4 Informatics in Perioperative Medicine

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KEY POINTS

- Individual computers are connected via networks to share information across many users.
- Information security is about ensuring that the correct information is available only to the correct users at the correct time.
- Healthcare information storage and exchange is regulated to protect patient privacy.
- Information regarding the provision of anesthesia care is highly structured and organized compared to most healthcare specialties.
- Anesthesia care documentation systems have evolved in complexity and are now widely adopted in the perioperative care of patients in the United States.
- Benefits of electronic documentation of anesthesia care typically emerge from integration with monitoring, scheduling, billing, and enterprise electronic health record (EHR) systems.
- Active and passive decision-support tools may suggest typical courses of action or call to attention patterns that are not apparent to the clinician.
- Secondary use of EHR data is valuable in understanding the impact of clinical decisions on patient outcomes and the measurement of quality of care.
- Electronic devices may act as distractions within the operating room (OR) care environment.

Introduction

Computers have become ubiquitous in modern life. Their use has penetrated every medical field and the practice of perioperative care is no different. Computers have given rise to the academic discipline of informatics, the study of information creation, storage, handling, manipulation, and presentation. Within health care this is referred to as medical, biomedical, or clinical informatics.

Computer Systems

At their most basic, computer systems are complex electronic circuits that perform mathematical operations (add, subtract, multiply, divide, and compare) on information available to them. Even the most complicated computer systems consist of these operations repeated millions of times per second, which collectively generate the activity specified by the user. Every operation performed within the computer begins with the retrieval of information in the memory, a mathematical operation within the processor, and the storage of the output of that operation back to the memory. This cycle of retrieval, processing, and storage repeats millions of times per second.

Software applications execute the instructions that a computer uses to process information. The operating system is the fundamental software that controls the communication among the components of the computer. The operating system controls the order in which a processor completes tasks, allocates memory among different applications, provides a structure for organizing files in the long-term storage, controls access to files, determines which applications may run, and manages the interaction between the user and the computer. Modern operating systems provide graphic interfaces that act as paradigms to describe the organization of information and methods of user-specified computer action.

A software application is a set of instructions for a computer designed to perform a specific set of tasks. Electronic health record (EHR) software is an example of a software application. Software may (via the operating system) interact with external hardware devices, data held in long-term storage, and the user by way of input devices and display devices.

Because of the proliferation of mobile devices, traditional laptop or desktop computer systems have been supplanted in many environments by tablets or smartphone computers. These devices are structurally similar to traditional computing devices; however, the operating systems and software applications feature user interfaces that have been re-engineered to support use by touch screen or voice control operation. These devices trade off computational power, portability (size- and weight-related), and duration of operation (battery power).

Computer Networks

Networks are the means for the exchange of information among computers, enabling the sharing of resources. These networks may be established using wireless (e.g., microwave radio spectrum) or wired connections (Fig. 4.1). Dedicated hardware (equipment) controls the sending and receiving of information across these links, with specialized devices required to ensure that information is sent correctly

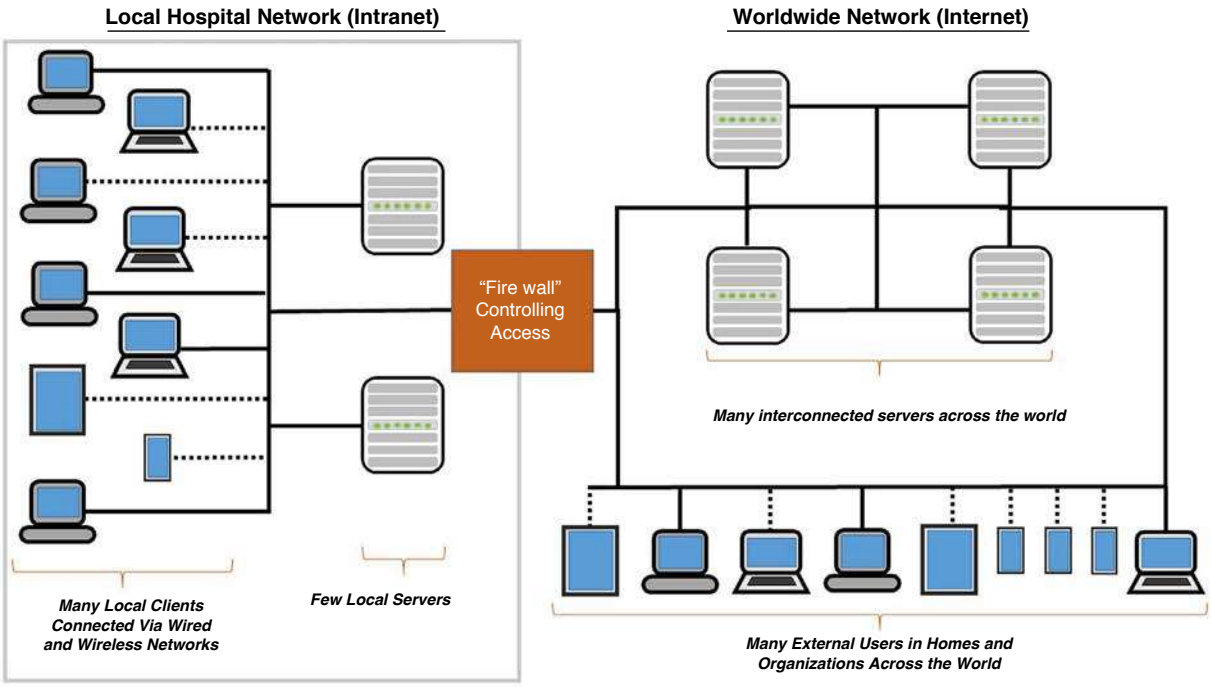

Fig. 4.1 Relationship between a local intranet (within an institution) and the wider Internet. Institutions may choose to use an external vendor to provide certain services hosted on external servers, this is referred to as "cloud" computing or services. Prevention of unauthorized access to the intranet from external parties while allowing users to access the Internet and other remote resources is of paramount concern. "Firewall" devices aid in the separation of the institutional network from the wider Internet and control access.

to the intended computers on the network. Software is used to ensure communication is performed according to predefined standards. In order for a computer to be accessible in the network, each computer must be given a unique address on the network so that information can be identified as destined for that computer. The process of obtaining and maintaining network addresses is performed within the local operating system and network hardware. This allows software applications to specify the information to be sent and the operating system and network hardware to manage how it is exchanged between computers.

Wired networks require the computer system and the receiving hardware to be physically connected by electrical or optical cable. This limits the flexibility in the connection points, which must be placed in preplanned areas, with any subsequent adjustments requiring re-routing of cables. However, information travelling on the network cannot be intercepted or accessed without physical access to the network cables or connection points.

Wireless network systems offer advantages of convenience and the ability to move around a work environment without maintaining a physical connection among the computer systems. However, this usually occurs at the expense of speed of information exchange. Information exchange via wireless links is an order of magnitude slower than the fastest wired connections. Because wireless systems require the availability of strong radio links between the computer and the network equipment, they are subject to issues of poor reception (possibly because of physical barriers) and interference, which manifest as inaccessible or degraded network performance. It is difficult to control the precise limits of where a wireless network is available (i.e., only within a building and not immediately outside of it), therefore processes to limit wireless network access to authorized users and to encrypt data transmitted across wireless links are required.

In practice, healthcare facilities use a blend of both wired and wireless networks to ensure that the advantages of each system are available to support the users.

In most settings, the network is organized as a "client-server" model. The computer that hosts the shared resources is referred to as the "server" and the computer accessing the resources is the "client." The server is responsible for ensuring the client is an authorized user of the shared resource (access control) and ensuring the resource remains available to multiple users, potentially by preventing one client from monopolizing the use of the resource.

The client-server concept stands in contrast to peer-to-peer architecture, whereby resources are distributed across systems, with each computer on the network contributing its resources (e.g., files or specialized hardware). All computers are both clients and servers in this arrangement. There is limited ability to control access in a planned and coordinated manner.

Use of a client-server infrastructure may allow for a significant amount of the computational tasks to be outsourced to the central server. When the client has very limited computational resources this is referred to as a "thin client." Computationally intensive tasks can be performed by the server and the client receives the results of the computation. Fundamentally, the thin client is viewing and interacting with a software application that is running on the server. The client is little more than a means of sending user input to the server and a dynamic display of application results. In order for this arrangement to work, there must be a limited, predictable set of software applications

that the client accesses on the server, with a reliable network connection. Without the network connection, the thin client has no functionality. This model may be easier to maintain because any changes are done centrally and need to be made once and then become available to every client connecting in.

An alternative model is the "thick client," where the client is capable of significant computational activities, retains a fully functional state when not connected to the network, accesses only the information required across the network, and processes it independently. However, these clients require individual maintenance.

A hybrid solution is the concept of "application virtualization," whereby a single software application is hosted and uses the computational resources centrally and the client systems access this application regardless of their configurations. This blends the advantages of a thin client—control of the application's availability, ease of maintenance, and ensuring compatibility (by not requiring any level of computational resources aside from running the connection to the server)—with users having a fully functional computer or device to use for the remainder of their tasks. Additionally, this hybrid enforces a separation between the information stored on the server and any applications running on the client and thus information can be secured within the server that is housed within the institutional network.

The Internet

The Internet is a global network of networks. Best known by two of the ways in which it can be used—websites and email—the Internet is at its simplest a method for transferring electronic information across the world. Internet service providers (ISPs) provide access to optical and electrical cables, which transfer information across the world. As these cables are all interconnected, multiple paths are available to transfer data at any one time. Routers control the flow of Internet traffic and ensure that it takes the most direct and fastest routes across the multiple paths available to it. Although the delay that a user may experience in accessing information varies widely and is dependent on many factors, the flow of information around the world can be measured in the order of hundreds of milliseconds or less.

Use of the Internet has led to the development of a series of technologies where computing resources are offered to multiple clients using an Internet connection as a means of distribution and interaction with the clients (see Fig. 4.1). These "cloud" platforms allow on-demand and scalable use of computing resources. Computing resources can be bought and sold based on the variable amount of time they are used or the amount of information stored; additional capacity can be flexibly added. These resources are accessible from anywhere with an Internet connection. Furthermore, cloud platforms give organizations the ability to transfer the management of the specialized computer hardware needed to provide these services to another party.

The integration of mobile phone data networks and the proliferation of increasingly powerful handheld devices (such as smartphones or tablets) has increased further the number of potential clients. For healthcare organizations, there is significant user pressure to be able to access healthcare information systems remotely or from these mobile devices.

The most ubiquitous usage of the Internet is in the delivery of "web pages." Information is stored on a "web server" and upon request from an application being run on a remote client computer (web browser), the information and display formatting instructions (i.e., size, shape, position of text, or graphics) are sent to the client. The web browser then interprets these instructions and displays the information according to the specified instructions. This process is highly dependent on well-defined and accepted standards of information exchange between client and server and rendering by the client.

These web pages have become increasingly sophisticated incorporating text, video, audio, complex animations, stylesheets, and hypertext links. Technologies have evolved into an interactive process that can dispense information specific to only one user (e.g., a record of the user's bank transactions) and that can be supplied in a manner that is generalizable to many different users (so all customers can access their bank transactions this way). When these instructions are assembled to generate specific business processes, they function as software applications that are web based and are referred to as "web applications" or "web apps." Interaction with web pages may lead to complex business processes being undertaken in the physical world. For example, the ability to buy a book over the Internet starts with a web page displaying the information and ends in someone delivering it to the door, with many physical steps in between. Healthcare organizations have embraced these technologies to support their delivery and administration of patient care, including scheduling systems, laboratory result reporting, patient communications, and equipment management systems, all of which are delivered in this manner.

Of note, information which is travelling across the Internet, without additional measures, is not necessarily private. A salient metaphor would be to consider the difference between information being conveyed in an envelope (where the contents are not visible) and information being conveyed on a postcard (where the message is clear to anyone who holds it).

Information Security

Although computing technology has significantly influenced the delivery of medical care, it has also brought a series of challenges that must be addressed. A major consideration is information security. Core to these considerations is ensuring that the correct information is available to the correct users at the correct time.

These threats to information security may come from within or outside an organization. Within organizations, an employee may access information that they are not authorized to so do or by transferring and storing it in an insecure manner. They may introduce security threats by using applications that may transfer information outside of the organization or by modifying an existing network by using a personal device. External threats may seek to improperly access information ("hacking") by obtaining passwords or

identities from legitimate users (via "phishing" attacks) or by introducing applications that degrade computer function to extort payment ("ransomware" attacks).

The paradigm used for controlling access to computing resources is users and accounts. Each person who uses the computer is considered to be a user. Users can be identified and mapped to real-world persons. Users may belong to groups that share common attributes. It should be known in advance which resources should be available to which users or groups of users. A group of users (i.e., anesthesia providers) may have access to particular resources (e.g., a document of anesthesia policies) but each user may also have access based on their individual parameters (e.g., an individual anesthesiologist may have sole access to his or her own private files). A group of users with similar functional roles who have a defined set of resource privileges is known as "role-based security." Changes in privileges affect all users in that functional group.

Users should be able to positively identify themselves; commonly this involves the combination of a username and password with the password being known only to the user and the computer system. However, other methods of authentication, such as biometric information (fingerprint, iris scan, or face scan) or physical access tokens (e.g., identification badges) are now commonplace. Password policies that enforce a mandatory level of complexity (minimum length, mixing letters and numbers, or special characters), specific expiry dates, and prevent password reuse are designed to make it harder for passwords to be guessed by an unknown party or to mitigate or minimize the risk of passwords being accessed or used externally. However, requirements for increasing complexity or frequency of changes may pose additional burdens on users that they consider unacceptable and may not decrease risk.

Organizations may also choose to adopt "two-factor authentication" methods, which can be summarized as requiring "something you know and something you have" to gain access to the computer system. The password fulfills the first part of this concept as it is meant to be known only to the user. Devices such as physical token code generators (which provide a predictable response to be entered alongside the password) or an interactive system (authentication via a smartphone application or phone call) may satisfy the second concept. Thus, in order for someone to impersonate the user they must have both the password (that may have been taken without the user's knowledge) and a physical device (that the user is more likely to detect the absence of). This makes remote access less likely because an external user on the other side of the world may be able to obtain or guess a password but is very unlikely to also be able to obtain the token or smartphone required for access.

Physical security is an integral part of information security. Ensuring that an unauthorized person does not have physical access to computer hardware or access to the means of connecting to that computer hardware are important considerations. This can be accomplished by physical measures (such as locked rooms, doors, and devices that prevent movement of computer hardware) and considerations of where computers containing controlled information are placed (to prevent an unauthorized person from having access to a computer that is available in a public area).

However, as alluded to before, these restrictions are balanced against desires for increased usability and portability of computing devices from computer users and the need to make information available to the provider at the point of clinical interaction.

Therefore, it is necessary to ensure secure access to information across wireless links and across the Internet. One method for doing this is to ensure that the information transferred is not readily visible along its means of transmission. This is performed by a group of processes known as encryption. Encryption is the process of transforming a piece of information from its original and accessible state to one that is not accessible and lacks meaning without an additional piece of information (an encryption key).

The transformation to and from encrypted text takes place in a manner that is relatively easy to perform with the known encryption key but is infeasible to do so without knowing this key. Encryption processes are based on mathematics involving multiplication of very large numbers, which creates many possible combinations of different factors that could have led to the same outcome. Therefore, it would be computationally infeasible, with current technology, to attempt to try all possible solutions.

External threats to an organization involve outside entities attempting to access services or applications that are meant for internal use only. Because healthcare organizations must be connected to the Internet to enable many information exchange functions, their data may potentially be available to every Internet-connected device in the world. "Firewalls" are used to ensure that only legitimate transactions and interactions with the external world are exposed to the internal hospital network. These hardware or software tools, collectively known as a firewall, prevent the creation of unauthorized connections from outside the organization to the internal computing systems. Firewalls can also limit the types of network traffic that are allowed to exit from the internal networked system. For example, it may restrict network traffic typically used for the sharing of files.

In order to allow legitimate external access, organizations may allow the creation of virtual private networks (VPNs). After appropriate authentication and verification, VPNs set up an encrypted path for information from an external Internet-connected computer to the organization's internal network. This allows the external computer to act as if it was physically connected to the organization's internal network and to access resources such as specialized software or shared files. This adds an additional layer of access security to the connection and ensures the communication is secure. A healthcare organization may require use of a VPN to access an EHR from outside the organization's network.

Standards for Healthcare Data Exchange

Although not always obvious, the EHR is typically an amalgamation of multiple computer systems and devices of various complexity. These systems exchange data according to common standards, languages, and processes.

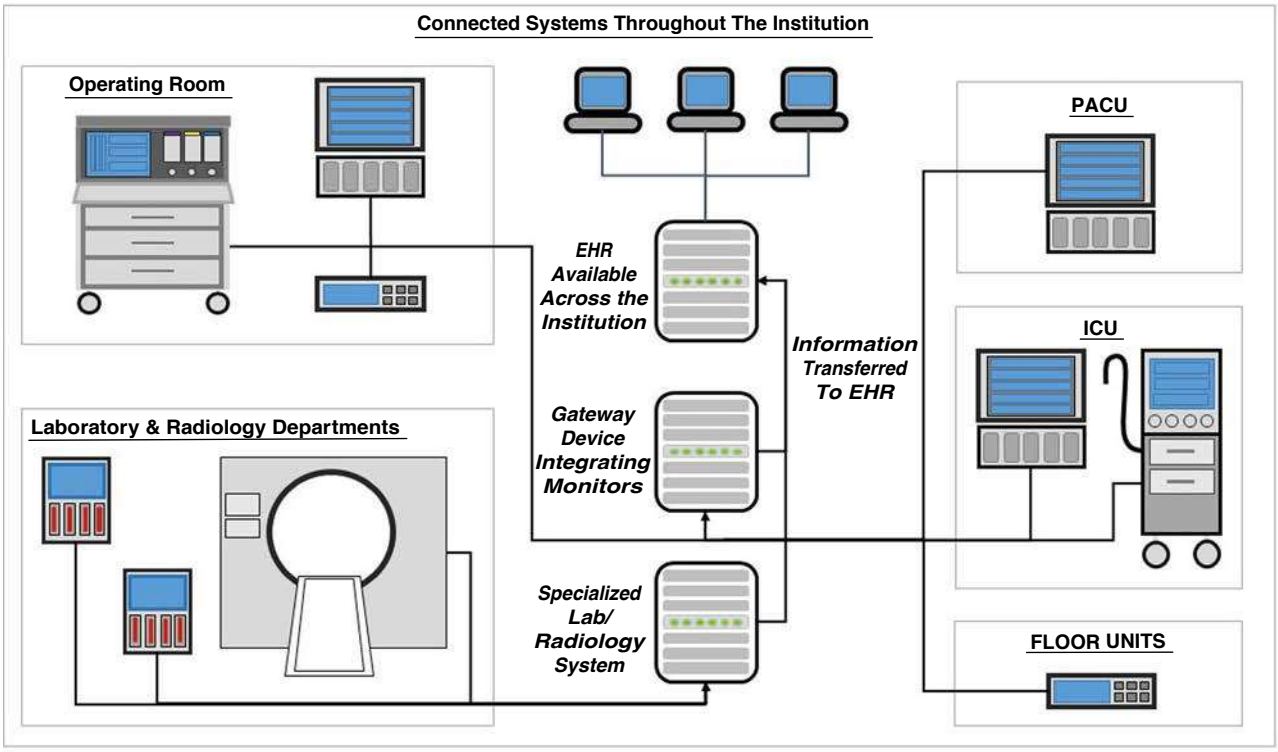

Fig. 4.2 Information flows from connected devices across the institution into the electronic health record (*EHR*). Some departments maintain specialized software to manage the needs specific to their workflow—for example Radiology departments using Picture Archiving and Communication Systems—that are interfaced into the EHR (i.e., to allow a report to be connected to the original CT scan). Similarly networked monitor data is made available by the use of a gateway interface device. *PACU*, Postanesthesia care unit

Common connections include monitoring devices that allow automatic transfer for measured parameters into the electronic chart, infusion pumps (recording programmed settings), laboratory instruments (blood gas machines, cell counters, biochemistry analyzers, point-of-care testing devices), or systems that manage patient admission, identification, and bed occupancy (admission, discharge, and transfer [ADT] system). All of these devices and systems need methods of communicating with the EHR (Fig. 4.2). Although in some situations it may be possible to use a proprietary standard for communication between systems, it can quickly become difficult to manage across an entire institution. As a consequence, a series of commonly used standards have been established that allow the communication of healthcare information.

The Health Level-7 (HL7) standard, originally developed in the late 1980s, is still used widely in the exchange of health information. HL7 allows the transmission of data in a standardized manner among devices and clinical systems. The information can be identified to a specific patient and organized into different data types, indicating laboratory results, monitor data, and billing information. It can also cause the receiving system to perform an action, such as update previously obtained data. The HL7 standard and subsequent derivatives that address the exchange of clinical documents in a structured and identified manner support communication among different clinical systems. However, this standard was based on data exchange within different software application systems within an institution and did not envisage the proliferation of Internet-connected devices remotely accessing shared resources across many healthcare organizations.

This new paradigm led to the development of Fast Health Interoperability Resources (FHIR). This communication standard is analogous to how modern Internet applications exchange data via simple standardized requests to a central resource. FHIR enables easier integration across different types of software and integrates security features necessary due to the proliferation of mobile devices. This standard is designed to facilitate the exchange of data regardless whether it is a single vital sign or a scanned document from a physical chart.

Regulation of Electronic Data Exchange

In the United States, the 1996 passage of the Health Insurance Portability and Accountability Act (HIPAA) established a common regulatory framework that defined health information and the processes by which it should be stored and transferred, and established powers to investigate concerns regarding noncompliance with these rules.

There are four major regulatory rules: the HIPAA Privacy Rule, Security Rule, Enforcement Rule, and the Breach Notification Rule. Each update is a complex regulatory document and professional advice should be sought on the applicability and relevance of each of these to a particular situation.

The HIPAA Privacy Rule details the allowable uses and disclosures of individually identifiable health information,

which is referred to as "protected health information" (PHI). Identifiers that are considered PHI are listed in Table 4.1. The privacy rule additionally defines the healthcare agencies covered by the rule. It defines processes that must be taken when working with business partners outside the healthcare agency through the creation of business associate agreements. Further, it establishes the concept of a limited data set, which is a set of identifiable healthcare information that is devoid of direct identifiers and can be shared with certain entities for research purposes, healthcare operations, and public health reasons; use of these is governed by "data use agreements."

The HIPAA Security Rule applies specifically to electronic PHI (e-PHI). The rule requires that e-PHI created, received, maintained, or transmitted by an organization should be done so confidentially and in a manner that ensures data integrity and availability. Additionally, the rule requires that threats to information security be monitored and measures be taken to mitigate these threats; this includes audits of computer systems to ensure unauthorized access has not occurred. The specification includes physical, technical, procedural, and administrative measures, all of which need to be undertaken for compliance. In general, the rule does not specify a particular set of computing resources that should be used, but instead specifies the standards to which they should be verified.

The HIPAA Enforcement Rule established the processes whereby a breach of the privacy rule could be investigated, and sanctions enforced. The Office of Civil Rights (OCR) within the Department of Health and Human Services (HHS) is responsible for receiving and investigating these complaints. Complaints may also be referred to the Department of Justice if it is believed that a criminal breach has occurred. Penalties for noncompliance can involve significant monetary fines or imprisonment in the context of criminal acts.

Finally, the HIPAA Breach Notification Rule defines what a breach of PHI data security is and obligates covered organizations to report to the OCR breaches of PHI that are discovered. Differing timelines for reporting apply, depending on if the breach involved greater or fewer than 500 individuals. Notification must also be provided to affected individuals and potentially to the media, depending on the number of individuals involved.

TABLE 4.1 Data Elements that Allow Patients to Be Identified

HIPAA IDENTIFIERS
Names
All geographic subdivisions smaller than a state, including street address, city, county, precinct, ZIP code
All elements of dates (except year) for dates that are directly related to an individual. Ages over 89 and all elements of dates (including year) indicative of such age
Telephone numbers
Vehicle identifiers and serial numbers, including license plate numbers
Fax numbers
Device identifiers and serial numbers
Email addresses
Web Universal Resource Locators (URLs)
Social security numbers
Internet Protocol (IP) addresses
Medical record numbers
Biometric identifiers, including finger and voice prints
Health plan beneficiary numbers
Full-face photographs and any comparable images
Account numbers
Any other unique identifying number, characteristic, or code
Certificate/license numbers

HIPAA, Health Insurance Portability and Accountability Act.
Adapted from https://www.hhs.gov/hipaa/for-professionals/privacy/special-topics/de-identification/index.html. Accessed March 3, 2019.

The Nature of Healthcare Information in the Anesthesia Encounter

In the conduct of anesthesia care, much of the information gathered could be considered as frequently-occurring structured data. That is, much of the information contained within the encounter can be categorized into one of a relatively small number of groups. This information is present commonly across anesthesia encounters. And the information itself can often be restricted to a small number of possible options—consider the example of an airway assessment.

This applies to information gathered in the preoperative phase of care (i.e., Mallampati classification from an airway examination) and the intraoperative phase of care (i.e., heart rate or systolic blood pressure). Furthermore, the intraoperative phase of care is marked by repetition of information at predefined intervals with measurements that may be taken in an automated manner (e.g., noninvasive blood pressure recordings every 3 minutes).

A majority of data gathered during an anesthesia case is structured, limited, and predictably repeated. However, the data are also voluminous with data generated and captured continuously on monitors, anesthesia machines, and medication pumps. More than 50 different parameters may describe a single minute of anesthesia care.

This is in contrast with the nature of the information captured in many medical specialties that are not easily constrained by content or structure. The documentation of a primary care visit may follow a standard format, however the number of variables captured may not be easily defined in advance or constrained to a standard structure; the range of possible issues to be documented may be too broad.

Anesthesia-derived data is well suited for capture into electronic charting systems. A number of mature commercially available systems are available for undertaking this task. These systems are often not standalone, and we will discuss how they are integrated in the next section.

Development and Deployment of Anesthesia Information Management Systems

Given the suitability for automated capture of recurring high-volume data, the concept of using computerized capture and storage for parts of the anesthesia record is not new. McKesson in 1934 described an early form of monitor that integrated with a vital signs data recorder (Fig. 4.3).[1] Early pioneering systems included the Duke Automatic Monitoring Equipment (DAME) System and its more compact successor, microDAME, which combined an internal monitoring platform with an integrated network architecture for central data recording.[2] Anesthesia Record Keeper Integrating Voice Recognition (ARKIVE) developed commercially in 1982 by Diatek included both a voice and touch screen interface.[3,4] Over time, other systems became available and these progressively morphed from being described as "anesthesia record keeping" (ARK) systems to "anesthesia information management systems" (AIMS) as the range of features and integration with other systems progressed.

Despite extensive development of a number of commercial systems, the use of AIMS was relatively limited in the early 2000s. Survey estimates suggest that by 2007 market penetration in academic medical centers increased from approximately 10% to approximately 75% by the end of 2014. By 2020, it is estimated that market penetration will reach 84% of all medical centers.[5-7] In the United States, the implementation of EHRs has been encouraged by federal government financial incentives including the American Reinvestment and Recovery Act of 2009, which authorized up to $11 million dollars per hospital to finance the adoption of health information technology.[8]

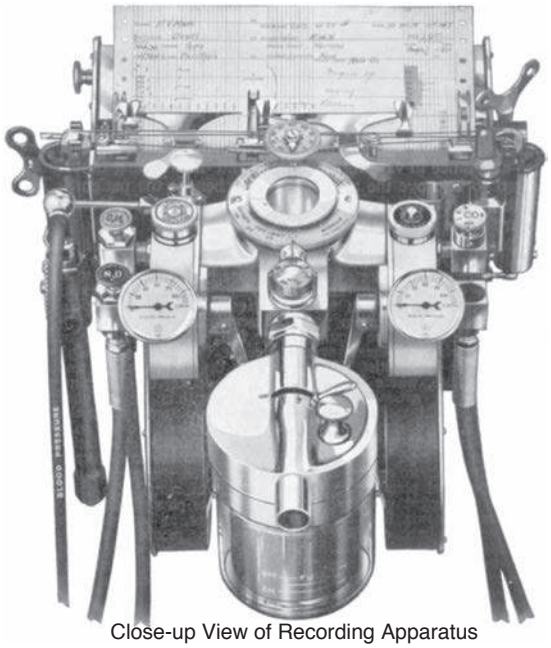

Fig. 4.3 McKesson's apparatus for the automated recording of physiologic recordings and gas mixtures. From 1934. (From McKesson EI. The technique of recording the effects of gas-oxygen mixtures, pressures, rebreathing and carbon-dioxide, with a summary of the effects. *Anesth-Analg.* 1934;13[1]:1–7 ["Apparatus" Page 2])

The adoption of health information technology has resulted in the increasing integration of the anesthesia record with other clinical systems. The American Society of Anesthesiologists (ASA) has produced a statement on the documentation of anesthesia care.[9] Such systems can be used to fulfill clinical documentation needs; however, much of the promise of these systems is in the potential for integration with the broader hospital environment and secondary uses of the data that they potentially facilitate.

ANATOMY OF AN ANESTHESIA INFORMATION MANAGEMENT SYSTEM

A mature AIMS must be capable of (1) recording all aspects of the anesthesia encounter (preoperative, intraoperative, and postanesthesia care unit [PACU]); (2) must automatically gather the high-fidelity physiologic data generated by monitoring platforms and anesthesia machines; and (3) must allow the anesthesia provider to record observations regarding the conduct of the anesthetic. These three simple requirements allow us to closely specify the anatomy of an AIMS.

The first requirement for access of the same patient record during multiple phases of a case suggests the use of a system organized on a computer network, where the computer record is maintained on a central server and accessed by multiple clients. This capability requires accessibility of computer workstations at each patient-care location to facilitate documentation. The computer must be accessible during the clinical interaction but in a way that does not interfere with this interaction, which is both an issue of ergonomics and of provider behavior. In the operating room (OR), the system should be directly accessible at the time of clinical care to allow contemporaneous documentation without the anesthesia provider physically moving away from the patient or care area. In many deployments, this is achieved with a computer mounted to the anesthesia workstation alongside the monitoring equipment. Because the computer hardware is located in clinical environments, these may become contaminated with pathogens and it is important that the hardware can be cleaned in a manner that is compatible with infection control policies.[10,11]

The second requirement for automated capture of data from OR monitors and anesthesia machines is some form of interface device between the computer hardware and the hemodynamic monitors, anesthesia machines, and other patient-connected equipment (infusion pumps or ventilators)—Table 4.2. In most AIMS implementations, this interface occurs at a central level, where a network of the physiologic monitors and the central server hosting the AIMS communicate via a gateway device. Typically, interfaces use standardized data formats, such as those described earlier that transmit communication among devices and software solutions from different manufacturers and developers. Interfacing these devices with a computer network may require specialized hardware and additional cost. However, the interface enables the automated capture of

TABLE 4.2 Examples of Parameters Commonly Included in the Anesthesia Record Gathered Automatically from Different Sources

FROM CORE PHYSIOLOGIC MONITOR
Arterial blood pressure (systolic, diastolic, mean)
Cardiac index
Cardiac output
Central venous pressure
End tidal CO_2
Heart rate (ECG monitoring and SpO_2)
Intracranial pressure (ICP)
Noninvasive blood pressure (systolic, diastolic, mean)
Pulmonary artery pressure (systolic, diastolic, mean)
Pulse pressure variation (PPV) and systolic pressure variation (SPV)
Saturation of peripheral oxygen (SpO_2)
ST segment analysis
Systemic vascular resistance
Temperature (all sources)
FROM STAND-ALONE DEVICES (MAY BE AVAILABLE WITHIN SOME CORE PHYSIOLOGIC MONITORS)
Acceleromyography value
Cerebral oximeter (NIRS)
Continuous cardiac output measurement devices
Level of consciousness monitors
Mixed venous oxygen saturation (SvO_2)
FROM ANESTHESIA WORKSTATION
Fraction of inspired oxygen (FiO_2)
Fresh gas flows: oxygen, air, nitrous oxide
Volatile anesthetic agents (inspired and expired concentrations)
Minute volume
Nitrous oxide (inspired and expired concentrations)
Oxygen (inspired and expired concentrations)
Peak inspiratory pressure (PIP)
Positive end-expiratory pressure (PEEP)
Respiratory rate (ventilator and $ETCO_2$)
Tidal volume
Ventilator mode

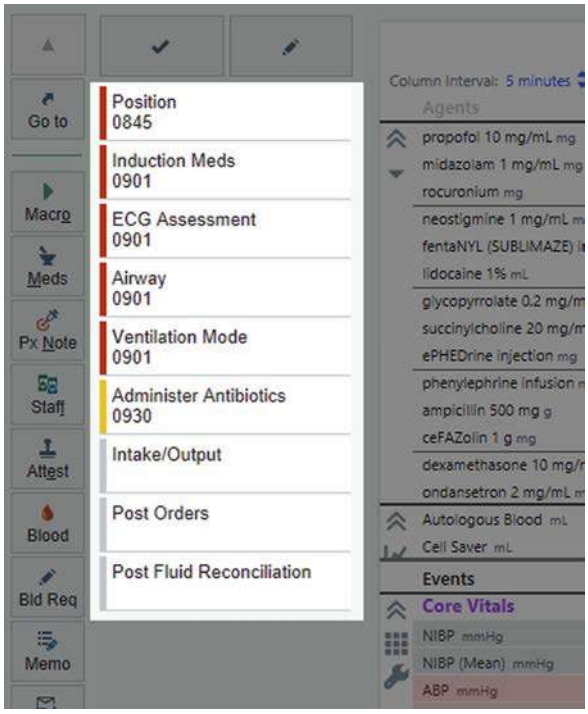

Fig. 4.4 A pre-defined set of charting elements for a given case. These may function as an example of passive decision support built into the EPIC Electronic Health Record Anesthesia Documentation (EPIC Systems, Verona, WI). The macro *(highlighted)* prompts the user to complete next documentation element. The "Administer Antibiotics" acts as an *aide-mémoire* reminding anesthesia providers that this is likely the next step in the process of care. (Image: © 2018 Epic System Corporation. Used with Permission.)

monitor and anesthesia machine data, freeing up clinical providers from the recording of these data elements. In light of the cost and practical challenges, some AIMS situated in low-resource settings (e.g., an office-based anesthesia location) may choose to eliminate the data interface feature.

Theoretically all electronically generated data can be recorded in the AIMS. As a consequence, the anesthesia provider must determine how much data should be incorporated into the system. Although some monitoring data is obtained with a defined frequency, such as a noninvasive blood pressure measurement taken every 3 minutes, most parameters are sampled from continuous data sources. In the OR, a pulse oximeter is not a single parameter checked at a discrete interval, but a continuous source of data. Continuous data sources (e.g., electrocardiogram [ECG], pulse oximeter, invasive blood pressure, or end-tidal carbon dioxide [$EtCO_2$] tracings) are transformed into measures that can be recorded with lower data intensity requirement, a process known as sampling. An ECG tracing may be sampled and interpreted to report heart rate and ST segment analysis results. Although it is technically possible to record continuous sources of data electronically for future review, this usually does not occur because the resulting data stream is difficult to present, archive, and review. Therefore, continuous data sources are usually reported as sampled values at a prespecified frequency.

The third requirement of an AIMS is to allow the user to annotate information (e.g., medications administered, descriptions of procedures performed, annotations to describe significant clinical events, or attestations for regulatory compliance) to the automatically collected data. Because of the similarity of one anesthesia encounter to another, some charting elements may be predefined to facilitate these documentation tasks and minimize the use of nonstructured or "free text" entries. Because of the possibility of similarity among cases, many systems use organized templates (sometimes referred to as "scripts," "templates," or "macros") that give the anesthesia provider easier access to charting elements required for a specific case type (Fig 4.4). For example, a cardiac anesthesia template may make charting elements regarding cardiopulmonary bypass

prominent and easily selectable. These charting elements and templates are typically customizable at each installed site, thus providing flexibility in documenting site-specific practices or procedures.

Although the three AIMS requirements described give some specifics about how a system may be constructed, they are minimum requisites. The AIMS that only provides these requirements is not one that would be considered high value. The major advantages of AIMS come from their integration into other clinical systems and healthcare processes, which will be explored in the coming sections.

ADVANTAGES OF IMPLEMENTATION OF AN ANESTHESIA INFORMATION MANAGEMENT SYSTEM

The shift to an AIMS is a key improvement in the quality of clinical documentation. Removing the task of manual documentation of physiologic parameters has not been shown to decrease vigilance to the clinical situation and may free up anesthesia providers to perform other tasks.[12-15] An AIMS also establishes an independent, unbiased record of monitoring and machine data. Finally, legibility issues noted in handwritten charting are resolved by the use of an electronically assembled record.

Early studies compared blood pressure values recorded in handwritten charts and those recorded by automated collection. The blood pressure recordings on handwritten charts had lower maximum systolic pressures and higher minimum diastolic pressures when compared with automated collected values in OR studies.[16-18] This variation has been termed the "smoothing effect" of handwritten charting and may result in loss of clinically meaningful data.[16,19] A subsequent study demonstrated that errors in handwritten charting were clustered during high-intensity periods; that is, induction, emergence, and significant clinical events.[20,21]

Although documentation of physiologic parameters may be more complete in AIMS-charted records compared with handwritten charts other data elements may remain incomplete.[22,23] As AIMS deployments have matured, it has become apparent that documentation quality varies among providers and important clinical fields can often be left incomplete, particularly when completion requires the entry of free text.[24] Medication administration has also been incompletely documented or omitted in the AIMS compared with observed practice with a similar effect of inaccuracies occurring during high intensity periods of care.[25] AIMS support degrees of customization, including designating certain data elements as mandatory prior to completion of the case, but the decision to add more mandatory elements must be traded off against risks of arbitrary data entry ("clicking through") or provider frustration, both of which detract from the aim of improved data quality.[26] It is clear that the system design and decisions made for default values or required data elements have significant influence on the quality of record created.

One solution to the challenge of excessively burdensome documentation requirements is to use an adaptive method that changes the required elements for documentation based on the clinical context—for example, requiring documentation of bilateral breath sounds in cases involving an endotracheal tube, but not with an laryngeal mask airway.[26]

In addition, to improve compliance with the capture of individual, high-priority data elements alternative strategies may be employed. Real-time provider notification by text page for allergy or procedural notes has demonstrated increases in completeness of this documentation.[27,28] Non-real-time feedback, via dashboards, email feedback, or informational campaigns may leverage AIMS data to improve data element completion.[29] These effects may be sustained past the interventional period.[27,29]

Integration with billing processes allows the automated capture of case elements necessary to facilitate anesthesia billing, such as care start and stop times, details of the surgical procedure for which anesthesia care is being provided, the nature of anesthesia care, any separately billable procedures, and the involved providers. This information can be extracted by reporting functions and integrated with the patient identifiers. Compared to solutions that require the manual review of copies of paper records, AIMS-based workflows offer significant overall process efficiency gains; although some designs unfortunately redistribute administrative tasks to point-of-care clinicians. The potential impact of AIMS use on anesthesia procedure includes improving capture of data elements needed for billing, improved documentation to support billing of anesthesia procedures, and billing capture at time of clinical care leading to more rapid processing.[27,28,30,31]

An advantage of an AIMS system is the ability to check concurrency of anesthesia providers across one entire organization in real time. In the United States, an "in-room" anesthesia provider must be physically present when anesthesia care is provided at all times. This is typically documented by "sign in" and "sign out" documentation times. An in-room provider may be supervised by a supervising provider who may supervise a number of ORs up to maximum specified by institutional or payer policy. The AIMS system can, at time of sign-in, check that no in-room provider is documented in more than one OR simultaneously and no supervising provider exceeds the prespecified supervision ratios. Checking at time of sign-in assures that these standards are not violated by documentation errors and prevents delays in the billing process. In certain billing environments, violation of the concurrency rules may cause rejection of claims at the time of billing.

Providing an anesthesia record that can be accessed concurrently by multiple users may facilitate remote monitoring of care being provided by the in-room anesthesia provider by a supervising anesthesia provider. This increased visibility of patient care being provided at each care location allows the supervising provider to maintain a better level of awareness on the course of the case and gives the supervising provider additional guidance on management decisions. OR managers benefit from similar insight and may be able to make decisions about resource utilization based on the documented care.

Integration of Anesthesia Care Information with Operating Room Information Systems

Given the necessity of maintaining information regarding locations of care, case, patient, staffing, and case progress, it is natural to integrate anesthesia information systems with OR

management systems. These systems are used in the scheduling of OR cases and assignment of staffing and supplies.

ORs are finite resources. There are a set number of available rooms, set number of available staff for these rooms, set times of availability of these staff, defined experience and specialization of these staff, and finite amount of specialist equipment for use in the rooms. As a result of these factors, ORs create enormous costs prior to any procedure being performed; efficient allocation and utilization of these resources are tied to financial outcomes of a hospital.

Each procedure performed requires allocation of procedural space, staff, and equipment that may be specific to the particular case. Therefore, it makes sense for this to be coordinated in a centralized manner. OR management systems are designed to accomplish this task controlling the allocation of these resources. These systems allow these resources to be allocated both generally (e.g., on Mondays OR 12 is dedicated for thoracic surgery cases [block scheduling]) and also specifically (e.g., John Smith is undergoing a right upper lobectomy by Dr. Jones from 11 AM to 1 PM on August 20), and further allocate staff and equipment to this procedure (case scheduling). Case scheduling may be enhanced by using historical procedural lengths to estimate future time needs stratified by proceduralist and specific procedure to be performed.

Scheduling of a case by a specific proceduralist allows the generation of a specific list of required equipment/instruments to be recalled based on anticipated requirements and proceduralist preferences. These "case pick lists" of "surgeons preference cards" can be used by supply teams to ensure that necessary equipment is available and predict future utilization.

The integration of OR management systems with AIMS provides the cases and procedures against which charting functions can be performed. Furthermore, communication between these systems can create common charting, such as phase of procedure (induction, procedure begun, procedure complete, etc.) which can be useful in understanding utilization of the OR environment for daily management and ascertaining longer-term trends. Given the enormous fixed expense incurred in the OR suite, an extensive literature has developed from the analysis of information derived from these systems regarding variability in procedure time, "turnover time" between sequentially scheduled procedures, and effect of variability of anesthesia-related case timings.[32-37]

A more recent trend is the integration of the AIMS and Operating Room Management Systems with the wider hospital-wide or "enterprise" EHR. This occurs via the development of specialized modules which account for the differences in workflow between the OR environment and the inpatient floor/ward units. These systems leverage common patient information—such as patient identification, demographics, registration, and location—then add specialization discussed above. Furthermore, this allows medical documentation, and laboratory and other diagnostic results to be made available to the perioperative providers on a single computer system.

One of the larger contrasts emerging from the OR workflow versus the rest of the inpatient environment is the process of medication documentation. When using an inpatient EHR, a provider enters a computer-based order for the routine administration of a medication. After pharmacy verification of the order, the medication is delivered to the appropriate unit for administration to the patient by a bedside nurse. In the OR environment, the medication administration decision making, selection of the medication from a pre-stocked cart, and administration is handled by an individual providing anesthesia care. This shortens the time from provider intent to patient administration. Therefore, the documentation needs to reflect the concept of care provided rather than care to be provided in the future (i.e., scheduling a medication to be administered). Given the high intensity of medication administrations, short time interval between administrations and supply from the bedside cart of the medications to be administered, the ideal documentation system should not be burdensome and allow rapid entry.

A number of features of the inpatient EHR are unavailable due to this mode of medication administration and documentation: positive identification of the patient and medication with a specified order—typically performed by "barcode" scanning of medications and patients at time of administration—is not performed as medications are typically documented retrospectively, although patients are positively identified at the beginning of each anesthesia care encounter. Additionally, automated medication interaction, dose, and allergy checking may not function in the context of perioperative administration due the practice of retrospective documentation. As the documentation of anesthesia care is quite different from that of most medical interactions. The differences in workflows must be accounted for in the development of modes of interaction and creation of documentation.

While most medications administered in the OR have a relatively short duration of action, there are important cases where medications which are administered in the OR have important consequences beyond the OR. Examples such as neuromuscular blockade, long-acting opioids, long-acting local anesthetic agents, and antibiotic administrations all may lead to important medication interactions well beyond the OR or need for modifications of postoperative care. Therefore, information regarding these administrations must be available to care providers working in the postoperative period. The use of "stand-alone" AIMS may contribute to a failure of communication of the use of these important medications. Interfaces between the stand-alone systems and enterprise EHRs allow this information to be communicated, however this poses additional development, maintenance, and deployment burden. Similarly, documentation of difficult airway management in the OR has impact beyond the OR as the patient may require emergent airway management in the intensive care unit or during future visits; information gleaned during the perioperative encounter may have enduring value to many other providers.

Development of Decision Support Tools

One of the most exciting promises of AIMS and enterprise EHRs is their ability to improve patient care by improving the decisions made by providers.[38] While medical decision making must be provided by responsible care providers, it is possible to aid decision making by providing default choices that support particular practice patterns, suggesting options which may be appropriate based on the type of care (see Fig 4.4), providing additional notification of important updated trends or results, and providing alerts based on the integration of multiple pieces of information. The former

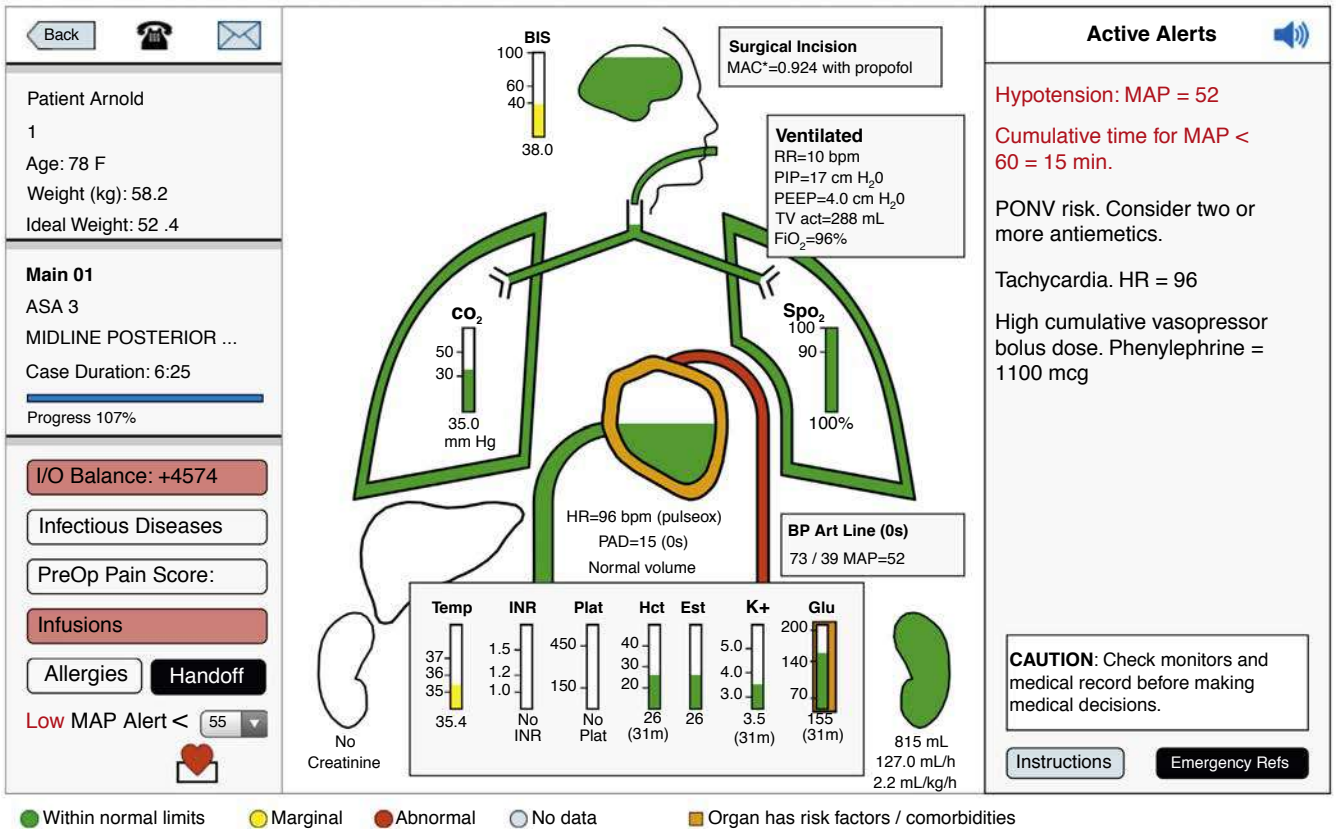

Fig. 4.5 The Alertwatch OR (Alertwatch, Ann Arbor, MI) multiparameter decision support system, illustrating the physiologic status of a patient under anesthetic care. This integrates data from physiologic monitors and electronic health record elements. Based on pre-specified rules it prompts providers to consider a specific course of action or indicates additional markers of patient state. * Indicates a calculated additive MAC value of inhaled agents and propofol and dexmedetomidine infusions.

two are examples of passive decision support, the latter two are examples of active decision support. Collectively these tools are referred to as decision support and are an integral part of the perioperative information system.[39]

PASSIVE DECISION SUPPORT SYSTEMS

In considering these tools it is helpful to move from the simplest to the most complex. At the simplest level in the configuration of the perioperative information system, decisions regarding the choices presented to users (default doses, units, and range checks) may act as prompts for users in their selections—the so-called anchoring effect. This is an example of passive decision support. Over time it is important to continue to assess how usage aligns with users' practice to ensure that the default options presented do indeed capture the typical usage at a particular institution.[40]

Systems for the documentation of anesthetic care typically feature methods for documentation of aspects of clinical care which cluster together based on aspects of the procedure, anesthetic technique employed, or location of service. For example, a template for cases performed via a spinal anesthetic would not be configured to require documentation of the endotracheal intubation technique as these do not frequently overlap. These can form the basis of decision prompts for providers; for example, in a cardiac case, the charting element available immediately after documentation of full cardiopulmonary bypass may be regarding discontinuation of mechanical ventilation. This may act as a reminder to the provider to perform this task. The level of sophistication of these prompts depends on the time devoted to their construction at the time of system installation and configuration.

One feature to improve documentation is the utilization of mandatory documentation elements that are required prior to the completion of case documentation. Extreme care needs should dictate what elements of documentation should be made mandatory. There are likely exceptions to even the most universal documentation element and forcing completion or entry of such items may undermine trust in the entirety of the clinical documentation.

ACTIVE DECISION SUPPORT SYSTEMS

In the intraoperative space, a number of more sophisticated approaches to decision support have been developed (Fig 4.5). These decision support tools continuously evaluate the medical record for incoming information and provide feedback to the user. These tools may be separate from the EHR but access the information being recorded by that software. These tools apply rules to alert providers to aspects of care which may have been overlooked or need to be addressed. This may guide users to re-evaluate patient status (if a blood pressure monitoring gap is detected), or consider additional interventions (prompts to treat extremely elevated blood glucose) or alternative management strategies (e.g., if large tidal volumes are being used).[41-46]

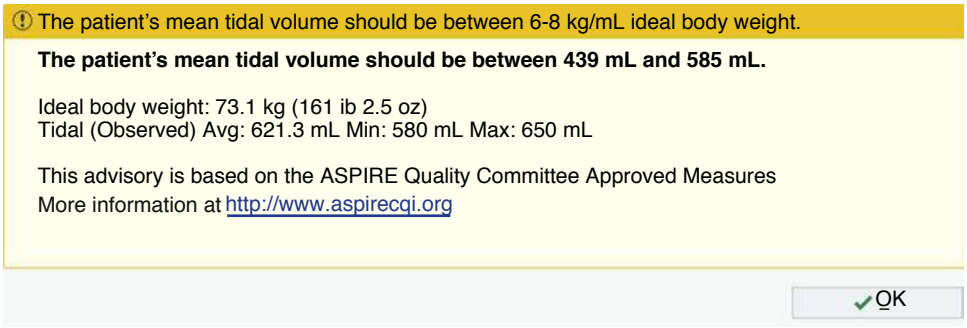

Fig. 4.6 An example of active decision support. Providers prompted to consider the tidal volume, with information which may allow them to consider change in clinical practice. This alert is triggered in the context of an averaged measured value which is above a predefined threshold. Image: © 2018 Epic System Corporation. Used with Permission.

In order to function, these more sophisticated forms of decision support are designed around a common architecture. They run in parallel with the clinical documentation functions of the EHR. They may be built into the EHR (Fig 4.6) or may run as separate software alongside the EHR (see Fig 4.5). Regardless of the specifics of the software implementation, it is best to consider the construction of these systems as being in components.[39] In addition to the modules which capture incoming device data and enable provider manual documentation, three additional modules are added.

The first module is a component which allows a user to define a series of rules against which the incoming information will be assessed. These rules should define the population to which the rule applies (i.e., patients aged over 18 undergoing surgeries in the main hospital operating rooms), the details of the rule (i.e., determine if blood glucose value is >300 mg/dL), and then the proposed action (i.e., notify provider of this finding by text page or display a pop-up window in the EHR software). The second component is the surveillance process which repeatedly assesses the patient status against the rules using newly updated laboratory results, charting elements, monitor or device data; the process determines when a rule has been triggered. The final component is the notification module; this is the method of interacting with the user. This may be within the EHR (as a pop-up message at the front of the patient's attention), separate to the EHR (in dedicated software running on the anesthesia workstation to display notifications regarding patient status), or alternatively may use a completely separate means of communication such as text paging, text messaging, or even phone calls.

Calibrating the alert to the clinical scenario is important and should take into account the lead time involved in data acquisition and notification. If an EHR obtains updated monitor information every minute, the rules require repeated values (to ensure non-artifact) and the output system has a 1-minute lag time, then this restricts the kinds of clinical events which are best addressed via this system. Second-to-second changes (such as in oxygen saturations) translate poorly through systems which have delays in the order minutes.[47] Therefore it is important in the design of decision support systems to target the correct events and recognize that extreme or rapidly occurring events may best be addressed via alternative notification systems or embedded into clinical monitors at the point of care.

The other key consideration is who is the intended recipient of the clinical decision support alert. In the US practice setting, there may be providers responsible for anesthesia care who are both within and outside the anesthetizing location. Alerts for providers in the OR may focus on supporting clinical decisions and selections, whereas those which are targeted at the supervising provider may be best focused on ensuring that the provider retains awareness of the current state of the OR cases being supervised. A provider in the role of OR anesthesia supervisor or manager may have additional concerns regarding allocation of anesthesia resources to support the anesthesia care being provided; notifications of significant deviations from schedules or occurrence of emergency events may be relevant to this group.

Various tools are available which incorporate these features. As discussed earlier, many passive decision support features are built into the EHR software natively. While more active decision support systems may be integrated into the EHR software it is also possible that this may come as part of stand-alone software which provides a mechanism for delivering these alerts to providers. More sophisticated implementations may additionally attempt to provide information about overall patient state drawing widely from EHR-derived data elements. This may be of use to providers in supervisory or OR manager roles seeking snapshots of the course of care.

IMPACT OF DECISION SUPPORT IN ANESTHESIA CARE

Evaluation of implementation of clinical decision support in anesthesia care has typically been focused around specific aspects of care, usually process measures. Examples include changes in ventilation parameters, perioperative β blockade, antibiotic administration, blood pressure management, administration of postoperative nausea and vomiting (PONV) prophylaxis and decreases in anesthesia agent usage (by reductions in fresh gas flow).[44,48-58] What is less well established is the relationship between clinical decision support and relevant patient outcomes. Perioperative decision support tools in the domain of perioperative glucose management in diabetic patients has been able to demonstrate differences in surgical site infection alongside improvements in perioperative glucose control in a single-center study.[59] It is likely that measurable changes in patient outcome do not come from use of a single decision rule in most

circumstances. Therefore, patient outcome impact is more likely in systems which include multiple elements in their decision support; this type of implementation is not widely implemented or studied. This is supported by a single-institution study which has demonstrated that deployment of a multiparameter perioperative decision support system may reduce hospital charges and therefore resources.[45]

Integration with the Enterprise Electronic Health Record

Given the substantial shared pool of information from which the AIMS and the enterprise EHR may draw on and contribute to, it is not surprising that these systems have become integrated at many institutions into a single system. It is important to note that this increases the complexity of the EHR. For organizations where the IT support for an OR or anesthesia information system was supported and maintained through an anesthesia or surgery department relationship, the migration to an enterprise EHR will result in these duties being transferred to the hospital or enterprise-wide support group. This may reduce the customizability of these systems as changes and alterations now become handled by groups with broader responsibilities and competing priorities.

An emerging feature of EHRs, which fulfills an early promise of their utility, is meaningful transmission of data from different EHR platforms across institutions. Typically, each institution maintains an EHR that is unique to that institution. As smaller medical practices have aggregated into larger health systems, providers come under the same umbrella EHR system. This has allowed records from more health interactions to be available in a single location; a satellite clinic in a physically separate location may use a health–systemwide common EHR for documentation, making it available to the anesthesiologist who sees the patient presenting for surgery at main campus. However, when a patient presents to a nonaffiliated practice or hospital, documentation from the other institutions are unavailable and have to be obtained as printed paper, or communicated by the patient manually.

To address this issue, healthcare information exchanges (HIE) have been developed. These exchanges facilitate the transfer of health information between multiple distinct healthcare system's EHRs. This can occur in a directed way: a user at one facility chooses to send imaging data to another and uses the EHR's HIE user interface to discover records available via the HIE. These come in multiple forms but are typically based on a geographic (i.e., at the state or regional level) or a shared EHR platform (i.e., EPIC Systems Care Everywhere functionality).

In order to function, HIEs must be able to correctly match the same patient across different hospitals or clinics. Failures of this process (both incorrectly matching two patients across institutions or failing to match the correct patient across institutions) could have potential for catastrophic consequences in clinical care. Matching must consider different identifiers used at each hospital; a medical record or registration number is usually unique to the institution so is not suitable for this task. Additionally, unique identification assigned for other reasons—such as social security numbers—may not be suitable for this task as their use may shift over time and the accuracy may not match the level of confidence required for medical care. Furthermore, social security numbers may pose risk to patient privacy as they are connected to multiple other datasets including financial records.

Typically, combinations of identifiers are used to uniquely identify patients. This is joined with logic that balances a degree of uncertainty to account for the challenges previously noted with the risks of failure to match and false matches. However, this may still lead to the exchange of patient identifiers. Cryptographic solutions may be employed to prevent the need to exchange patient identifiers.

In some situations, even acknowledging the existence of a record may be revealing and pose risk to patient privacy—for example a record existing in a clinic specializing in the treatment of a particular illness may cause an inference to be drawn about a particular diagnosis. One way to minimize this issue is to limit the links to another health system's records to patients in common at the source health system. Rather than allowing a user at one institution to search freely for patients at another institution, such an approach would allow users to access the "matched" patient records at another institution only. Access to remote systems could further be controlled to limit it to the context of an active patient-provider encounter. Each of these options contains trade-offs with maximizing information availability with patient privacy.

Billing System Interactions

Billing for hospital services involves capturing accurately the resources used in the delivery of care; for example, in the perioperative setting, OR and PACU times, or specific surgical supplies and equipment used. This is recorded via the OR management system and may be linked to a broader process which manages surgical supplies, resource utilization, and scheduling. In this manner, information captured as part of OR clinical care documentation may be reused for billing, supply, and utilization management. The management of information in a centralized EHR accessible by multiple users enables simultaneous use for clinical, operational, and administrative reasons. Automated export of documented parameters may form the basis of these other uses.

In the United States, professional charges for anesthesia care are based on the duration of the care provided and the procedure for which the care is provided. Additional charges may be possible for specialized monitoring, specialized vascular access, or pain management procedures provided for postoperative analgesia. Data necessary to aid the billing process can be extracted from the EHR: for example, basic case information such as duration of anesthesia care, ASA physical status classification, staff providing for anesthesia care, and procedure performed. Reports can be run at or near to the conclusion of the anesthesia care and allow a case to be rapidly

turned over to the billing staff for further processing. This may speed up the billing process and make it less dependent on paper billing sheets or other means. The implementation of automated billing alerts via text paging and email have been shown to increase prevention of documentation practices that may have been erroneous and alter reimbursement, reduce time to documentation being complete and ready to be billed, reduce time to correct errors, and increase capture of arterial line placement leading to increased reimbursement.[28,30,60]

Challenges in Anesthesia Information Management System Implementation

Just as the OR must be available for emergencies at all times, the underlying perioperative information systems which capture this activity must also be highly reliable. Despite architecting extensive EHR redundancy, backup processes must be available in cases where the system is unavailable due to hardware and software failures, or in times of planned maintenance. Typically, these result in reverting to a paper-based system for the limited periods of planned or unplanned downtime. Processes must be in place to determine how documentation captured during these downtimes is subsequently handled.

Due to the complexity of these systems it is possible that certain elements fail without the entire system becoming unavailable. For example, if the link between the monitoring platform and the AIMS system becomes unavailable, anesthesia providers may have to respond by manually entering monitoring data. Importantly, this data link failure has to be recognized. Unfortunately, it is unlikely that manual data entry will replicate the degree of completeness of the automatically gathered information. Concerns have been raised of the possibility of legal liability arising from such scenarios.[61]

In all situations where electronic records are created, a plan needs to be created to ensure that access in the future is preserved. Medical records retention requirements vary significantly by state. These typically extend for a period of time past the last contact with the health service, even up to 10 years beyond that period for adult patients. For minor patients, this period typically extends beyond the time in which the patient reaches the age of majority, even up until the patient turns 30 years old. These time periods may extend past the life expectancy of the software which created the records. Operators of EHRs, including those in the perioperative period, need to have a plan in place to ensure that data can be archived, retained, and remain accessible in line with these legal requirements.

Even with the most comprehensive of EHRs there may be a need for a physical medical record to be created as part of care—consent forms may be provided on paper, patients may write letters to their providers, and outside hospitals may send printed or paper records with a transferring patient. Decisions need to be made as to how these physical documents are retained and archived. This may involve making electronic copies which become available within the electronic record.

In situations in which separate systems are used in the perioperative process from the rest of the institution there may be situations where a paper record is printed and placed inside a patient's physical chart. When a paper record and an electronic record exist simultaneously at a given institution, then a decision needs to be made as to which has primacy. If a provider creates a paper record at the end of anesthesia care and then subsequently updates a documentation element at a later time, a process needs to be in place to ensure that this can be transferred to the patient's physical record for the paper record to maintain primacy.

Additionally, if differing systems are used in the perioperative period there may be failure of communication of important information to the entire healthcare team. While specific examples regarding medications with prolonged duration of action and challenges in airway management have been discussed above, the siloing of information in a separate system (potentially with different access requirements) contributes to the appearance of the perioperative period as being one which is completely distinct from the rest of the clinical encounter. This can contribute to failures of communication of events which occur during this important phase of care and thus potentially patient harm.

Ensuring coverage of all locations where an anesthetic may be performed can be challenging. There may be many sites where anesthesia care is provided infrequently. These are likely "non-operating room sites." In such cases the economic justification for the capital investment required to allow these sites to participate in electronic charting may not be justified. In such situations, cases performed in non-connected locations may require traditional paper charting. This creates a significant overhead as business processes need to be maintained to support the documentation of activity in these locations and ensure that the paper documentation is archived as the record of care, available for billing processes and quality assurance review.

Additional Uses for Collected Data

Secondary use of EHR data has become commonplace and is part of the value proposition of the transition to these systems. In addition to the primary purposes of clinical documentation, operational and support tasks, information contained within the EHR may find secondary uses including in the ascertainment of practice quality measures and research endeavors.

USE FOR MEDICAL RESEARCH

The rapid emergence of AIMS led to a proliferation of research into anesthesia care practices and outcomes. This proliferation has occurred because of the improved ease with which study data may be acquired. Queries of the underlying EHR databases are far quicker to perform and may be more extensive in scope than review of paper documentation in the same population. Collectively, this has led

to a rapid development of retrospective database research within anesthesiology. This work has allowed quantification and identification of risk factors for both rare events, such as difficult mask ventilation combined with difficult intubation or epidural hematoma after neuraxial anesthesia, and more common perioperative events, such as acute kidney injury.[62-67]

The use of an EHR as a data source for research initiatives has offered advantages of scale in study size but also allows a wide range of risk factors to be considered. It is now routine for observational research studies using EHR data to include thousands of patient records. Given the relatively infrequent occurrence of catastrophic complications or major adverse outcomes in modern anesthetic practice, extremely large sample sizes are necessary for quantification of risk factors and rates of occurrence of significant patient outcomes.

Despite the rarity of intraoperative complications, long-term complications of the surgical procedure remain common. The ability to utilize information drawn from the entire hospital record to characterize patient outcome is extremely important to the perioperative outcome researcher, as postoperative complications may have substantial impact on patient outcome.

It has become apparent that even the largest of single center studies may not be able to generalize well across sites. Substantial heterogeneity in clinical practice exists between institutions and across geographical regions. This has driven the development of multicenter studies, facilitated by the interchange of electronic data. The Multicenter Perioperative Outcomes Group (MPOG)* is one example of such an undertaking, bringing together investigators from over 50 institutions across the United States and Europe who have assembled, standardized, and identified over 10 million perioperative records for research and quality improvement.† By including data from many sites and seeking to include diverse practice locations, such efforts aim to develop generalizable knowledge.

One of the challenges in performing this work is the level of abstraction required to summarize the patient's clinical encounter into a small number of variables for inclusion in any analysis. For example, studies on the relationship of intraoperative hypotension and postoperative outcome need to consider how to develop a measure of hypotension which summarizes multiple hours of highly granular blood pressure information into a small number of variables for inclusion in the research study. A single 3-hour case may have 60 or more non-invasive blood pressure values recorded. To include in any analysis, these need to be summarized in a manner which remains biologically plausible. Many options are available, such as averages of all collected blood pressures or time or fraction of the case above (or below) absolute (i.e., mean arterial pressure [MAP] <65 mm Hg) or relative (<20% drop from baseline MAP) thresholds. Each approach would have very different output values and may alter the results and interpretation of a research finding. With any automatically collected information, methods for handling artifacts should be considered as artifactual values may have been propagated from the monitoring platform to the automated record without clinician intervention. Given the abundance of possible data to be included in any study, it is key that a clear hypothesis and approach be developed a-priori rather than post-hoc decisions that may evaluate particular statistically or clinically significant outcomes.

While most of the research thus far has been in the context of retrospective observational studies, an emerging theme in EHR-derived research is the use of this data in near real time (within days) for prospective interventional trials. These studies attempt to gather much of the information required for the trial as a byproduct of the clinical documentation created in the EHR. Additional information regarding patient progress in the study can be appended via traditional study management software. More novel methodologies such as embedded pragmatic clinical trials where hospitals or clinics choose to standardize their management in a coordinated manner for all patients (i.e., one class of antihypertensive or another as the usual first agent for adult patients without chronic kidney disease) are dependent on EHR data collection for patient follow up and perhaps even delivering the "usual choice" via decision support tools (see Chapter 89).[68]

MEASUREMENT OF QUALITY OF CARE

Information regarding the quality of care delivered and patient outcomes may be obtained from review of the EHR. Traditional models of quality management frequently depended on the use of trained abstractors reviewing medical records and applying standardized definitions. While these systems work well, they do not scale well into high volume clinical settings due to the time-consuming nature of detailed review and the resultant staffing costs. Interest has developed in the use of EHR data for the automated derivation of quality of care information. With careful design, both process of care (i.e., appropriate antibiotic prophylaxis administration) and outcome measures (i.e., surgical site infection) may be tracked using data derived from the EHR. Decision support tools may be used to aid in the alignment of the quality measures and the clinical practice which they seek to measure. Care needs to be taken to ensure the pattern of care which may be promoted is consistent with good clinical practice.

Using automatically derived measures, it is possible to provide feedback to medical providers near the time of clinical care. Automated data extraction and processing is well developed, with feedback being described across provider groups using email, provider and institutional specific "dashboard' reporting tools, and real-time paging alerts (Fig. 4.7).[38,49,51] Various groups have worked to make available tools to enable the widespread deployment of quality measures via submission of data from individual sites to a centralized database.[69] This approach is designed to limit the need for each site to develop the required technical architecture to build and deploy such tools—a significant hurdle for many organizations. However, this likely comes at the expense of flexibility of measurement offered at each site and some degree of delay in processing.

*Multicenter Perioperative Outcomes Group: http://www.mpog.org
†Personal communication, October 2018.

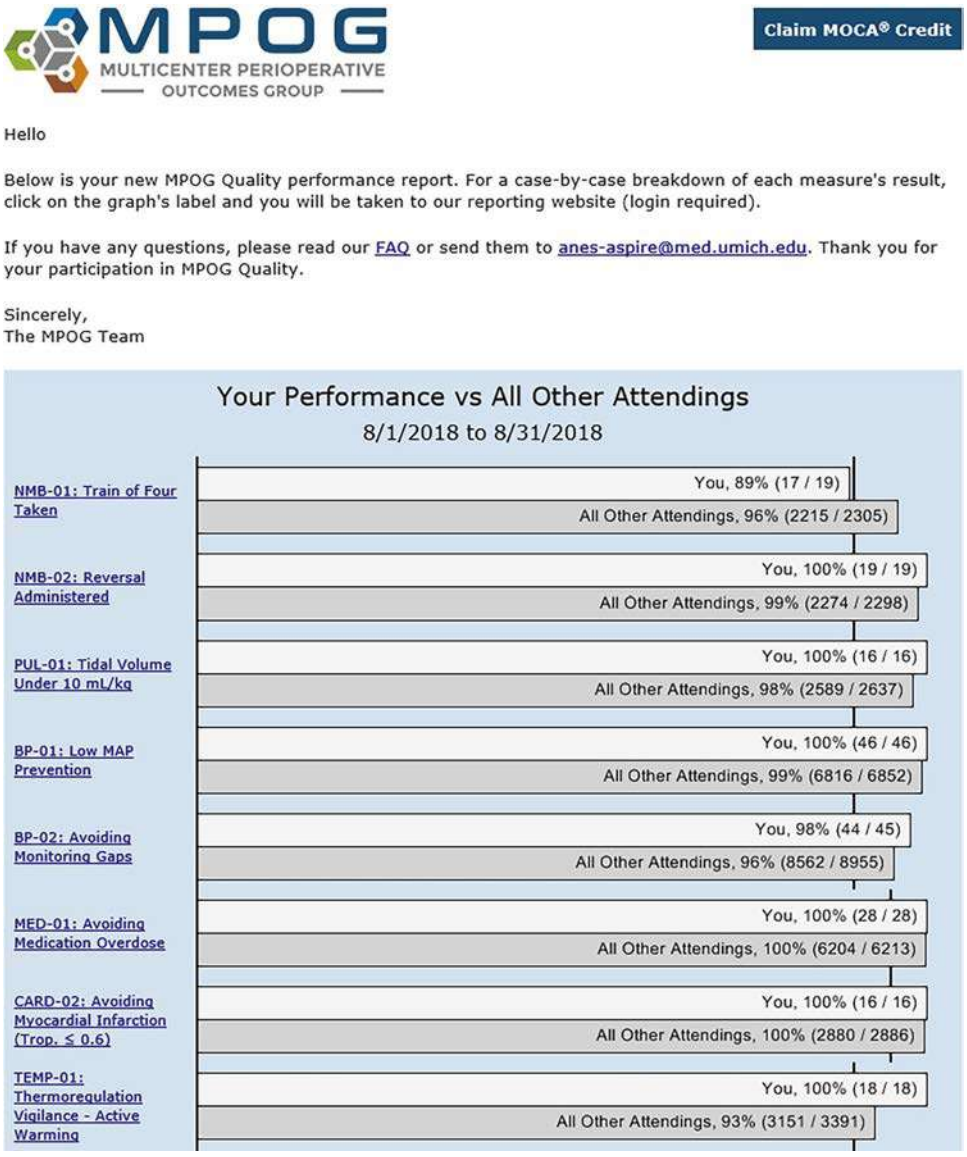

Fig. 4.7 Example of feedback email summarizing performance based on an automated assessment of compliance against predefined measurement instruments using data derived from the electronic health record. This figure has been lightly edited to remove identifying information of the recipient.

Interactions of Electronic Devices with the Delivery of Anesthesia Care

Safe anesthesia care requires the maintenance of a high degree of vigilance to multiple sources of information concurrently. When combined with required clinical tasks, estimates suggest that anesthesia care has high workload requirements.[70] Workload includes the factors related to the nature of the task, the situation in which it is performed, and the operator performing it.[71] In relation to phases of OR care, workload is clearly not uniformly distributed, clustering particularly in the induction and emergence phases of care.[70] The ability of providers to engage in tasks additional to patient care is debated.

Distractions from current patient care may include communication with other team members in the OR unrelated to patient care, preparation for subsequent patients, clinical reference lookup, pursuit of educational activities, and attention to personal issues. Attempts to quantify providers' attentiveness to the clinical situation or impact of a distracting event have been performed and note that distractions are a common feature of anesthesia care.[70,72-75] Given the common occurrence and diverse sources of possible distracting events during anesthesia care, mitigating the effects of distraction to maintain focus on patient care may be a required skill of an anesthesia provider.[74]

In particular, the proliferation of electronic devices in the OR including personally owned devices by providers (such as smartphone and tablet devices) and those that are part of the anesthesia workstation (frequently Internet-connected computers for accessing EHR and documentation purposes) has raised concern for the new sources of distraction in the OR.[76] A study from eight anesthesia workstations in one institution found that the computer attached to the anesthesia workstation was used for non-anesthesia documentation purposes for 16% of the procedure time. Importantly,

this study did not differentiate between time spent in this category that was related to patient care (i.e., accessing a separate lab or EHR system) or not.[77] Additional research has observed self-initiated distractions occurred in 54% of anesthesia cases.[78] Distractions related to personal matters were found in 49% of cases and related to educational activities in 24% of cases.[78]

Professional societies have issued guidelines on the role of distractions, including electronic devices, in the OR, some of which recommend the development of local policies to cover usage of electronic devices.[79-81] These policies may differentiate between clinical, educational, and personal usage of electronic devices and resources, and the appropriateness of each during patient care. It should be noted that many aspects of use of perioperative information technology, including use of personal devices, are subject to logging or recording. This may allow medicolegal review of activity performed on electronic devices contemporaneous to anesthesia care being provided in the future.

Conclusion

Information technology is very much part of the perioperative care process. It has significantly impacted clinical care, organizational performance, provider satisfaction, research, and assessment of quality of care. It is important that anesthesiologists understand the principles behind its use and be keenly aware of the benefits and potential shortcomings that applications of these tools may have. It seems likely that the future will hold a more connected perioperative environment with even more information available. The challenge, and the promise, of perioperative informatics still lies in ensuring the right people have access to the right information at the right time to enable them to make the right decision for the patient care they are providing.

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Complete references available online at expertconsult.com.

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