encounters [31,32].

PEPs provide a convenient modality for rapid wound assessment through image sharing and expedite the modification of treatment plans for concerning wounds [29,30].

With the onset of the COVID-19 crisis, practices with PEPs already deployed were able to use them to quickly and efficiently deploy alternate treatment pathways for patients whose surgery was canceled or pending. Other systems enrolled the patients retroactively and used the platforms to rapidly share information and answer questions to patients stranded at home.

3D-Printing Technologies

As the COVID-19 pandemic spread across the United States, it became evident that areas affected by an outbreak of coronavirus would stress the supply chains for many devices and tools required for a functioning health care system. Government regulators endorsed strategies for conservation of limited resources and the FDA relaxed import restrictions to allow equipment not approved by the National Institute for Occupational Safety and Health to be used in health care settings [33].

Across the globe, engineers and hobbyists with access to additive manufacturing platforms ("3D printers") rushed forward with innovative solutions to help mitigate some of the equipment shortfalls. Designs for the manufacture of masks, face shields, and ventilator splitters were made available online through the National Institute of Health 3D Print Exchange [34]. Many community projects worked to provide personal protective equipment to frontline health care and other essential workers without adequate access to personal protective equipment. These grassroots volunteer campaigns organized to manufacture masks and face shields in their homes or businesses and distributed them widely at no cost in settings ranging from grocery stores to large hospital systems [35]. Additive manufacturing has also been utilized to produce other complex components during this crisis. When the original supplier for a connector valve for a ventilator in use at an Italian hospital was unable to meet the sudden increase in demand, a local engineering firm was able to produce 100 of the components utilizing 3D printers within 24 hours [36]. A multidisciplinary team is testing a novel design for a ventilator splitter that may allow paired patients to be ventilated by one machine [37].

Additive manufacturing has been utilized in the last decade by the orthopedic implant industry to manufacture implantable components fundamentally altering the engineering and manufacturing constraints for these devices [38]. The COVID-19 crisis has increased awareness of the potential to use this manufacturing technology in orthopedics.

Conclusion

COVID-19 has challenged the health care system in ways that will reverberate for years to come. The orthopedic community has risen to the challenge of caring for patients sheltering in place by exploring and adopting a set of digital health technologies that have extended the community's ability to triage and deliver care in the most appropriate venue, whether that be at home, the clinic, or the hospital. We believe that many of the technologies presented in this communication will prove to be useful at simplifying or addressing pain points that exist in current care models. It can be argued that the pandemic has afforded us a glimpse into a future where clinical orthopedics partners with digital health solutions to create a hybrid: digital orthopedics. As we look forward to the end of the pandemic, it is likely that we will emerge to find a care delivery model that is fundamentally and permanently changed.

References

[1] Furr N, Shipilov A, et al. Digital Doesn't Have to Be Disruptive. The best results come from adaptation rather than reinvention. Harvard Business Review July August (2017): 94-103. https://hbr.org/2019/07/digital-doesnt-have-to-be-disruptive.
[2] Gidwani R, Nguyen C, Kofoed A, Carragee C, Rydel T, Nelligan I, et al. Impact of scribes on physician satisfaction, patient satisfaction, and charting efficiency: a randomized controlled trial. Ann Fam Med 2017;15:427.
[3] Bibault JE, Chaix B, Nectoux P, Pienkowsky A, Guillemasse A, Brouard B. Healthcare ex Machina: are conversational agents ready for prime time in oncology? Clin Trans Radiat Oncol 2019;16:55–9.
[4] Bettger JP, Green CL, Holmes DN, Chokshi A, Mather III RC, Hoch BT, et al. Effects of virtual exercise rehabilitation in-home therapy compared with traditional care after total knee arthroplasty: VERITAS, a randomized controlled trial. J Bone Joint Surg Am 2020;102:101–9.
[5] Fisher C, Biehl E, Titmuss MP, Schwartz R, Gantha CS. HSS@ home, physical therapist-led telehealth care navigation for arthroplasty patients: a retrospective case series. HSS J 2019;15:226–33.
[6] Ioannidis JP. A fiasco in the making? As the coronavirus pandemic takes hold, we are making decisions without reliable data. Stat 2020:17.
[7] Shear MD, Goodnough A, Kaplan S, Fink S, Thomas K, Weiland N. The lost month: how a failure to test blinded the US to Covid-19. New York, NY: The New York Times; 2020. p. 1.
[8] Markel H. Flattening the curve for COVID-19:Expert Howard Markel Weighs. https://ihpi.umich.edu/news/flattening-curve-covid-19-expert-howard-markel-weighs; 2020 [accessed 15.04.20].
[9] Baker N, Alexander F, Bremer T, Hagberg A, Kevrekidis Y, Najm H, et al. Workshop report on basic research needs for scientific machine learning: Core technologies for artificial intelligence. Washington, DC: USDOE Office of Science (SC); 2019.
[10] Gonzalez-Dias P, Lee EK, Sorgi S, de Lima DS, Urbanski AH, Silveira EL, et al. Methods for predicting vaccine immunogenicity and reactogenicity. Hum Vaccin Immunother 2020;16:269–76.
[11] Zhang W, Lin W, Zhang D, Wang S, Shi J, Niu Y. Recent advances in the machine learning-based drug-target interaction prediction. Curr Drug Metab 2019;20:194–202.
[12] Zhao K, So HC. Using drug expression profiles and machine learning approach for drug repurposing. In: Computational methods for drug repurposing. New York, NY: Humana Press; 2019. p. 219–37.
[13] Senior AW, Evans R, Jumper J, Kirkpatrick J, Sifre L, Green T, et al. Improved protein structure prediction using potentials from deep learning. Nature 2020;15:1–5.
[14] Jumper J, Tunyasuvunakool K, Kohli P, Hassabis D, the AlphaFold Team. Computational predictions of protein structures associated with COVID-19. https://deepmind.com/research/open-source/computational-predictions-of-protein-structures-associated-with-COVID-19; 2020 [accessed 15.04.20].
[15] Daskivich TJ, Houman J, Lopez M, Luu M, Fleshner P, Zaghiyan K, et al. Association of wearable activity monitors with assessment of daily ambulation and length of stay among patients undergoing major surgery. JAMA Netw Open 2019;2:e187673.

[16] Haufe S, Kerling A, Protte G, Bayerle P, Stenner HT, Rolff S, et al. Telemonitoring-supported exercise training, metabolic syndrome severity, and work ability in company employees: a randomized controlled trial. Lancet Public Health 2019;4:e343–52.
[17] Manini TM, Mendoza T, Battula M, Davoudi A, Kheirkhahan M, Young ME, et al. Perception of older adults toward smartwatch technology for assessing pain and related patient-reported outcomes: pilot study. JMIR Mhealth Uhealth 2019;7:e10044.
[18] Erdem NS, Ersoy C, Tunca C. Gait analysis using smartwatches. 2019 IEEE 30th International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC Workshops) (pp. 1-6). IEEE. 2019.
[19] Dan MJ, Lun KK, Dan L, Efird J, Pelletier M, Broe D, et al. Wearable inertial sensors and pressure MAT detect risk factors associated with ACL graft failure that are not possible with traditional return to sport assessments. BMJ Open Sport Exerc Med 2019;5:e000557.
[20] Logishetty K, Rudran B, Cobb JP. Virtual reality training improves trainee performance in total hip arthroplasty: a randomized controlled trial. Bone Joint J 2019;101:1585–92.
[21] Logishetty K, Gofton WT, Rudran B, Beaulé PE, Cobb JP. Fully immersive virtual reality for total hip arthroplasty: objective measurement of skills and transfer of visuospatial performance after a competency-based simulation curriculum. J Bone Joint Surg Am 2020;102:e27.
[22] Gumaa M, Rehan Youssef A. Is virtual reality effective in orthopedic rehabilitation? A systematic review and meta-analysis. Phys Ther 2019;99:1304–25.
[23] Gianola S, Stucovitz E, Castellini G, Mascali M, Vanni F, Tramacere I, et al. Effects of early virtual reality-based rehabilitation in patients with total knee arthroplasty: a randomized controlled trial. Medicine 2020;99:e19136.
[24] Hibbard JH, Greene J. What the evidence shows about patient activation: better health outcomes and care experiences; fewer data on costs. Health Aff 2013;32:207–14.
[25] Greene J, Hibbard JH. Why does patient activation matter? An examination of the relationships between patient activation and health-related outcomes. J Gen Intern Med 2012;27:520–6.
[26] Begum N, Donald M, Ozolins IZ, Dower J. Hospital admissions, emergency department utilisation and patient activation for self-management among people with diabetes. Diabetes Res Clin Pract 2011;93:260–7.
[27] Obermayer JL, Riley WT, Asif O, Jean-Mary J. College smoking-cessation using cell phone text messaging. J Am Coll Health 2004;53:71–8.
[28] Holtz B, Lauckner C. Diabetes management via mobile phones: a systematic review. Telemed J E Health 2012;18:175–84.
[29] Pérez F, Montón E, Nodal MJ, Viñoles J, Guillen S, Traver V. Evaluation of a mobile health system for supporting postoperative patients following day surgery. J Telemed Telecare 2006;12(suppl):41–3.
[30] Sosa A, Heineman N, Thomas K, Tang K, Feinstein M, Martin MY, et al. Improving patient health engagement with mobile texting: a pilot study in the head and neck postoperative setting. Head Neck 2017;39:988–95.
[31] Cook DJ, Manning DM, Holland DE, Prinsen SK, Rudzik SD, Roger VL, et al. Patient engagement and reported outcomes in surgical recovery: effectiveness of an e-health platform. J Am Coll Surg 2013;217:648–55.
[32] Bell K, Warnick E, Nicholson K, Ulcoq S, Kim SJ, Schroeder GD, et al. Patient adoption and utilization of a web-based and mobile-based portal for collecting outcomes after elective orthopedic surgery. Am J Med Qual 2018;33:649–56.
[33] FDA.gov. FAQs on shortages of surgical masks and gowns. https://www.fda.gov/medical-devices/personal-protective-equipment-infection-control/faqs-shortages-surgical-masks-and-gowns; 2020 [accessed 15.04.20].
[34] NIH.gov. NIH 3D print Exchange. https://3dprint.nih.gov/discover; 2020 [accessed 15.04.20].
[35] Nafso M. Fenton man producing COVID-19 protective gear amid supply shortage. https://www.abc12.com/content/news/Fenton-man-producing-COVID-19-protective-gear-amid-supply-shortage-569242091.html; 2020 [accessed 15.04.20].
[36] Petch M. 3D printing community responds to COVID-19 and coronavirus resources. https://3dprintingindustry.com/news/3d-printing-community-responds-to-covid-19-and-coronavirus-resources-169143/; 2020 [accessed 15.04.20].
[37] Graham C. Johns Hopkins engineers develop 3D-printed ventilator splitters. https://hub.jhu.edu/2020/04/02/3d-printed-ventilator-splitters-for-covid-19/; 2020 [accessed 15.04.20].
[38] Sing SL, An J, Yeong WY, Wiria FE. Laser and electron-beam powder-bed additive manufacturing of metallic implants: a review on processes, materials and designs. J Orthop Res 2016;34:369–85.