

Editorial

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Surgery 4.0: the natural culmination of the industrial revolution?

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Introduction

The topic of this issue of *Innovative Surgical Sciences (ISS)* is “Surgery 4.0”. The term and its meaning are as yet unfamiliar to most surgeons. It was, to our knowledge, coined in 2016 [1] and was used to describe a vital development in surgery, which could conceivably become as disruptive as the current trend toward economic and industrial digitalization. To make the parallels and contrasts more evident, a reflection on the Fourth Industrial Revolution is helpful.

The global economy is assumed to move forward to the Fourth Industrial Revolution. Commonly, the mechanization of production using water and steam power is considered to have driven the First Industrial Revolution. The next “revolutionary” impact on industrial productivity came from mass production facilitated by the availability of electrical energy and improved workflow organization (assembly line, etc.). This was followed by the Third Industrial Revolution, which is characterized by the use of information technology (IT) and robots to automate production.

Today, a systematic transformation of industrial production is under way, which can be grossly defined as the comprehensive computerization of manufacturing (Figure 1).

The vision is some type of self-organizing or autonomous production: the factory with its production lines “understands” what has to be produced and autonomously carries out all necessary steps and adjustments. This strategy, originally propagated by the German Government as the Industry 4.0 initiative, is evidenced in the customization of products under the condition of highly flexibilized production. This highly automated technology is enabled by the introduction of methods of self-optimization, self-configuration, self-diagnosis, cognition and intelligent support of the few human beings who are still required to master this complex process. The main pillars are as follows:

1. Interoperability: The ability of machines, devices, sensors, and people to connect and communicate

with each other via the Internet of Things (IoT) or the Internet of People (IoP).

2. Information transparency: The ability of information systems to create a virtual copy of a physical world by digital models with sensor data. The very dense net of information is available for all stakeholders. A huge amount of raw data have to be collected and interpreted in a higher context.
3. Technical assistance: Decision-making has to be facilitated by preparing all necessary information. Humans have to decide all necessary preconditions (information) that have already been provided.
4. Decentralized decisions: The ability of lower-level systems to make decisions on their own and to perform their tasks as autonomously as possible. Only in the case of exceptions and/or conflicting goals are tasks to be escalated to a higher level.

Autonomous decision-making by mechatronic support devices is the real disruptive element of Industry 4.0. Humans will need to be confident that machines are able to act and react reasonably, reliably, and as fast and as safely as a human worker.

There are, however, some necessary preconditions for this vision to become reality.

1. The IoT must support direct communication or dialogue with the technical equipment. If one device alters its functionality, the whole technical environment is informed.
2. Data/information must be provided wherever it is needed in real-time and by a high-quality, reliable service (5G telecommunication).

Surgery and the 4.0 development

What then has all this to do with surgery? Some context in the form of a brief review of modern surgical history may be helpful.

The beginning of scientific surgery dates back about 150 years. Retrospectively, this comparatively short period of time can be subdivided into three different eras. In the

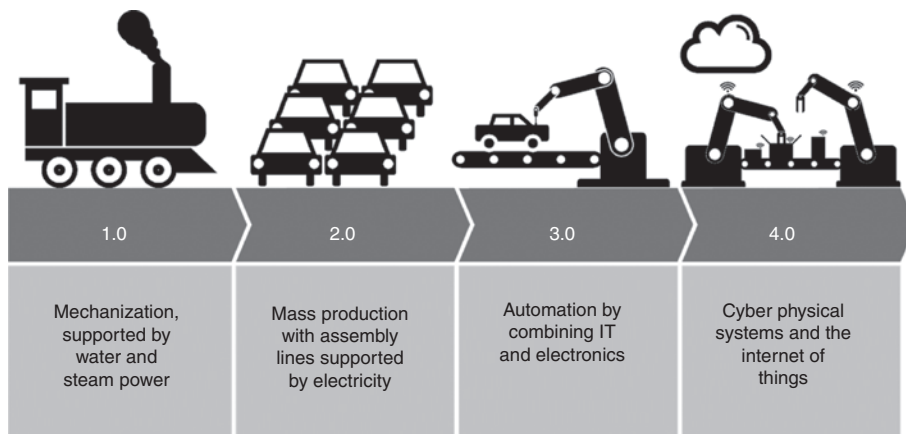


Figure 1: Industry 4.0 attempts to describe the transformation process of industrial production from passive automated production to an active, cognitive support of the production process.

beginning, surgeons learned to master the specific challenges of the different anatomical regions – beginning with the abdomen and ending with the brain. In the next phase, surgery was not any longer confined to resection/amputation, but the focus was now laid on substituting deficits. Destroyed joints were replaced by artificial implants, and functional reservoirs were developed to accommodate for the roles of the stomach or rectum, for example, after their resection. The ultimate highlight of the era was the transplantation of whole organs (the heart, liver, kidneys, etc.).

The trend today is to further minimize the surgical trauma – collateral damage to other organs, functional impairment, and pain due to the operative intervention. This third era of surgery started with the introduction of laparoscopic surgery. Laparoscopy was, however, only the beginning of a broad development in many medical disciplines toward minimally invasive therapy.

We are now arguably on the threshold of a new era. This does not mean that further advances in reconstruction (phase II) or trauma reduction (phase III) should no longer be pursued, but the innovative impact comes now from another discipline: information/digitalization (Figure 2).

Although surgery is often considered a manual or technical discipline, it will not remain unaffected by the general trend toward the information age development. This issue of *ISS* is thus dedicated to the question of surgery in the information age. The sum of these relevant issues is covered by the term “Surgery 4.0”. The aim of this volume of *ISS* is to present to the surgical reader the “hows and whys” of new technologies and methodologies, such as the IoT, process modeling, cooperative learning machines, and new approaches to the generation of knowledge that will affect surgery – all with the aim to

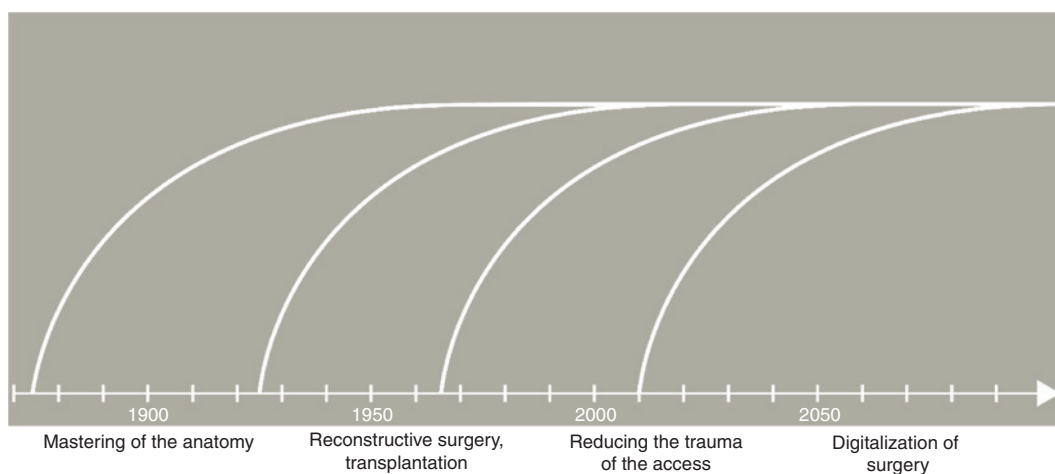


Figure 2: Is surgery entering a new era of development right now?

improve the quality, efficiency, and outcomes of surgical care. Surgery 4.0 might be the chance to master the difficult situation we are currently in Figure 3.

The surgical community should then strive for familiarity with this new domain and an awareness of the wealth of new opportunities that will result from it.

In this issue, the theoretical background of Surgery 4.0 is outlined by Vedula and Hager [2] in their paper “Surgical data science: the new knowledge domain”. They posited compellingly that future transformation in surgical care will be driven by data/information. The key elements on the path toward evidence-based surgery are new tools to measure, model, and quantify surgical processes including intraoperative decision-making and knowledge extraction. An intelligent collaboration between care providers and devices/technologies will be enabled. In addition, they also emphasized the significant impact on surgical education and training. Surgical data science (SDS) not only enables objective computer-aided skill evaluation but also automated coaching. They concluded, “As surgery continues to evolve through advances in technology that enhance delivery of surgical care, SDS represents a new knowledge domain to engineer surgical care of the future”.

Each of us – particularly those who have not thought much about future scientific developments in surgery – needs to start paying attention. If “engineering of surgical care” is a remotely viable prospect, then we, the surgeons,

must lead this exploration and evaluation as the strongest (and ultimate) advocates for our patients. We are obliged to contribute our specific domain knowledge. We are the experts, and as thought leaders, we must be the ones to develop the patient models and surgical models that will form the basis of model-based surgery.

For many of us, the term “surgical model” or “model-based surgery” may be foreign or seem obscure. The following paper facilitates a better understanding.

Neumuth explained that a “surgical model” is an evidence-based, detailed plan of a particular surgical intervention with a clear description of the workflow from skin incision to closure. It not only includes the normal course of an operation but considers potential modifications and deviations as well. He also explained how to create “surgical models” either by a bottom-up or top-down approach [3]. Modern SDS methodologies such as machine learning will become extremely helpful to establish “model-based surgery”. However, even the most advanced computer technology cannot substitute for surgical expertise – a clarion call for the surgical community to engage and scientifically collaborate in the development of Surgery 4.0.

Stauder et al. [4] provided an insight into a practical application of SDS: the systematic utilization of future smart intraoperative assistance systems.

The reader is introduced to new computer science tools that enable the machine to understand workflow. It is anticipated that surgeons will be supported by active, cooperative support systems in the foreseeable future.

Finally, Kenngott et al. [5] envisioned the scenario where Surgery 4.0 comes together in a truly comprehensive manner.

Starting with the integrated “cognitive” operating room, previously described by Stauder et al., as the “core of cognitive surgery”, they enlarged the vision by giving an overview of the additional preoperative and postoperative applications of “cognitive surgery”. They analyzed the possibilities of new intelligent devices and software across the entire patient treatment cycle culminating in the evolution of an “intelligent hospital”. This “Hospital 4.0” uses technology to bridge the divides between IT infrastructure, medical devices, medical personnel, and patients. They concluded, “the Hospital 4.0 will be an intelligent system, which gives the right information, at the right time, at the right place to the individual stakeholder and, thereby, helps to decrease complications and improve clinical processes as well as patient outcome”.

We believe that this outline describes the goal for which surgeons must strive.

To complete the issue, Karpeh and Bryczkowski [6] emphasized a particular facet of Surgery 4.0, requiring

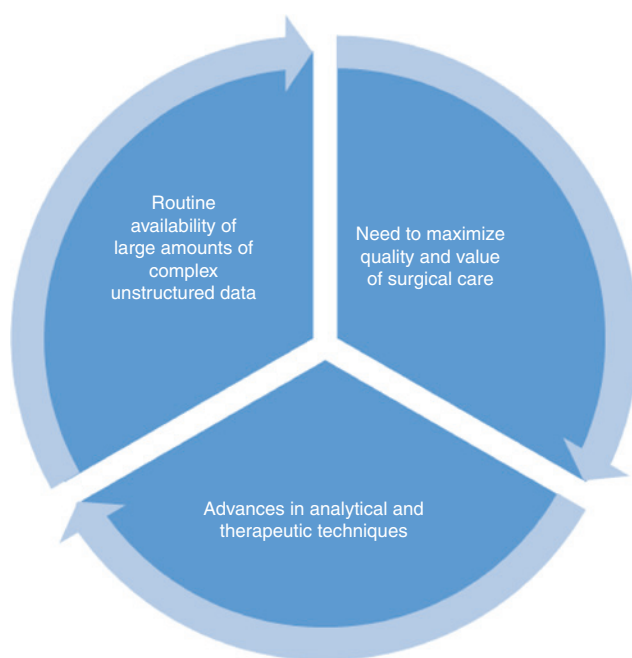


Figure 3: Key elements of surgery of today and tomorrow: Surgery 4.0 may become the lever to handle these challenges.

attention, namely the practical use of digital communications and social media in surgery. They highlighted the manner in which digital technology is changing the way surgeons communicate with colleagues and patients while also addressing its potential pitfalls and problems.

The topic of communication is further explored by Miehle et al. [7] in considering the very promising outlook of natural voice interaction systems as a tool for man-machine interaction. They will enable the technical environment to engage in an active dialogue with the human master, closing the loop between the surgeon and his/her assistant systems.

In conclusion, Surgery 4.0 does not mean that robots will perform surgery on their own in the future. This can neither be the vision of surgeons nor would it be accepted by the majority of patients in societies with a highly developed healthcare system, as one very recent study [8] has shown. However, artificial intelligence, robotics, model-based surgery, and many additional principles of Surgery 4.0 will certainly help to make surgery more evidence-based, safer, and easier, all with the goal of a better outcome and experience for the patient.

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