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REVIEW ARTICLE

# Industry 5.0 in Orthopaedics

**Madhan Jeyaraman**[1,2] · **Arulkumar Nallakumarasamy**[3] · **Naveen Jeyaraman**[4]

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## Abstract

**Background** Industrial revolutions play a major role in the development of technologies in various fields. Currently, the world is marching towards softwarization and digitalization. There is an emerging need for conversion of Industry 4.0 to Industry 5.0 for technological development and implementation of the same in the digital era. In health care, digitalization emerged in Industry 4.0 revolution. To enhance patient care and quality of life, Industry 5.0 plays a major role in providing patient-centric care and customization and personalization of products. The integration of human intelligence with artificial intelligence provides a precise diagnosis and enhances the recovery and functional outcome of the patients.

**Materials and methods** In this manuscript, the domains and limitations of Industry 5.0 and further research on Industry 6.0 were elaborated on to bring out technologies in better health care.

**Results** Industry 5.0 lessens the work of medical professionals and integrates software-based diagnosis and management. It provides cost-effective manufacturing solutions with limited resources compared to Industry 4.0. Industry 5.0 focuses on SMART and additive manufacturing of implants, and the development of bio-scaffolds, prosthetics, and instruments. In this manuscript, the domains and limitations of Industry 5.0 and further research on Industry 6.0 were elaborated on to bring out technologies in better health care.

**Conclusion** 'The personalization and customization of products' are the hallmarks of this evolving Industry 5.0 revolution. The major uplifts in various domains of industry 5.0 such as advanced automation, digitalization, collaborative robots, and personalization bring this an inevitable mechano-scientific technological revolution in this current medical era.

**Keywords** Industry 5.0 · Digitalization · Personalization · Customization · Bio-scaffolds

## Introduction

Industry 5.0 evolved in 2015, which is poised to have a significant impact on modern medicine, especially in the branch of orthopaedic surgery. Michael Rada coined the term Industry 5.0, specified for manufacturing mass personalized products and empowering humans in that process of productivity [1]. Industry 5.0 is regarded as the current industrial revolution, it aims to anchor human intelligence with efficient, and accurate working machines, to obtain cost-effective manufacturing solutions with limited resources compared to Industry 4.0 [2, 3]. It has evolved with the new concept of 3-dimensional symmetrical innovation by utilizing the modified Internet of things (mIoT). The concept of real-time health care primarily relies on the availability of effective communication systems. The development of the Internet of Space provides the highest possibility of pervasive connectivity, thus enhancing throughput connectivity across unreachable rural areas [4]. The production area of Industry

Madhan Jeyaraman and Arulkumar Nallakumarasamy equally share first authorship.

✉ Arulkumar Nallakumarasamy
arulmmcian@gmail.com

[1] Department of Orthopaedics, Faculty of Medicine, Sri Lalithambigai Medical College and Hospital, Dr MGR Educational and Research Institute, Chennai, Tamil Nadu 600095, India

[2] South Texas Orthopaedic Research Institute (STORI Inc.), Laredo, TX 78045, USA

[3] Department of Orthopaedics, All India Institute of Medical Sciences, Bhubaneswar, Odisha 751019, India

[4] Department of Orthopaedics, Atlas Hospitals, Tiruchirappalli, Tamil Nadu 620002, India

5.0 depends on intelligent healthcare, customized manufacturing with cloud computing, supply chain management, and virtualization [5–7]. Nevertheless, the supporting technologies for Industry 5.0 are collaborative robots (cobot) [8], machine-to-machine (M2M) communication [9], multi-access edge computing (MEC) [10], Network slicing digital twins [11], Internet of Space (IoS) things [12–14], and integration of softwarization, blockchain, and 6G and beyond networks [15].

## Industrial Revolution in Orthopaedics

The advancement in the industrial revolution over the centuries enlightens orthopaedic surgery practice. In 1800, the industrial revolution began with the development of basic infrastructures for a livelihood by humans, and it has evolved with water, steam generated mechanical production of surgical equipment. The industrial revolution in orthopaedics has been depicted in Fig. 1.

Industry 2.0 evolved in the 1870s with the production of electricity; the discovery of the X-ray using electromagnetic radiation in 1895 was considered a breakthrough in the clinical practice of orthopaedics [16].

Industry 3.0 evolved in 1969 with the development of automation and computer-based technologies. In the late 1970s, the emergence of magnetic resonance imaging improved the diagnostic ability of various Musculoskeletal disorders [17]. Since 1984, the development of intraoperative fluoroscopy using a C-arm image intensifier has improved the accuracy of fracture reduction and fixation and decreased the procedure's total duration.

Industry 4.0 evolved in 2011 with the objective of digital manufacturing using emergent technologies. In this industrial revolution, the quality of orthopaedic practice has been improved by manufacturing customized implants, supply chain optimization, better connectivity with the internet of things (IoT), automation, data analytics, and artificial intelligence. It provided innovative changes in orthopaedics by making customized tools in less time and cost using interconnectivity, self-monitoring, flexibility, and smart productivity in large scale industries. The major drawback is the paradox of automation, where human involvement becomes more critical in preventing catastrophic events [18].

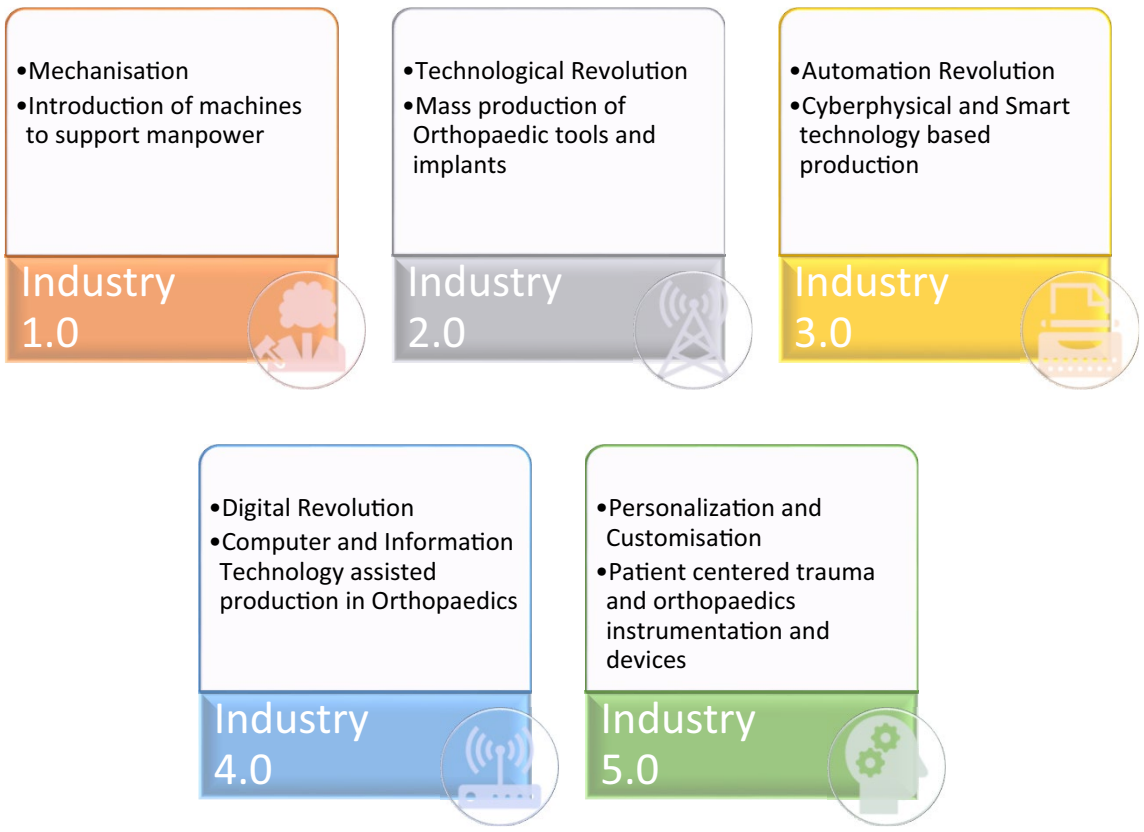



**Fig. 1** Evolution of Industrial Revolution in Orthopaedics

## Industry 5.0 Technologies in Orthopaedics

Industry 5.0 provides an enhanced collaboration between humans and technology through specific industrial sustainability backed by critical predetermining criteria. It is to generate sufficient tools that help to strengthen the manufacturing process with limited investment in medical and other associated fields.

In orthopaedics, the birth of industry 5.0 fulfils the need for high-quality personalized implants with an extended self-life period. The innovative technology helps to solve different challenges such as demand forecasting, environmental consciousness, overproduction, supply chain disruption, lack of transparency, increasing reshoring, handling global competition, labour shortage and wrong instrument selection [5, 19]. This revolution is to impact skilled labour gap, machine intelligence, product reliability, product lifecycle, digital marketing strategy, profit, efficiency, customer self-service application and business model, system usability, environment, need for a supply chain visibility, machine and human safety [1, 5].

The main objective of Industry 5.0 is the personalization and customization of the desired products in the field of interest [20, 21]. Human intelligence along with cognitive computing aids the production of personalized implants and prostheses as per the patient's requirements and upskilled to provide the value-added task in production. It allows the customer to per personal needs [22]. In future, this revolution of machine learning will be helpful in orthopaedics by solving problems over a long-term gentle life cycle [23]. It can take data on diseases from the different sets of patients, analyze them and efficiently make changes in detecting the personal level of diseases and assisting in treatments without even patient asking for the same. The integration of technology with human knowledge digitalizes the operating room. The shift of paradigm from steel saw to cold light laser with robotic arms (Swiss based) improves the precision of bone surgeries.

## Domains of Industry 5.0

The various domains of Industry 5.0 in Orthopaedics are depicted in Fig. 2.

### Personalization and Customization of Products

The main objective of Industry 5.0 is the personalization and customization of the desired products in the field of interest. In the 1980s, computer-aided design and computer-aided manufacturing (CADCAM), orthopaedic implants were used to personalize orthopaedics [24]. A new wave of patient-specific surgical planning, production of patient-specific instruments, and 3D printing of a customized implant has been sparked by recent technological developments. Cognitive computing and human intelligence work together to produce patient-specific implants and prostheses and retrained to perform the production's value-added task [25]. There are no restrictions on what the customer can do with it. When it comes to orthopaedics in future, this revolution in machine learning will unclog the long-drawn-out problems such as low productivity, defective customization, and poor patient–doctor communication system.

### Integrating Edge Computing Within IoT Networks—Supercomputing

There are smart nodes that sense, interpret, process, and respond in a network using the Internet of Things (IoT) in the medical field. Creating a new ecosystem for information and communication demand could be facilitated by the use of edge computing (EC). EC architecture will be required for several emerging healthcare applications, including remote surgery. To communicate with the surgical team remotely, the teleoperator needs real-time commands to control the movement and rotation of the robotic arms, as well as a voice stream from the surgeon's communication. Additionally, 3D video and physiological data must be streamed to the surgeon during the procedure. Data propagation through network backhaul, response times, privacy and security, and cloud overhead can all be reduced using edge computing architecture in general.

There are three essential characteristics of healthcare data monitoring: medical urgency, energy consumption, and cost considerations. As a result of this super-computing technology, doctors can now monitor non-critical patients at home rather than in a hospital, and this has revolutionized the healthcare sector. IoM-edge cloud computing integration has increased the demand for smart healthcare as a module that provides seamless and fast response [26].

Blockchain-enabled healthcare infrastructure ensures interoperability of medical records, improves the quality of insurance claim adjudication, and provides high-quality patient-centred services [27]. Besides addressing data protection concerns, blockchain can also ensure privacy, accountability and shared access to the data that is stored on the network [28]. To reduce the time it takes to respond from request to request, Fog computing consists of a variety of smart devices and computing technologies [29]. Tasks are handled simultaneously by all the devices in the system because they all act as processing nodes.

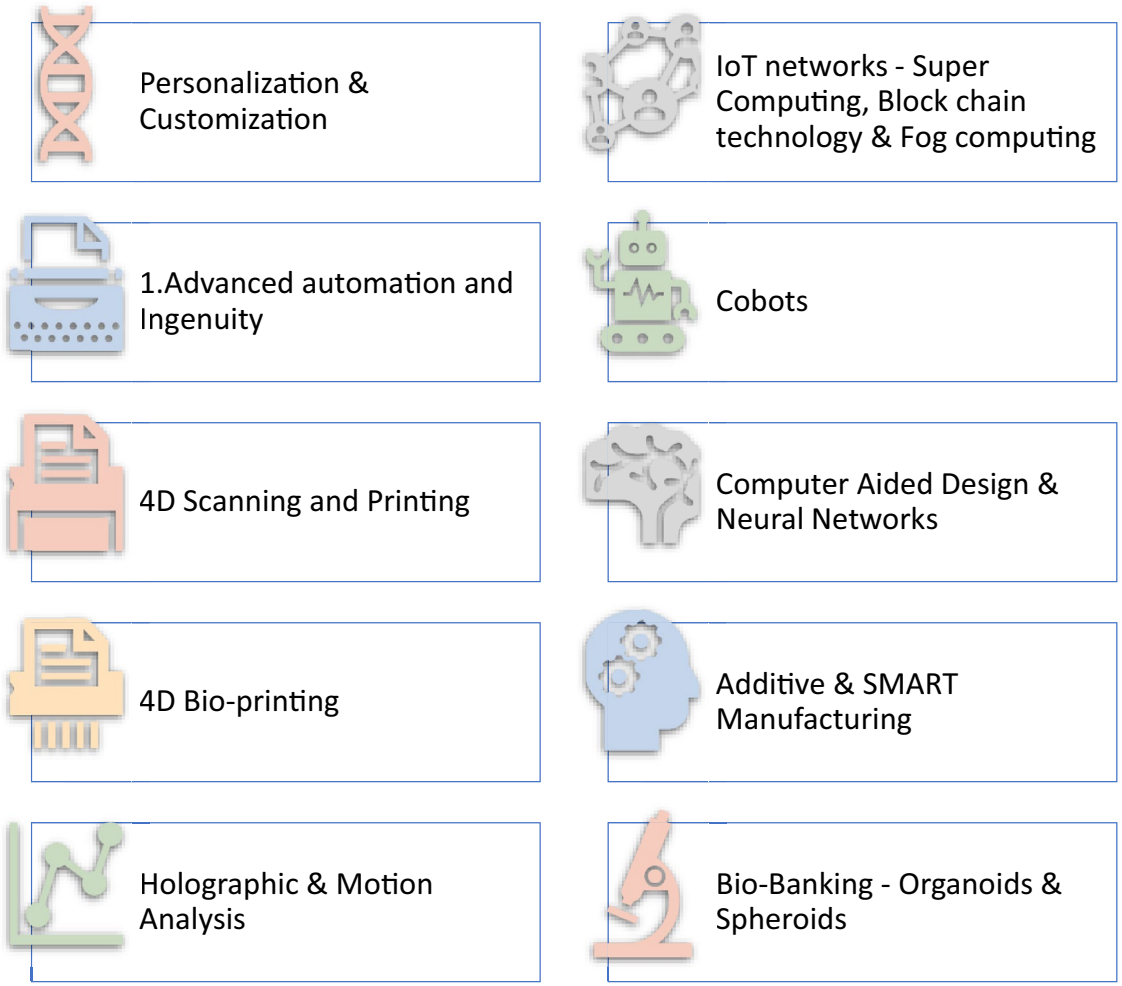



**Fig. 2** Domains of Industry 5.0 in Orthopaedics

## Advanced Automation and Ingenuity

Since its inception in 2012, Industry 5.0 has made it a priority to expand automation technology throughout its entire manufacturing floor. It has a large number of high-end HASS 5Axis machining centres, which are used to produce a wide range of orthopaedic implants, instruments, and parts for those devices. The use of 5-axis machining reduces the number of setups required to produce complex parts while still avoiding the use of human or manual labour [30].

In the last few decades, artificial intelligence (AI) has gained a foothold in orthopaedic surgery, including fracture prediction, radiographic analysis, Orthopaedic imaging, fracture detection, aseptic loosening of implant arthroplasty, and grading of chondral lesions or osteoarthritis have all benefited from integration with other Drivers of Industry 5.0 [31–34]. In the field of orthopaedics, adaptive learning, logic regression analysis, and problem-solving using AI, ML, and DL algorithms have the potential to improve surgical precision, accuracy, patient journey planning, in-hospital stay length, and mortality. It's no secret that Industry 5.0 is dedicated to making its manufacturing floor more automated.

## Cobots

It is becoming increasingly important for humans and robots to work together harmoniously in this new era of automation and robotization [35]. The surgical robots can collaborate with humans, and these robots are called collaborative robots [8]. Human abilities are supposed to be improved through this collaboration in a safe manner. In terms of 5G and cobots, there is a clear synergy. Surgeons use images of a patient in the intervention position to plan the implant's placement during surgery. After that, the implant's "position and orientation" can be adjusted via the interface. The CoBot "automatically align[s] the pedicle targeting instruments on

the chosen trajectory" while the surgeon maintains control of the surgery [36].

## 4D Scanning and Printing

In orthopaedics, a patient's joint problem can be accurately diagnosed by observing the patient's physical motion. Images are captured using 4D MRI/CT and these images are used to create a CAD model, which can be printed using 4D printing, by converting them into the required format. The final requirements of orthopaedic applications guide the selection of smart materials. Predicting how much a physical model should be expanded using a 4D CT/MRI helps determine the exact requirements for how many shapes change the model should undergo [37]. Using these new technologies, orthopaedic models can be created that help surgeon better understand their patients during difficult situations and that can also be used for education and research. Using a smart material, 4D printers can print a bone-like component that, over time, grows in the human body. 4D CT/MRI data provides the surgeon with information about the patient's anatomy that can be used to 4D print an orthopaedics model, which can be used for a mock surgery [37, 38].

Multifunctional medical and orthopaedic implants are now possible thanks to cutting-edge 4D printing technology [39, 40]. Using these scanning devices, you can imagine how an implant will look before printing it in 4D. Additionally, the higher cost and human expertise required for 4D CT and 4D MRI is a drawback. Future orthopaedics implants may benefit from 5D printing [41, 42], which can print curved implants with greater strength than 4D printing.

## Deep Learning with Computer-Aided Detection (CAD) and Deep Convolutional Neural Networking (DCNN)

With computer-aided detection (CAD), an emerging branch of AI, surgeons are less likely to make mistakes when diagnosing fractures in an emergency department because of their heavy workloads [43, 44]. Delays in fracture diagnosis can result in malunion, necrosis of the aorta, post-traumatic arthritis and malpractice claims and legal issues due to human error. To improve diagnosis, CAD serves as an invaluable second opinion for treating physicians [45]. Algorithm-based CAD suffers from the problem of being less sensitive to diagnostic tests and resulting in more unnecessary tests and procedures.

## 4D Bioprinting in Scaffold Engineering and Ortho-biologics

Using autologous chondrocytes to treat articular lesions is a relatively new technique. Magnetic resonance imaging (MRI) can be used to measure the thickness of articular cartilage using machine learning algorithms with high accuracy and validity. The intelligently controlled 4D printed bio-scaffolds are better for bone tissue engineering and use nearly identical processes and techniques to 3D printing, such as CAD modelling and 3D printers [46–48]. It's only been a few years since the introduction of 4D printing, but it has already seen widespread use and development in a wide range of fields, including bioprinting for regenerative and reconstructive orthopaedics (e.g., tissue engineering scaffolds and artificial organisms). This opens up a new route for the production of customized implants and personalized gear. For 4D printing, intelligent biomaterials and living cells have already been deemed promising bio-inks [49, 50]. Many SMM (shape-memory materials) have begun to be investigated for bone scaffold fabrication as a representative of potential programmable biomaterials [51, 52]. Their adaptability and flexibility make them superior in the repair of bone fractures and bone loss, especially in irregular, minor or large-sized bone defects. To create a synthetic meniscus scaffold, Bakarich et al. printed fibre-reinforced Alg/PAAm ICE hydrogels from a CAD model [53]. Hardware devices and software algorithms are expected to be majorized to speed up and improve the precision of a complex programme of 4D printed artificial bones. Even though the implantation of scaffolds can be guided by automation, the surgeon's experience still plays a role in determining the proper position of the implants.

## Eco-friendly: Enhanced Additive and SMART Manufacturing

The advent of industry 5.0 in orthopaedics fills a long-felt need for high-quality, personalised implants that can withstand repeated use for many years. Enhanced additive manufacturing (AM) advances the development of patient-specific orthopaedic implants, biocompatible, long-lasting implants, osteointegration, and improved tissue engineering to replace traditional tumour prostheses or allografts [54, 55].

"SMART ((Self- Monitoring Analysis and Reporting Technology)) implants" are at the heart of orthopaedics' use of Smart Sensor technology [56, 57]. Existing orthopaedic implants have smart sensors built into them, but these have smart sensors built right into the implants and/or prostheses. To monitor implant performance and patient outcomes, the sensor device can provide real-time or post-implantation data that can be used. As a result, these sensors can detect changes in the physical environment as well as changes in the biochemical environment of implants. Surgeons can use this information to keep tabs on their patients' progress and intervene when necessary, resulting in better patient outcomes.

### Holographic Teleportation, Extended Reality and Motion Analysis

An orthopaedic structure and pin and rod fixations can be studied and measured using holography. The piezoelectric coefficient of human bone can be determined using this non-contact tool in conjunction with an external fixture used in a bone fracture. This new technology could revolutionise medical care by providing incredibly accurate images of human organs, skeletons, muscles, and blood vessels. The data from 3D holographic orthopaedics provide a multi-angle view of an original object based on its original size and shape [58, 59]. For spine surgery, trauma, prosthetic, joint replacement and reconstruction of complex maxillofacial and calvarial defects, we have found it to be a useful tool [58]. Better information about bone, tissue, osteochondral and chondral defects, surgical planning, orthopaedic cost-effectiveness, surgical training, and patient care are all made possible by this new technology.

Movement analysis systems, whether based on markers or non-invasive, can be used in biomechanical rehabilitation clinics and sports settings to evaluate how people move. Injured sports trainees can avoid further musculoskeletal damage using motion analysis to predict when they can return to physical activity [60]. Optoelectronic stereophotogrammetric multi-camera capture system is essential to track marker-based motion analyses [61]. Patients with postural imbalance disorders, non-specific back pain ailments, cerebral palsy disorders, spinal cord damage, and amputees benefit from this service's therapeutic and rehabilitation platform [60]. A 3D model of the spine's topography can be generated using raster stereography, a noninvasive computerised analysis. Posture Screen Mobile (PSM) applications, such as Upright Go 2, alert the user when their posture is out of alignment, so they can fix it right away.

### Biobanking-Organoids and Spheroids Modelling

Tissue engineering technology based on biological theory can be used to build organoids in vitro, which can mimic the complex biological functions of organs in vivo. Anatomical structures similar to human skeleton can now be replicated using organoids and organotypic cultures, which are unique in that they are self-organizing and develop features that can be exploited to understand disruptions in molecular pathways that lead to disease. There is always a need for bio-scaffolds to build the hierarchical tissue structure in the bone organoids [62–65]. Biomineralization is a term used to describe the process by which bone tissue is primarily made up of inorganic structures. Even though 3D cellular interactions would be introduced by common bone tissue engineering, the real physiological microenvironment is still not represented due to unfit cell types and excessive human manipulation.

It all started in the year 2000 when bone–cell-formed spheroids developed micro-crystalline mineral particles known as spicules; more recently (2019), spheroids that recapitulate stages of endochondral bone formation, as well as preliminary reports of irregular, fibrous bone organoids, were discovered [66, 67]. For the first time, we have successfully grown an organotypic bone system using highly osteogenic periosteal cells, which replicated the bone deposition process and matured for more than a year in culture, re-creating many stages of physiological tissue and apatite mineral phase formation [67].

Osteoblasts are the primary focus in the creation of a basic bone organoid for bone disease research. Several types of human stem cells, including induced pluripotent stem cells (iPSCs), mesenchymal stem cells (MSCs), human periosteum-derived cells (hPDCs), and the osteoblast/osteocyte population derived from embryonic stem cells (mESCs), have the potential to be used in the creation of bone organoids in the lab [65, 68, 69].

## Limitations of Industry 5.0

The major drawbacks of the concepts of Industry 5.0 involve the configurability, extensibility, supportability, portability, sustainability, and security of the designed software architecture. Further, we are lacking in the productivity of skilled technicians and professionals including cyber-physical systems analysts, collaborative operators, artificial intelligence operators, and virtual device linkers to operate the intricate networks and paradigms. Nevertheless, the major advancement of automation, digitalization and personalization constituted by the various domains of industry 5.0 brings this as an upfront mechano-scientific technology in the medical era. However, supportive clinical research and the ecological and economical benefits to the population are still lacking. Hence, it is postulated that the need for optimistic clinical research, education and mechano-scientific training of workers.

## Future Research

Further research in improving precise patient care depends on the technological developments in the next three decades. We gravitated toward research challenges to advance further the industry 5.0, which includes multi-sensory holographic teleportation [70], 4G bio-printing scaffolds in orthobiologics, organoids, the internet of BioNano things [71], network automation [72], 6G wireless quantum communication [73], and virtual and augmented reality [74]. Industry 6.0 is

the futuristic ideology and a theoretical concept which come into existence by 2050. Industry 6.0 rely on hyper-interface the ventures to enterprises, Li-Fi, human-driven virtualized homogeneous resources, medi-robots, anti-fragile technology, automated flexibility, and customer-focused ethos [75, 76].

## Conclusion

The evolution of the 5th industrial revolution over the recent years paved the way for the 'personalization and customized manufacturing' of products. The emergence of collaborative robots digitalizes the operating room. Henceforth, it decreases the surgical duration, the iatrogenic complications, and thereby improving the patient-reported outcome measures. The shift of paradigm from obtaining expertized opinion to deep learning with computer-assisted detection sets the target of human-error free diagnosis, especially fracture screening in the sub-speciality of traumatology. The 'advanced automation and digitalization' improve diagnostic precision, and newer therapeutic interventions and enhanced the possibility of remote monitoring. Further, the inception of 4D diagnostics, bio-scaffolds and organoid manufacturing technologies in this revolution intensified the growth of regenerative orthopaedics. Nevertheless, the amalgamation of human intelligence with machine learning foreshadows the inevitable perspective of this technology in the practice of technological orthopaedics.

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## Declarations

**Conflict of interest** The authors declare that they have no conflict of interest.

**Ethical standard** This article does not contain any studies with human or animal subjects performed by the any of the authors.

**Informed consent** For this type of study informed consent is not required.

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