Journal of Anesthesia History 5 (2019) 93–98

Contents lists available at ScienceDirect

Journal of Anesthesia History

journal homepage: www.anesthesiahistoryjournal.org

Anesthesia Information Management Systems: Evolution of the Paper Anesthetic Record to a Multisystem Electronic Medical Record Network That Streamlines Perioperative Care

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A R T I C L E   I N F O

Article history:
Received 30 November 2018
Received in revised form 6 March 2019
Accepted 25 April 2019
Available online 28 April 2019

A B S T R A C T

Initially devised in the 1890s, the traditional anesthetic record comprises physiological changes, crucial anesthetic or surgical events, and medications administered during the perioperative period. The timely collection of quality data facilitates situational awareness and point-of-care clinical decision making. The burgeoning volume and complexity of data in conjunction with financial incentives and the push for improved clinical documentation by regulatory bodies have prompted the transition away from paper records. Anesthesia Information Management Systems (AIMS) are specialized electronic health record networks that allow the anesthesia record to interface with hospital clinical data repositories, resulting in improvements in quality of care, patient safety, operations management, reimbursement, and translational research. Like most new technological advances, adoption was slow at first due to the challenges of integrating complex systems into daily clinical practice, questions about return on investment, and medicolegal liability. Recent technological advances, coupled with government incentives, have allowed AIMS adoption to reach an acceleration phase among US academic medical centers; widespread utilization of AIMS by 84% of US academic medical centers is expected by 2018-2020. Adoption among nonacademic US and European medical centers still remains low; information concerning Asian countries is limited to literature describing only single–hospital center experiences.

Introduction

The traditional paper anesthetic record represents physiological changes, significant events, and pharmacological interventions that occur during the perioperative period. Timely and faithful collection of such data facilitates point-of-care clinical decision making. The burgeoning volume of complex data, financial incentives, regulatory body compliance, and initiatives toward improved clinical documentation have promoted the transition to electronic health records (EHRs).[1,2] The anesthesia EHR has evolved beyond its fundamental purpose of facilitating automated data capture. Anesthesia Information Management Systems (AIMS) are specialized EHRs that interface with hospital clinical data repositories and provide users with access to patient data, including laboratory, billing, imaging, pharmacy, and scheduling systems.[2–4] Benefits include enhanced quality of care and patient safety, as well as improvements in operations management, reimbursement, and translational research.[5] Widespread AIMS adoption will foster future platform development and allow for sharing of novel functionalities across systems.[6] The Anesthesia Patient Safety Foundation recognized this potential with unanimous approval of the following motion: “The APSF [Anesthesia Patient Safety Foundation] endorses and advocates the use of automated record keeping in the perioperative period and the subsequent retrieval and analysis of the data to improve patient safety”.[7] Herein, we review the history, benefits, limitations, and future of AIMS.

History of AIMS

In the 1890s, Drs. Cushing and Codman created the earliest paper anesthetic record that quantified measurable physiological data, which included pulse, temperature, and respiratory rate.[5] Blood pressure was additionally incorporated into the record in 1902.[8] The format of the record as a longitudinal, graphical representation of

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https://doi.org/10.1016/j.janh.2019.04.001
2352-4529/

physiological data, medications administered, intraoperative procedures, and critical events has largely remained unchanged. The anesthetic record has since evolved to incorporate other metrics, including electrocardiographic data, pulse oximetry saturation, end-tidal carbon dioxide, ventilation data, and volatile anesthetic concentration.[5]

The need for faithful capture and interpretation of repeatedly sampled metrics led to the advent of computer and EHR systems for documentation.[9,10] Automated capture of physiological parameters was first described in 1934, and early attempts continued into the 1970s. However, a complete transition from paper records did not occur until recently.[11–13] Electronic records were initially modeled from ICU computer records, which have the "capability to assemble information to address problems" by temporally organizing physiological monitors and treatment response.[9,10,14] During the 1980s–early 2000s, automated anesthetic record systems were usually homegrown local hospital applications.[10,11,14] Beginning in 1988, Burbank Hospital in Fitchburg, MA, was credited to be the first US hospital to computerize all anesthetic records.[15,16] Early electronic records were printed at the end of the case and stored in the patient's paper chart because these primitive systems could not communicate the information with other hospital systems.[11] Automated anesthetic records initially consisted of microcomputers that interfaced to large mainframe computers but now comprise sophisticated workstations, medical devices, client server, and Web-based software.[9,13]

The first demonstration of AIMS data computerization was at the 1989 American Society of Anesthesiologists (ASA) annual meeting.[16] In 1980, Duke University's Duke Anesthesia Monitoring Equipment was believed to be the first software application to provide a direct clinical monitor interface with electronic capture of a patient's vital signs (Figure 1a).[17,18] A transition from home grown to commercial vendor–developed systems began in 1982 with the emergence of the first commercial vendor product, Diatek's Anesthesia Record Keeper Integrating Voice Recognition (ARKIVE). ARKIVE was a voice-activated software system that was based on a touch screen user interface and allowed anesthesiologists to input data by using a high-resolution touch screen whose display mimicked the paper anesthetic record (Figure 1b).[17,19] Alternatively, voice entry of all data was also possible, which was subsequently stored on a data diskette.[19] Although ARKIVE was associated with fast keyboard entries and recognized for creation of template-generated documentation, its user interface was ultimately regarded as inferior because it was subject to sonic artifact. Therefore, this system is no longer in widespread use.[17]

Stimuli for the Growth of AIMS

Following inception in the 1980s, AIMS were met with initial sluggish adoption and momentum impedance until 2009, when <5% of US operating rooms were using AIMS.[6] The expansion of the AIMS market was incentivized by both government and private financial perks, as well as the promise of improvement in quality of care, expansion of translational research efforts, and containment of institutional costs. The 2009 Healthcare Information Technology for Economic and Clinical Health (HITECH) Act was among the catalysts that bolstered AIMS adoption by encouraging providers to demonstrate meaningful use of health information technology.[20] The concept of meaningful use to improve the quality of patient care was introduced in 3 successive stages from 2011 to 2015 (Figure 2). The first stage of the HITECH Act promoted use of EHR for data capture and sharing to advance continuity and coordination of care. The second stage encouraged comprehensive health information exchange among providers, which was further refined in the third stage with a focus on EHR interoperability to facilitate improvement of patient outcomes.[21] Attestation to each of these stages required completion of a certain number of objectives and attainment of specified measures. In a 2011 random survey of ASA members, only 24% of respondents were using an AIMS, whereas another 26% were in the process of installing or planning to install a system.[24,25]

EHR incentive payments varied from $44,000 over 5 years for the Medicare providers to $63,750 over 6 years for Medicaid providers.[22] Failure of providers to participate in the EHR incentive program by 2015 resulted in negative adjustments to their Medicare/Medicaid fees that ranged from 1% to 5% reduction by 2018.[23] In addition, private pay-for-performance initiatives rewarded organizations that achieved specified quality scores and had certain clinical information technology capabilities.[22] EHR incentive payments were necessary to finance the exorbitant costs of AIMS installation and maintenance. In 2011, AIMS workstations in each operating room were purchased for $4000-$10,000, whereas server installation required an additional cost of $10,000-$45,000.[2] Furthermore, annual fees for server maintenance and technical support constituted 15%-20% of the initial software purchase price.[24] Despite these large upfront costs, improvements in operations management, billing, coding, and resource utilization with decreased staffing and medication costs helped provide a positive net return on investment.[2,24,25]

Regulatory standard compliance for data reporting and Joint Commission requirements for legible and comprehensive clinical documentation provided further impetus for AIMS utilization.[1,2,6,24] AIMS facilitates physician concurrency monitoring and prompts entry of information that is reported to regulatory bodies, such as attending physician attestation statements, case times, case types, and ASA status.[2] Furthermore, the AIMS interface is configured to prompt documentation of patient safety case milestones, such as immediate preinduction patient reassessment and intraoperative "time-out," as well as to elicit information about comorbid disease for the calculation of severity of illness indices and mortality risk scores, all of which are routinely audited by the Joint Commission.[2]

As a result of financial incentives and a mounting pressure to maintain compliance standards, adoption rate among academic centers climbed from 1% in 2001 to 5% in 2006 to 16% in 2007 to approximately 75% in 2014, with a projected rate of 84% between 2018 and 2020.[1,26] The growth among nonacademic, private practice groups and European university-affiliated hospitals has been substantially slower, likely due to limitations in financial resources and information technology infrastructure.[26] Asian countries have also recently adopted AIMS systems; however, reported literature describes single–hospital center use, and no wide-scale survey of continental AIMS use is available.[27–29]

Clinical Benefits of AIMS

Direct automated capture of data eliminates manual documentation recall bias and generates an accurate, legible anesthetic record.[30,31] Detailed records can be retrieved in the future, allowing for longitudinal care. AIMS intraoperative interphase organizes data recorded from monitors and retrieved from intrahospital systems within the context of manually entered case events in a meaningful manner. An end user interface facilitates work flow by providing a clear display of categories for data entry as well as critical case events. Furthermore, the interface alerts the provider of critical information by highlighting data elements in large fonts or various colors, in addition to providing on-screen notifications of impending events, such as antibiotic redosing.[2] The presence of a large dashboard on display in the OR also facilitates situational awareness and communication among all OR personnel by highlighting patient identifying information, planned procedure, allergies, preoperative risks, critical laboratory results, vital sign trends, case milestones, and timing of last antibiotic dose.[31]

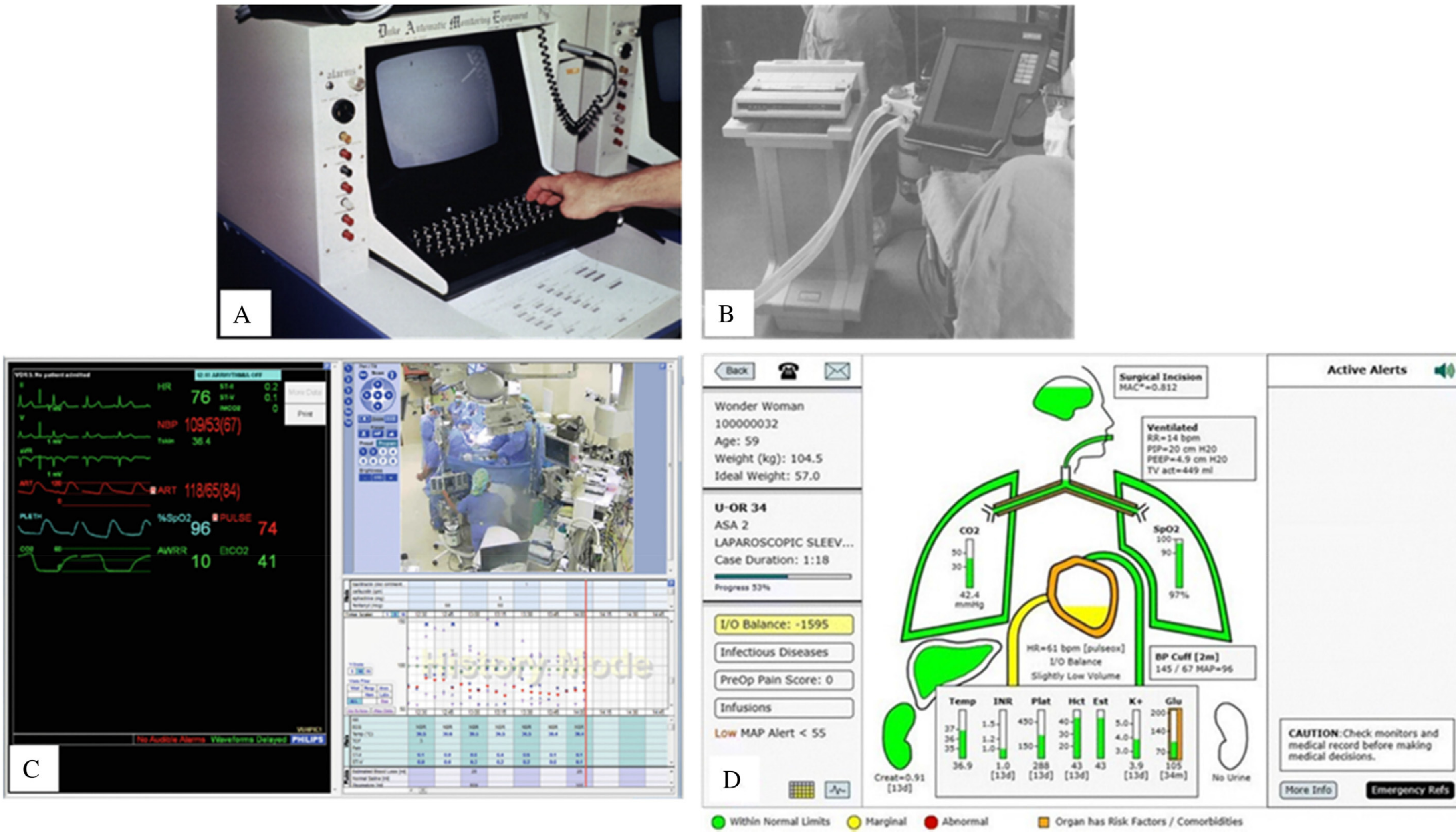

Fig. 1. Evolution in the design and features of AIMS. Images are representative of (a) Duke Anesthesia Monitoring Equipment,[18,50] (b) ARKIVE,[51] (c) VigiVu,[6] and (d) AlertWatch.[46]

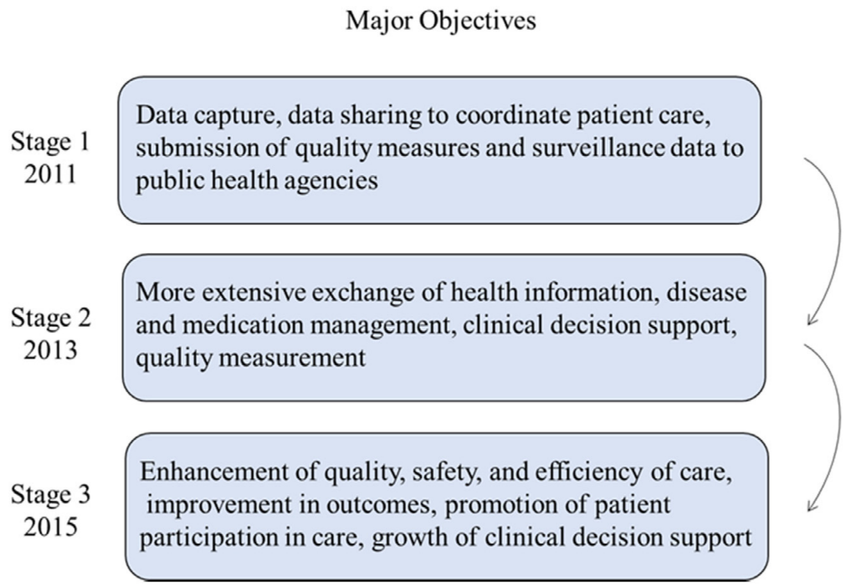

Fig. 2. The HITECH Act major objectives.[21,52]

AIMS contain customized management that provides active and passive point-of-care clinical decision support (CDS) for billing compliance, documentation, hemodynamics, patient management, medication administration, and protocol/pathway compliance.[2,31] CDS ranges from basic reminders to algorithm display and guidance subsequent to critical event detection. For instance, CDS might entail notifications for normothermia and antibiotics for surgical prophylaxis, medication support for drug-drug interactions and drug dosing, alerts for attending physician attestation statements, and elements necessary for billing, as well as guidance through Advanced Cardiac Life Support (ACLS) or the ASA Difficult Airway Algorithm.[2] CDS promotes adherence to clinical evidence-based guidelines, thus improving patient safety, decreasing cost of care, and enhancing Affordable Care Act quality of care measure reimbursement rates.[31]

Accurate and unbiased anesthetic records within the AIMS database support quality improvement and research initiatives.[2,5,31] Adverse events are detected through automated assurance screening and reporting, which elucidate systems errors. National organizations, such as the Anesthesia Quality Institute's (AQI), National Anesthesia Clinical Outcomes Registry (NACOR), and the Multicenter Perioperative Outcomes Group (MPOG), query large datasets to identify notable and rare trends in anesthetic risks, management, and outcomes (Table 1). The AQI created NACOR to capture clinical, quality, and patient satisfaction data and map it into a single schema using accepted standard definitions or consensus guidelines.[32] MPOG collects large volumes of clinical data to promote outcomes research and examine the validity of perioperative clinical practices.[31] Quality management data allow both providers and hospitals to track their performance relative to national cohorts.[31] Rapid retrospective data analysis accelerates development and validation of evidence-based guidelines.[5,31,33]

Limitations of AIMS

The integration of complex systems into daily clinical practice could lead to usability inefficiencies and recording inaccuracies. Concerns regarding medicolegal liability and return on investment have limited widespread adoption.[17,34] Automated records introduce the possibility of artifactual readings that could be interpreted to reflect abnormal vital signs, necessitating data cleaning and processing.[3,33] Network disconnection or failure (without warnings) might result in lapses in data collection.[31] Data repositories might be vulnerable to cyber-attack.[33] Despite these challenges, the medicolegal experience of 55 North American anesthesiology departments suggests that AIMS are more likely beneficial for malpractice defense.[26,35] There are currently no reports of successful malpractice lawsuits on the basis of artifactual data.[35–39]

The utility of AIMS is limited by heterogeneity in implementation by providers, which could result in incomplete patient records and poor documentation, especially during transfer of care.[2] Currently, no national standard exists. Systems are individually tailored and variable such that facilities that use common vendor AIMS may be unable to share data.[2,31] Proper training for processing and analysis of unstructured data requires infrastructure and investment.[40,41] The absence of consistent definitions for data elements undermines data uniformity and limits conclusions from analysis.[2] National efforts through AQI can help standardize anesthetic records through the use of particular methods, formats, and definitions to report

Table 1
AIMS serve as a conduit for key national organizations

Organization	Origin	Type of data	Description
AQI	ASA	Administrative, clinical, quality capture, patient satisfaction	Infrastructure that aggregates all anesthetic data and narratives from unusual cases or adverse events to promote education and quality improvement. Collects expert opinions to create consensus r ecommendations to fill gaps in standard guidelines.
NACOR	AQI	Administrative, clinical, quality capture, patient satisfaction	Integrates digital structured data and maps it into a single schema using accepted standards, such as ASA status and terms developed by the International Organization for Terminology in Anesthesia.
MPOG	University of Michigan	Clinical	Consortium of university anesthesiology departments that aggregates data to promote outcomes research and explore perioperative clinical practices. Data are directly transmitted to MPOG, like NACOR.

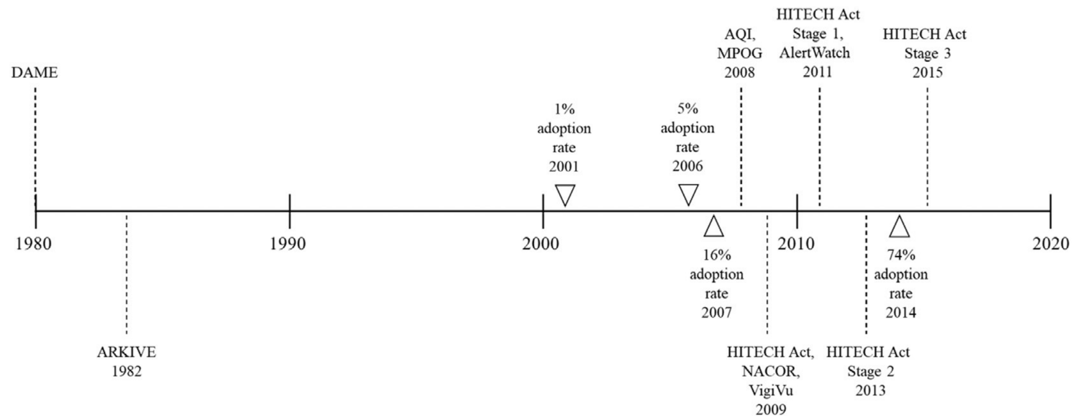

Fig. 3. Timeline of major milestones in the history of AIMS.

outcomes data to NACOR. AQI uses existing standard definitions, as defined by International Organization for Terminology in Anesthesia, and supplements any gaps with definitions from national consensus organizations, such as the procedural times glossary from the American Association of Clinical Directors.[42,43]

Cutting-Edge Applications of AIMS

Despite the tremendous impact of AIMS on patient care, provider clinical practice, and hospital operations, the full potential of these multi-interface systems has yet to be realized. There is a need for a central authoritative body which, together with efforts by the AQI and MPOG initiative, may help achieve standardization among AIMS vendors.[20] Precise consistent definitions of specific data elements, events, and outcomes will facilitate uniform documentation that can be compared across multiple institutions.[2]

Interoperability improvements and cross-platform integration between different vendors are needed.[5,31] Four vendors—Picis, Draeger Medical, Philips, and General Electric—control 75% of the marketplace.[6,17] Sharing of functionalities across systems is limited by vendor variability and a lack of interoperability features.[2] For example, Vanderbilt University developed an iPhone application in 2009, VigiVU, that allows anesthesiologists to remotely access intraoperative data (Figure 1c). However, this innovative functionality's use is limited to only Vanderbilt University. AIMS have yet to transition to open, flexible platforms that could accommodate novel applications even though such a change system was introduced in University Hospital at Stony Brook in 1990.[4,6]

The application of real-time analytics has tremendous risk assessment and outcomes prediction utility.[44,45] The integration of real-time data collection with interactive visual interfaces helps simplify effective critical information and complex concept communication. Founded in 2011, AlertWatch is an advanced FDA-approved clinical decision support tool that generates a “live” organ system view based on implementation of algorithms that detect over 250 data elements, such as physiologic data, comorbidities, and laboratory results.[46] Like clinical decision alerts (CDAs), AlertWatch provides real-time alerts in response to hemodynamic changes and ventilation parameters to improve patient care in opportune moments (Figure 1d). However, the scope of CDAs extends beyond critical events to include the process of care, that is, compliance with protocols and pathways, as well as management of documentation and billing. Furthermore, AlertWatch establishes an alert hierarchy using color-coded font, whereas CDAs may lack such sophisticated organization.[2,46] Such real-time monitoring platforms help combat information overload and improve situational awareness.

Conclusion

AIMS user growth follows that of most new technologies with initial adoption limited for years since inception (Figure 3).[26] Technological breakthroughs and government incentives allowed life cycle growth among US academic medical centers. AIMS now appear to follow the theory of Rogers' 1962 diffusion of innovation, which suggests that the life cycle of novel and ultimately successful technologies follows an S-shaped curve.[49] The curve illustrates an initial long period of slow adoption and subsequent periods of faster adoption until the innovation reaches critical mass where further adoption is self-sustaining. Rogers' 1962 theory of diffusion of innovation attributes this life cycle to sequential acceptance by innovators (initial period of dormancy), early adopters (slow sustained rise), early and late majority (rapid rise), and laggards (achievement of critical mass).[26,47] The theory of diffusion of innovation is projected to account for a massive (84%) uptick in adoption by 2018-2020. Among nonacademic US and European medical centers, however, adoption remains limited.[1,26,48]

Acknowledgments

The authors would like to thank the Department of Anesthesiology faculty for their assistance with manuscript revisions.

Funding

This work did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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