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INSTRUCTIONAL LECTURE: GENERAL ORTHOPAEDICS | 8:5 | 283–290

Best practice in digital orthopaedics

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- Digitization in orthopaedics and traumatology is an enormously fast-evolving field with numerous players and stakeholders. It will be of utmost importance that the different groups of technologists, users, patients, and actors in the healthcare systems learn to communicate in a language with a common basis.
- Understanding the requirements of technologies, the potentials of digital application, their interplay, and the combined aim to improve health of patients, would lead to an extraordinary chance to improve health care.
- Patients' expectations and surgeons’ capacities to use digital technologies must be transparent and accepted by both sides.
- The management of big data needs tremendous care as well as concepts for the ethics in handling data and technologies have to be established while also considering the impact of withholding or delaying benefits thereof.
- This review focuses on the available technologies such as Apps, wearables, robotics, artificial intelligence, virtual and augmented reality, smart implants, and telemedicine.
- It will be necessary to closely follow the future developments and carefully pay attention to ethical aspects and transparency.

Keywords

- EFORT
- instructional lecture
- digital orthopaedics

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Introduction

Digitization has changed our lives with great impact in private milieus, professions, and thereby even transforming societies. This transformation process seems to have endless potentials; however, the possibilities and the speed of the change process also bear risks that have to be considered. In orthopaedics and traumatology, this technical evolution has taken place in various forms that may support medical decision processes, surgical procedures, ease of communication with and between patients and healthcare providers, and more.

In this transformation process, we need to adapt and to integrate various stakeholders, such as scientists, technologists, industry representatives, and politicians. It will be a great opportunity to act for the benefit of patients and healthcare professionals (surgeons, nurses, and physical therapists).

To date, the digitized solutions in orthopaedics and traumatology are mainly driven by the new digital technologies and methods to exploit data. Thus, this compact review is structured by the main digital technologies rather than organized by clinical applications to provide a clear framework for navigating all areas of digitization. Systems implemented for clinical use are considered innovative based on one main technology but usually combine several technologies such as for instance a virtual (digital) twin for preoperative planning where imaging techniques enhanced by artificial intelligence (AI) and virtual reality (VR) for visualization are combined.

The great advantages of digitization cannot be overseen at this time. With a focus on application rather than underlying technologies, such digital systems can e.g. facilitate doctor-to-patient or peer-to-peer communication, support diagnostics and decision-making, enable remote collaboration in interventions, or reduce the workload for healthcare professionals. Such tools and systems promise to provide time and capacity for personalized care over routine therapies, optimizing follow-up strategies, individualizing rehabilitation, improving and tailoring education and training, automating documentation, and answering research questions.

This manuscript can only provide a brief overview and try to summarize the nomenclature of digitization. It may guide the reader towards the main topics, terms, opportunities, trends, discussions, or controversies to clarify this transformation for the benefit of patients, colleagues, and the society. Digitization has started and will not stop to change our approaches to how we work, how we provide care, or how we work in basic research.

Therefore, we have to focus on the potentials of the various technologies, how their features may interact with the other, and if they may enable digital solutions in combination vs stand-alone techniques (1).

Apps

The term app broadly refers to a software application running on mobile devices such as smartphones, tablets, or smartwatches but also to so-called web apps working in browsers independent of the device type including their use on personal computers, smart televisions, or game consoles covering a wide range of usability requirements for patients or environments. Apps exclusively aimed at orthopaedic healthcare professionals mostly serve as digital information repositories to be available anywhere and anytime on the smartphone such as for examination techniques, classifying conditions such as fracture types, or referencing surgical approaches. Some professional apps facilitate storage and exchange with colleagues of clinical cases, including radiography, such as for example with the myAO app which also supports clinical portfolio documentation and online peer networking and discussion. There are also highly specialized apps for instance in order to support the identification of joint replacement implant types from photographed x-rays using machine learning (ML)-enabled computer vision to plan revision surgery.

Patient apps target or include the patient or digitize the communication with their surgeon or other healthcare professionals. A basic but effective functionality of so-called patient journey or care pathway apps is to host on their phones pre- and postoperative appointments, including calendar integration and alerts, patient-centred information (text, illustrations, and video) about the indicated surgery including instructions and reminders about correctly timed medications, nutrition, and preparations or behaviour before the procedure or during rehabilitation. This has shown the capacity to increase adherence to medication and therapy and improve outcomes and patient satisfaction (2). Some apps are focusing on patient education beyond a specific procedure but provide curated medical information, advice or exercise instructions for disease prevention, delay, management, and/or rehabilitation. When certain features are included for the patient to self-register pain events (pain diary), medications, events of fatigue, and flares or for setting goals, it is referred to also as a patient self-management app. Some of these apps also integrate patient messaging with the clinic, doctor, therapist, or a help desk. Compared to other disciplines, in the orthopaedic literature, evidence for efficacy of such apps is still scarce (3), but major trials are under way (4, 5).

Another stand-alone app feature that realizes the valuable ideas mentioned here is is patient self-assessment via pulling or pushing electronic versions of classic orthopaedic patient-reported outcome measures (PROM) questionnaires such as Knee Injury and Osteoarthritis Outcome Score (KOOS) or Oxford Hip Score (OHS). However, the digital environment facilitates alternative self-assessment formats such as computer adaptive testing, single-assessment numeric evaluation, or experience sampling methods, reducing the patient burden to answer lengthy questionnaires while increasing report frequency and adding new insights for remote patient monitoring or clinical research. Some health-related context may even be passively assessed such as screen time, app usage time, or geolocation if consented by the patients. Accessing the smartphone sensors enables further kinds of patient (self-) assessment such as movement tests or exercise repetition counters using the built-in inertial sensors or camera with computer vision or collecting voice-biomarkers from the microphone (6). On-screen games or tasks can assess cognitive capacity or hand/finger function. App connectivity to wearables, including consumer devices such as fitness trackers, allows to passively harvest data such as physical activity behaviour (e.g. steps, exercise, and calories) of interest when, e.g., monitoring rehabilitation.

Recognizing the large potential benefits of apps for patient self-management, some European countries have developed fast-track app certification and reimbursement procedures to enable deployment while still collecting direct evidence (7).

Wearables

The term wearables refers to sensors including electronics for signal processing, data storage, or connectivity which are body worn, directly on the skin, over, inside, or integrated into clothes, and measure data from its user or environment including health-related dimensions such as movement, heart rate, sleep, or exposure to, e.g., pollutants. So far, in orthopaedics, wearables have mainly been used to assess patient movement or activity, objectifying functional tests like gait during patient visits or monitoring physical activity behaviour like daily step counts in real life, mostly in research or remote monitoring of clinical outcomes (8, 9). The following, partially interdependent aspects can help to choose a wearable suitable for a desired use case. The (a) measurement domain refers to the heath-related dimension measured by the sensor and includes human movement (kinematics or kinetics to derive physical function and physical activity), muscle activity through electromyography, heart rate, respiration, sleep, geolocation, and more, all for which a clinical interest can be imagined, such as, e.g., pain-driven sleep disruptions. The (b) environment refers to settings such as a gait lab, a clinical examination room, a physiotherapy praxis (observed settings, can-do tests), a sports field or gym, a care home, or the real life (unobserved, does-do measures) which influence the optimal wearable choice, including usability aspects (f). The (c) measurement duration can be seconds (e.g. hop test in orthopaedic sports medicine), minutes (e.g. 6-min walk test), hours (e.g. therapy session and sports event), and waking hours or a full 24 h for one or several days, week(s), or continuously, including sporadically triggered functional tests at home (also 'guided routine'), all periods demanding specific compromises. The desired (d) clinical use scenario shall be considered because diagnostic use, outcome assessment, athletic performance measure, estimating injury risk, counting exercises, or monitoring therapy compliance define different opportunities and requirements. This extends to the (e) digital biometric parameter(s) desired such as for instance 'real-world walking speed' as validated disease-wide outcome measure or clinical trial endpoint (10) or 'lateral sway angle during sit-stand transfer' to support the specific diagnosis of, e.g., knee-related conditions like osteoarthritis (11). There are many (f) sensor modalities such as accelerometers, inertial measurement units (IMUs), piezo-resistive or capacitive sensors used in insoles capturing plantar pressure, barometers capable of resolving elevation changes in centimetre resolution, global positioning system (GPS) for geolocation including tracking athletes' positions on the pitch, and more with distinct advantages and disadvantages as well as complementary (sensor fusion) or redundant functionality. Regarding the (g) device type, it is helpful to differentiate between medical grade devices which are usually technically validated against a gold standard or consumer devices such as smartwatches or phones where clinical utility in orthopaedics is derived from application (8) while facilitating a so-called 'bring-your-own-device' approach reducing cost and usability hurdles to include patients. This relates to (h) usability in general where single, dual, or multiple sensor set-ups, the wear location (e.g. wrist, belt, shoe and pocket) size, weight, looks, battery life, charging needs, ease and robustness of placement must be taken into consideration. The aspect of (i) data processing refers to the need or capacity to perform real-time, delayed or post-processing, on-board, via a cloud-solution or offline, which define algorithmic complexity (e.g. ML) and flexibility but also data privacy, security, and ownership. In general, we have to consider the (j) user as doctors, patients, therapists, researchers, or other users have specific needs and capacity to apply and benefit from a wearable. This includes user-specific actionable data visualization for disease (self-) management via, e.g., a connected app.

Implantables

Implantables and smart implants are already in use in orthopaedic and trauma surgery (e.g. in total knee and hip arthroplasty, spine, and fracture surgery). The primary aim of this digital innovation is the improvement of patients' outcome in relation to post-surgery function as well as material changes in the long-term monitoring (12). The physical, biological, and chemical reactions integrated into the prosthetic and osteosynthesis implants may enable and provide these information. Moreover, major value is required for early noticing of implant failure or infections. This may be achieved through an interface bone–implant reaction that would be sent to a receiver after processing through a potential wireless communication (13). It may improve the diagnoses and reduce x-ray exposure by even potentially avoiding CT scans. However, there are further challenges that need to be addressed by further research and development in this area. Apart from developing inexpensive, revision-free sensors, the patients' daily activities must not be disturbed or influenced by the additional monitoring or clinician/surgeon–implant communication, either (13). Furthermore, the energy supply seems to be a serious problem to maintain function. The sensor must be compact to avoid relevant changes in the original architecture of the implant, but it still must be able to harvest and store energy or to provide a self-powering system (13). Hall *et al.* recently presented an *in vitro* trial to test an alternative for ultrasound-guided implant sensor that is able to detect loosening and temperature changes even though this technology does not expire (14). This leads to biocompatibility that is also an important aspect of implantables. Schaufler *et al.* reported a successful modification of the polyethylene (PE) inlay by total knee arthroplasty without electronics that is based on resonance frequency changes. It may contain a passive sensor which is compatible with an extracorporeal detector. This enables the early detection of inlay wear in case of decreasing thickness in relation to the femoral part (15). In addition, there are big concerns about smart implant failure and its possible cytotoxic, genotoxic, or pyrogenic effects directly in bone and soft tissue mostly in younger patients (13). At last, the collected data from sensors means an immense dimension of information. The storage and processing as well as privacy protection need to be settled before sensors are introduced for general use (16).

Robotics

In the 1990s, robotic technology was introduced in prosthetic surgery, with the aim of reducing possible surgeon mistakes and achieving more precise implant placement and more reproducible positioning. However, these initial autonomous or fully active systems were abandoned due to the occurrence of complications, high infection rate, and longer surgery time (17). Since the early 2000s, new semi-active surgeon-controlled robotic technologies have been introduced. Most part use haptic control –whereby the device used for reaming, broaching, or cutting is attached to a mechanical arm – is guided by the surgeon, but the machine provides haptic feedback in real time and does not allow for deviation from the limits that were set in preoperative planning. Planning can be done on the basis of preoperative digitized images and model creation (image based) or on the basis of intraoperative landmark acquisition alone (image less) (18). The rationale for these sophisticated devices is a more precise positioning and alignment in space of prosthetic components than conventional non-robotic techniques, including the possibility of personalized implant positioning that considers for example hip–spine relationships in total hip arthroplasty (19). Moreover, the acquisition of preoperative and intraoperative data could be used for research purposes, and robotic use can also be considered as a tool for education of surgeons in understanding implant positioning and biomechanics.

The everyday use of this technology is still controversial. Proven advantages include better and more precise positioning of prosthetic components and reduction of outliers and of intraoperative complications (20). Disadvantages include costs, increased operative time, pin-related complications, and learning curve (21, 22). However, whether the radiographic improvements will translate into clinical benefits for patients and better long-term implant survivorship remains unproven. Indeed, a network meta-analysis of randomized controlled trials showed a significant reduction of surgical time of manual total hip arthroplasty in comparison with computer navigation and robotics, and no differences were observed in the incidence of all-cause complications or revisions (23). Moreover, a recent systematic review and meta-analysis on RCTs about robotic assisted total knee arthroplasty (RATKA) and conventional total knee arthroplasty (CTKA) concluded that there is no clinically relevant difference in clinical outcomes between RATKA and CTKA, despite the fact that RATKA results in higher radiological accuracy, and the available evidence is inconclusive regarding revision and complication rates (24). Postoperative pain control is not reduced by the use of intraoperative technology (25). With regard to unicompartmetal knee arthroplasty (UKA), reduced postoperative pain, decreased opiate analgesia requirements, faster inpatient rehabilitation, and earlier time to hospital discharge have been reported in comparison with conventional manual UKA (26). Moreover, robotic UKA has been reported to be more cost effective than manual surgery when the number of cases exceeds 94 annually, and patient age is considered (27). Whether this is related to superior functional outcomes or improved implant survivorship anyway is not proven (28). For revision joint arthroplasty, current available evidence suggests that robotic assisted technology may help surgeons to reproducibly perform preoperative plans and accurately achieve operative targets. However, concerns remain regarding preoperative metal artefacts, registration techniques, closed software platforms, further bone loss after implant removal, and whether robotic assisted surgery will improve implant positioning and long-term survivorship.

At this time, RATKA is progressively increasing in daily clinical practice while technology is advancing. Selected high volume and experienced centres and the use for research and training purposes look to be the best current status (29) as further high-quality studies are needed to determine if this technology will translate into better outcomes and improved implant longevity to justify an extensive routine use.

Augmented reality/VR

VR and augmented reality (AR) are often discussed in a similar context; however, while VR involves an entirely computer-generated, simulated environment, AR involves superimposing computer-generated virtual elements onto real-world images (1). Many of the presented studies involving VR in the context of orthopaedic trauma surgery are focused on aspects of surgical training, allowing surgeons in training to practice different aspects of the surgical treatment process (preoperative planning, surgical techniques, and implant-related topics) in a virtual environment (30). In addition, VR has been used for patient education, gait training, as well as fall prevention (30). AR technology has been developed to support surgeons in performing surgical procedures by allowing them to visualize and integrate additional data, such as anatomical landmarks, clinical imaging, navigation-related information (i.e. hardware placement and screw trajectories), and other relevant information directly in their field of view (31). The common workflow to date is that models are constructed from preoperatively obtained imaging data, while intraoperatively a camera registers the surgical field, processes these data, tracks relevant structures, and then overlays the model and related information on a display to the surgeon . Tracking and accurate alignment of the digital information on the real-world image is currently mostly based on visual, external markers, with real-world patterns tracked for reference purposes (32). In the future, IMU and sensor-based tracking through the head-mounted display could potentially resolve the need for external markers during routine use (33). The common way to display is a head-mounted feature usually in the form of glasses or lenses. Currently, high-quality evidence for clinical implementation of AR technology in the orthopaedic surgery operating room and treatment process is lacking; however, growing literature highlights a multitude of potential applications, including increasing operative accuracy, improved biomechanical angular and alignment parameters, and potentially reduced operative time (31). Potential applications for these technologies thus lie in the fields of not only arthroplasty, trauma, and osteotomies but also oncological surgery. The technology has the potential to reduce risk, enable remote surgery and surgical assistance, increase surgical precision, and ultimately improve the patient care we deliver (1, 31).

Telemedicine

The barrier-free medicine also enters and revolutionizes the orthopaedic field. It started with already established mobile developments of scheduling medical appointments through teleconsultation and further up to remote surgery. These solutions show great satisfaction and require cooperation of both user/clinician and patients (34). Due to – but not only – the pandemic situation, the number of teleconsultation increases. The main cause remains cost reduction but also shortage of qualified staff in outpatient care. Telemedicine enables better and faster access to the professional and outpatient care (16, 35).

There are already studies that declare high patients' satisfaction and good clinical outcome by offering the possibility of easier communication and simpler access to the health status update (36). Chadhry *et al.* did not report any difference of patients' socio-economical status and self-security in their meta-analysis (37). However, there was no evidence with respect to false or missed diagnosis. It is certainly crucial to collect these data in further studies. On the other hand, there is still a large number of patients who prefer traditional visits and who view the consults via PC as quite controversial (35). Yamaguchi *et al.* analysed ethical and legal aspects of tele-orthopaedics. As a conclusion, there are doubtless advantages such as reduced travelling and waiting time and opportunity for professional help for disabled or immobilized patients. On the other hand, there are some limitations such as technical equipment or internet access (38). In some studies, concerns were also reported about the risk of losing privacy and confidentiality in both clinicians and patients. The lack of physical examination that is essential in the orthopaedic practice is also a major limitation in the assessment of the clinical patient condition and the correct choice for therapy (36).

A further aspect of this review is telesurgery, also known as remote surgery. This enables free skills and knowledge exchange between clinicians across borders and all over the world. The most recent achievements proved great outcomes through live surgery cooperation. This provides as well alternative learning potentials for young colleagues who can participate or even assist on these rare live surgeries (39).

AI and ML

AI including ML has emerged as a powerful tool in the field of orthopaedics, offering opportunities to improve patient care by assisting in diagnosis, treatment selection, and personalized medicine. AI can play a significant role in not only identifying and classifying fractures but also addressing degenerative orthopaedic diseases such as osteoarthritis and spinal disorders. By providing detailed classification and predictive analysis, AI can aid clinicians in determining optimal treatment plans for these complex and multifaceted diseases.

Orthopaedic surgery is heavily reliant on imaging modalities, including radiographs, CT scans, and MRIs. Convolutional neural networks have demonstrated remarkable success in analysing these images (40), assisting clinicians in diagnosing and planning treatment for various orthopaedic conditions. Furthermore, large language models, such as generative pre-trained transformer (GPT), hold great potential for enhancing patient care by guiding patients, managing referrals, summarizing patient history, identifying key events and patterns, and even writing up chart notes and patient surveillance (41).

To ensure that AI applications are clinically relevant, it is essential to follow best practices in research, which include using relevant data, providing actionable clinical insights, and integrating AI models into existing clinical workflows (42). In addition to adhering to standard ML practices such as splitting data, avoiding overfitting, and understanding data bias, addressing AI-specific issues that are not common in traditional orthopaedic research is crucial for success (43).

One critical aspect of AI application in orthopaedics is the ability to strike a balance between achieving high accuracy for common disease types while also detecting rare or unusual cases. Detecting rare subtypes and understanding their implications can help match patients with the most appropriate treatment options, reducing the risk of complications or ineffective interventions.

Developing and implementing AI in clinical settings requires adherence to rigorous standards and guidelines.

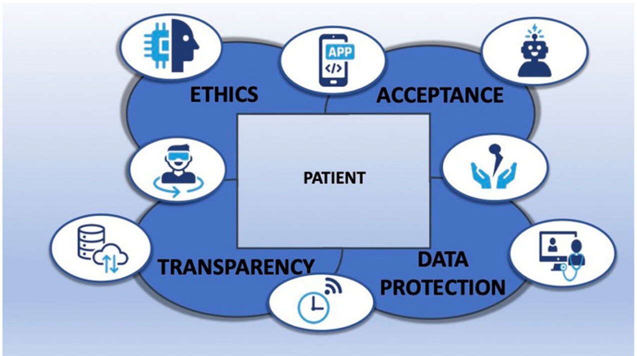

Figure 1
This figure shows the potential and interconnected effects of digitization on patients in the centre of care in addition to emphasizing the need of various important protective mechanisms such as ethics, transparency, data protection, and acceptance.

The TRIPOD-ML, SPIRIT-AI, and CONSORT-AI serve as important tools to ensure that AI research and applications meet the highest quality standards (44). These guidelines help validate AI models and promote transparency, replicability, and generalizability of results.

In addition to the mentioned guidelines, the clinical AI research (CAIR) checklist (42) serves as a practical guide for presenting AI studies to orthopaedic surgeons. By focusing on the clinical relevance and utility of AI applications, the CAIR checklist promotes the effective integration of AI technologies into orthopaedic practice.

Conclusions

Digitization in orthopaedics is a fast-evolving, dynamic field. The statements in this manuscript require to be updated, since further developments as well as challenges will regularly occur. Apart from all the benefits that come up with digitization and future technologies, we must not forget that this field in medicine is still a young area where some hype may lead to overestimate the short-term impact but, as seen in other areas of digitization, the long-term impacts may now be underestimated and cannot be foreseen today. Furthermore, it is necessary that the clinician remains a leader in the digitization of orthopaedic medicine, who steers the technology for patients' best benefit and defends it with other stakeholders (45). Ensuring patient privacy and data security is mandatory, as well as there is the need to prevent potential biases that could lead to disparities in care (46). The European Commission's initiative to regulate health data usage while unleashing its full potential via a 'European Health Data Space' is a major endeavour in this direction (Fig. 1). Furthermore, it is vital to maintain transparency in this process and in the use of various digital possibilities to foster trust between clinicians, patients, and technology developers. It is the 'trouble-free' interaction of all digital fields that may guarantee the best results to ensure a close cooperation and exchange of information that are necessary. Moreover, all the systems need to be as intuitive and self-learning as possible for both clinicians and patients and consider the economic challenges of healthcare provision. The aim is to facilitate and improve the care and treatment process, and it should integrate seamlessly or even unburden the daily routine and activities. This real-world challenge of deploying digital orthopaedic solutions in clinical practice warrants its own implementation research. In conclusion, digitization has the potential to revolutionize orthopaedic and trauma care by providing valuable insights into complex care to clinicians. Digitization may also fulfil patients' expectations for the best treatment options. By adhering to established best practices and frameworks, addressing ethical considerations, and ensuring data protection, digitization can contribute to improved patient outcomes, more efficient clinical workflows, and the continued advancement of orthopaedic research.

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