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Digitalization in Anesthesiology and Intensive Care

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24.1 Introduction

Knowledge management in anesthesiology, intensive care, and emergency medicine has received a considerable boost in the past 15 years through the introduction of automated measurement data transfer into electronic protocols and patient records. On the one hand, this provides an enormous opportunity to make data available in larger networks and cooperation, and on the other hand, to make predictions based on corresponding analyses that are not readily available to physicians due to their complexity. One example of this is telemetric applications in intensive care and emergency medicine, where intensive care units at lower levels of care receive decision support from maximum care providers. In emergency medicine, physician consultation services can be brought to the emergency scene when an emergency physician is not physically available there. All of these applications have led to quality improvements in patient care. In parallel, cost savings have even been demonstrated in some scenarios. One challenge remains the structuring and annotation of the data already during input in order to ensure the best possible evaluability and further processing here.

24.2 The Perioperative Process: Digitalization in Anesthesiology and Critical Care

The perioperative process defines all medical interventions before (pre-), during (intra-), and after (post-operative) a surgical procedure [18]. In the preoperative setting, the patient is evaluated by the surgeon and the anesthetist, leading to an initial estimate. Based on this estimate, the patient will either be scheduled for an operative intervention or requires additional medical attention first. After the operation, the patient usually requires medical attention in a Post-Anesthesia Care Unit (PACU), before being discharged (in case of ambulatory care), admitted to a regular ward, or in case of necessity of continuous medical attention or invasive procedures to an intensive care unit (ICU).

Therefore, anesthesiology and critical care medicine are tightly connected fields that share important features regarding the importance of high-resolution data evaluation during the care process. In both fields, patients are often subject to extreme physiological situations that need medical intervention in order to maintain the patients' homeostasis to the best possible degree. Therefore, tight and continuous monitoring of vital parameters as well as additional relevant variables of the perioperative care process is a central necessity to detect hemodynamic or respiratory instabilities and react accordingly. Such events can occur at any time during the perioperative process, due to the patients' health conditions, intraoperative events such as acute blood loss, clamping of vessels, triggering of physiological reflexes, or homeostatic imbalances. Depending on the type of surgery, the indication, comorbidities, and intraoperative events, patients might require prolonged attention. It was for this reason that the first ICU was established, a highly successful concept that immediately spread to other fields in medicine, specializing in patients where the physiological process is severely impaired and requires continuous attention [4]. Implementation of multiparameter early warning scores (MEWS) on normal care units, combining a range of physiologic parameters into a summated score, demonstrated a significant reduction in the incidence of cardiac arrest [23]. However, only 68% protocol compliance was achieved with manual MEWS paper curves [13]. One potential solution to this problem is MEWS-based electronic automated vital sign monitoring systems [6], which have been shown to increase survival during ward emergencies and reduce the time required to measure and record vital signs [3]. Follow-up studies with connection to paging devices also found reductions in both cardiac arrest and unplanned intensive care admissions in a high-risk surgical cohort. When using these systems, patient deterioration is more frequently detected by monitor alarms than by staff observation, and there is increased availability of physiologic data when MET arrives [6].

24.3 Digital Anesthesiology and Intensive Care in Research and Education

The digitalization process in anesthesiology and intensive care medicine also creates new opportunities in research and teaching. AIMS (anesthesia information management systems) or also known as PDMS (patient data management systems) are increasingly finding their way into anesthesiology and intensive care medicine. Increasing networking and digitization enables the seamless recording of all accruing data and thus comprehensive documentation in everyday clinical practice. In addition, ecological aspects are playing an increasingly important role and are leading to initiatives such as the “paperless hospital.” Although such digital PDMS originated in anesthesiology and intensive care, they are growing out of their infancy and are just beginning to triumph throughout the hospital.

Provided that they are compatible, a new digital world of medical data is emerging, enabling a new form of health services research.

Digitalization is giving simulation unimagined opportunities for training – and even educating – medical personnel. That is why simulation centers are widely used in anesthesia, but less so in critical care medicine. Various forms of simulation trainers exist from mannequins for training intubation to entire simulation operating rooms. This has become an integral part of education and training as well as an indispensable part of student teaching [7]. In this context, digital emergency checklists were also developed and made available free of charge by the German Federal Association of Anesthesiologists [19].

Another area of research is large patient databases, which are not only used to gain immediate insights into the course of illnesses or to make forecasts [21]. Rather, these data can also be used to simulate measures that cannot be carried out on the patient himself [2].

24.4 Fair Anesthesia: Data Sharing and Open Science

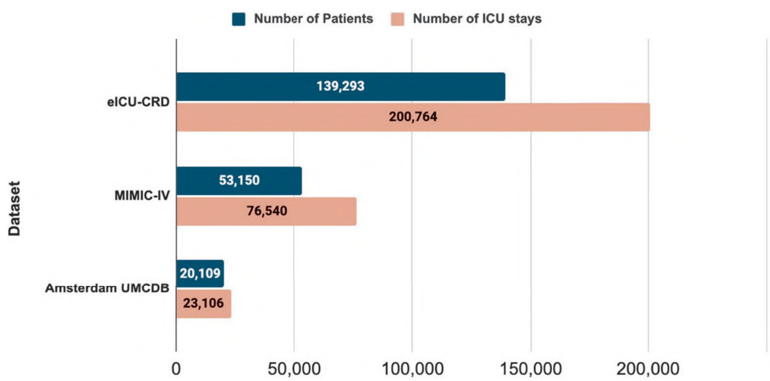

Figure 24.1 Overview of the three most popular open access ICU databases. eICU contains the largest number of patients and admissions, covering more than 250 hospitals across the USA. However, both MIMIC and Amsterdam UMCDB, even though single-hospital databases, contain more high-resolution data.

In the last couple of years, science has made a giant leap toward reproducibility, which is tightly linked to data availability.

One of the earliest efforts to make data available to the public to leverage scientific collaboration is MIMIC: the **M**edical **I**nformation **M**art for **I**ntensive **C**are [ref]. MIMIC is the result of a collaboration between academia (Massachusetts Institute of Technology), industry (Philips Medical Systems), and clinical medicine (Beth Israel Deaconess Medical Center) that was founded in 2003. Its vision was the utilization of data that was generated during patient care. As such, its initial version contained three types of data: clinical data retrieved from charts, high-resolution physiological data, such as arterial blood pressure waveform data, and survival status obtained from Social Security Administration Death Master Files (Critical Data 2016). Importantly, after anonymization, these data were made available to the public, such that biomedical research could advance to support patient care in this highly critical setting [9]. MIMIC is now available in its 4th version, and has added a significant number of data types, including imaging and emergency department data prior to ICU admission [8, 24]. However, MIMIC is more than just its data. The MIT Critical Data team established the concept of ICU datathons, a combination of the word data and marathon [16]. This format is characterized by interdisciplinary teams of both experts and enthusiasts from the medical as well as the data science world that get together for a weekend and work on relevant medical questions, competing with each other for the best project, analysis, and result [1]. This concept has become extremely popular and has become a regular event for the European Society of Intensive Care Medicine. MIMIC has also been the basis for important work on artificial intelligence in the ICU. Based on MIMIC's success, the team around MIMIC was then able to convince Philip's Medical Systems to share their database of ICU monitoring data as well. This database called eICU includes data from more than 250 hospitals across the United States of America and is also freely accessible [20]. MIMIC and eICU have greatly contributed to the advancement of knowledge in the field of intensive care. Komorowski and his colleagues drew attention to the field of reinforcement learning in intensive care by demonstrating that this type of machine learning might be used to support hemodynamic therapy decision-making [11]. MIMIC was also part of the basis for the development of the Hypotension Prediction Index© [5].

Even though MIMIC and eICU provide a plethora of exciting digital data for researchers interested in intensive care medicine, they cannot sufficiently represent patients and clinics from around the world. Recently, European institutions have started to follow a similar direction. A team from the University Medical Center Amsterdam was able to release a similar database despite the strict regulations that the General Data Protection Regulation imposes [22].

For perioperative data, there is currently only one database openly available. VitalDB contains 6388 surgical patients, including high-quality biosignal waveform data as well as more than 60 surgery-related clinical variables [25]. As a centralized approach, in 2008 the Multicenter Perioperative Outcomes Group (MPOG) was founded as a consortium of now more than 100 collaborators representing 51 hospitals mainly from the United States. The idea is to collect EHR and AIMS data to support research in the perioperative setting. Data access can be requested for a well-defined subset of the data tailored to answer a specific research question. A similar approach is followed by National Anesthesia Outcomes Registry (NACOR). NACOR started collecting data starting in 2010 with a focus on benchmarking and quality control. This is especially valuable since randomized controlled trials are especially challenging in the perioperative setting, because a) many times deviations from the standard protocol might raise ethical concerns and b) due to high-security standards and consequently low incidence rates, an unfeasible number of patients would need to be recruited to reliably prove intervention effects [12].

24.5 Clinical Decision Support

In order to promote digitization in medicine, the German government initiated the medical informatics initiative in 2018 with the vision to link research and healthcare in a more targeted manner. In the end, five consortia with different concepts and a wide variety of projects emerged nationwide with the goal of advancing digitization in research and care. Data integration centers were established at the university level to link the wealth of data generated daily in patient care, standardize it, and make it usable for research and care, with the aim of enabling more personalized patient care in all clinical areas.

One example from the first funding period is the development of an app that provides real-time support to improve the detection of acute lung failure in intensive care units so that therapy can be initiated more quickly [15]. In this context, the current technical possibilities of digitalization are used to recognize acute disease states more quickly and to initiate adequate therapy.

Another development in the field of clinical decision support is the digital linking of numerous measurement parameters in high-tech areas such as the operating room or in intensive care, where many vital functions are monitored in real time. The focus here is on making these numerous measured values from a wide variety of organ functions available to the treating physician in real time, bundled on a device so that a multi-functional monitoring platform is created that can support faster decision-making processes through decision support based on algorithms to be developed using machine learning [15]. Ideally, this will allow potential problems to be identified sooner in the future, before any potential deterioration in the patient's condition.

The German healthcare system faces the challenge of ensuring high-quality, nationwide healthcare in the face of an increasing shortage of medical and nursing staff in the future. As part of digitization, particularly in intensive care medicine, telemedicine cooperation structures can help make expert knowledge available around the clock in underserved regions and improve treatment quality cost-effectively and sustainably. In the fields of tele-intensive medicine and tele-emergency medicine, positive results in the care of critically ill patients have been demonstrated by numerous international studies and also Germany-wide projects. In anesthesia, supplementary tele-consultations offer the possibility of providing specialist supervision from preoperative risk evaluation to post-anesthesiologic care as needed and without delay. In pain management, telemedicine can also help support timely and individualized care [14].

In addition, the establishment of an "Anesthesiology Control Tower" represents further achievement in the field of perioperative clinical decision support. Especially in anesthesiology workplaces with which a wide variety of data can be bundled in real time and made available to a special team [17], beginning with patient-related factors and vital parameters recorded during the operation, as well as information about the operation and static and dynamic risk factors such a system leverages clinical care. In this way, especially in critical situations, a small number of practitioners can be supported in decision-making at the operating table by increasingly specialized teams. This concept, however, is relatively new and requires further research and evaluation before it possibly becomes routine in the future and finds its way into everyday life [10].

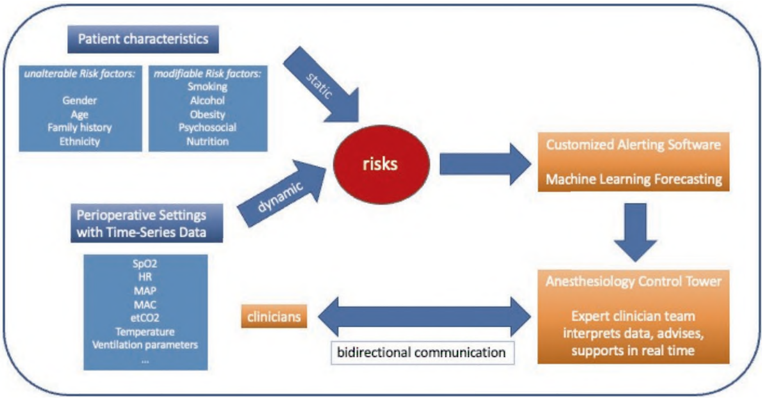

Figure 24.2 modified after Ref. [10]

24.6 Perspective and Vision

Digitization should be seen as a great opportunity in anesthesiology and intensive care medicine, enabling the practitioner to make decisions in less time and also to adapt to the therapy more quickly by recognizing changes. Especially in anesthesiology and intensive care medicine, the abundance of data generated every second by monitoring patients provides a very good basis for achieving automation with the latest methods of informatics in order to 1. enable faster detection of changes in the process as well as the occurrence of acute situations, 2. provide the practitioner with real-time decision support, 3. offer a more comprehensive basis for therapy decisions, and 4. lead to a shortening of decision-making processes. In addition, digitization is an opportunity to simplify and bundle necessary documentation.

As a further perspective, this paves the way for further specification and more patient-adapted individual decisions in therapies (ventilation, medication, etc.) based on patient-specific data in the operating room as well as in intensive care.

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