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Managing bottlenecks in the perioperative setting: Optimizing patient care and reducing costs

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Bottlenecks limit the maximum output of a system and indicate operational congestion points in process management. Bottlenecks also affect perioperative care and include dimensions such as infrastructure, architectural design and limitations, inefficient equipment and material supply chains, communication-related limitations on the flow of information, and patient- or staff-related factors. Improvement of workflow is, therefore, becoming a priority in most healthcare settings. We provide an overview of bottleneck management in the perioperative setting and introduce

Abbreviations: ICU, intensive care unit; OR, operating room; PACU, post-anaesthesia care unit; SCM, supply chain management.

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dimensions, including aligned strategic decision-making, tactical planning, and operational adjustments.

Introduction

Bottlenecks indicate a congestion point in optimized medical care, often causing delays, a backlog of patients or administrative processes, increased costs, and impaired medical care. Improvement and automation of medical care workflow have, therefore, become a priority. As an example, in the emergency department, efficient patient flow is crucial. Triage represents, perhaps, the most important initial tool to screen patients for the severity of their condition, but it may create a backlog of patients with less acute conditions, leading to a delay in treatment, inpatient care, or discharge. For those patients who need inpatient care, the transfer of care from the emergency department often represents a bottleneck and delays the length of stay [1–3]. In the perioperative setting, typical bottlenecks can be related to the hospital environment, equipment, infrastructure, material-related issues, as well as miscommunication, disruptions in staff and patient management, and perioperative surgical issues. These can affect surgical outcomes or lead to a delay in the transfer of care to postoperative care systems. A disturbance in any of these may lead to "congestion" and a delay in optimized patient care or suboptimal clinical outcomes for the patient (Fig. 1) [4].

Identification of bottlenecks in the perioperative setting

To identify possible patient-flow disruptions and start addressing the bottlenecks in the system, flowcharts, algorithms, and mapping of every step in the perioperative patient pathway need to be part of the multidisciplinary team setup [4,5]. As these processes are analysed over a longer period, delays can subsequently be localized and addressed individually, as they may differ between hospitals and even within departments. Therefore, optimization includes a detailed analysis of all processes and possible pathways for automated workflows.

The first possible bottleneck is the optimization of supply chain management (SCM). In healthcare, this refers to a continuous and reliable supply of material, technology, and personnel – that is, resources which enable the delivery of optimized medical care while maintaining cost-effectiveness [6]. When congestion occurs within this process, such as when too many patients arrive simultaneously at the postoperative care unit (PACU), the system may reach a bottleneck due to staff shortage. Bottlenecks create disruptions and lead to inefficiency and additional costs. In an attempt at cost containment [7], while keeping quality of care and patient safety as high, process mapping has found its way into implementation in the healthcare setting. These include, but are not limited to, blood bank supply, pharmaceutical supply, laboratory chains, and even surgical services [6].

Managing specific congestion points should start on a strategic level, despite the common "impression" that SCM is mainly an operational task [8]. This includes careful coordination and teamwork among surgical subspecialties, anaesthesia, postoperative care, and other supportive fields to ensure the best medical treatment while adapting to the current epidemiological, financial, infrastructural, and logistic situations [9]. The limitations on infrastructure, such as the number of operating rooms (OR), the setup of a waiting area, availability of PACU equipment and ICU beds, and strategies to overcome functional barriers in the interdisciplinary setting, have to be clearly defined [8]. Optimization of this process includes a shift to a systems- and resource-sharing mindset, also called "systems thinking". In systems thinking, cohesiveness, timeliness, and effectiveness are shared goals among all stakeholders [10].

Following such strategic changes, tactical tasks may then involve goal setting for each functional unit (each discipline involved in the perioperative setting) complementary with one another [8]. Restructuring on the operational level includes day-to-day planning, control and monitoring of

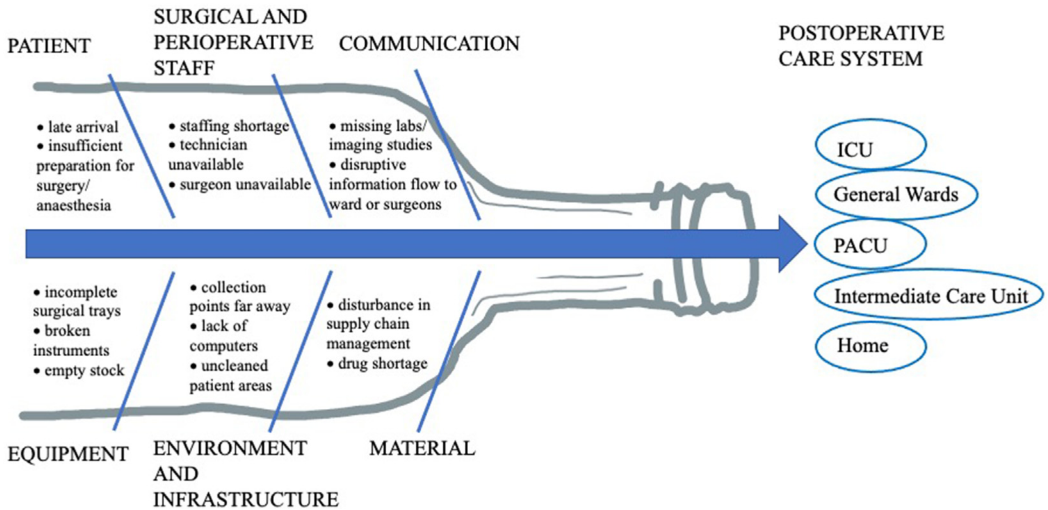

Fig. 1. illustrates the possible origins of bottlenecks in the perioperative setting. These include equipment-, environment-, infrastructure-, or material-related issues, as well as disruptions in surgical issues, staff and patient management, and miscommunication. A disturbance in any of these may lead to slower patient transfer due to “congestion” and delay optimized patient care or even impair clinical outcomes for the patient.

functionality of services, contingency scheduling (i.e., having capacity for an emergency case), same-day workload, and prevention of elective surgery backlog [11].

While efficient OR scheduling is key for patient flow, this multi-faceted OR management task is already covered extensively elsewhere [12]. Hereafter, we discuss bottlenecks in the perioperative setting happening at interfaces in the perioperative process. They can be divided into infrastructural (e.g., OR design or limited OR capacity), equipment- or material-related (e.g., empty stock of surgical or anaesthetic instruments, shortage of anaesthetic drugs, and shortage of personal protective equipment), communication-based (e.g., practitioner needs more laboratory findings), staff (e.g., staff unavailable or arrives late), or patient-associated factors (e.g., patient not fasting, hemodynamic instability, difficult anatomy, and late arrival) [13,14].

Optimizing the infrastructure

Tackling environmental factors by eliminating bottlenecks may be one of the most basic ways to maintain efficiency in surgical facilities. Identifying and eliminating non-value activities—such as walking from the OR to decentralized pathology collection points after every procedure—is a key step in reducing inefficiency [15].

OR infrastructure and design should allow for parallel work and help reduce delays. Sandberg et al. [16] have designed a “deliberate OR” which functions with parallel rather than serial workflows for both surgery and anaesthesia. In this way, the perioperative process could be included within and organized around the surgical steps.

Induction and anaesthesia preparation rooms allow the initiation of anaesthesia while the previous procedure is still under way. The patient from the previous procedure might wake up in the emergence room while a cleaning team prepares the OR for the next patient, who is already waiting in the induction room. The availability of different workspaces with proximity to the OR allows the surgeons and other OR staff to work on tasks outside the OR, such as coordinating patient appointments or dictating surgical reports. Finally, after spending time in the emergence area, the patient can be transported to the PACU, wards, ICU, or home by the nurse or physician, depending on the complexity of the surgical procedure and the hemodynamic stability of the patient. In a stable setting, a specially trained nurse may accompany the patient to the PACU or ward, allowing the anaesthesiologist in the OR suite to provide surveillance for the new anaesthetized patient, thus enabling the start of surgery without further delay.

With such a system, Sandberg et al. [16] were able to achieve an average 30 min reduction in non-OR-related activity, which allowed additional patients to be treated during regular working hours within the same financial and time margins. Such deliberate OR designs require planning based on solid process mapping, giving credit to all different stations along with the surgical patient flow. Another study by Friedman et al. [17] investigated changes in patient flow for patients undergoing hernia repair under general anaesthesia combined with local anaesthesia. Surgeons provided local anaesthesia already in the induction room while the OR was being cleaned. Thereby, OR turnover time and time needed for induction could be significantly shortened (45% and 61%, respectively).

Optimizing the equipment

Providing the necessary equipment when required is key to ensuring smooth and secure patient throughput in the perioperative setting. As in any institution, SCM must be based on objective inventory systems [4]. Such systems help monitor individual demands and stock levels and thus may prevent rush orders based on poor decision-making or the cost-intensive maintenance of unused materials that may be subject to expiration or expensive maintenance [4]. However, objective inventory systems are poorly established in the healthcare setting, as can be seen, for example, when looking at the causes of surgery start delays. Material supply chain issues were previously identified as the fifth most frequent cause of procedural delays [4].

Through the assessment of 21 surgical procedures, Fowler et al. found that “walking to obtain missing equipment” as accounted for 51 out of an average of 86 departures during a procedure [4]. Incomplete surgical trays may be caused by a lack of standardized setups. When staff members rely on experience and personal knowledge in preparing surgical trays, instead of officially standardized tray setups, task interdependence may occur [4]. Task interdependence is a dangerous limitation to de-bottlenecking [4]. Defining setups (surgeon- or procedure-specific) and informing teams about changes in preferences is key to improving equipment-related disturbances [18]. A lack of documentation of missing or broken instruments may lead to insufficient tray setups, leading to further delays [4]. Extensive inventory systems and standardizations help minimize consequential additional time and cost efforts, and should be implemented [18].

Large-scale implementation of such inventory systems is limited, as each team and surgical specialty prioritizes its individual goals. For example, medical staff is basically interested in flexible delivery of drugs, and in fast and reliable delivery of special medications when needed. They may not tolerate an “out of stock” notice or an alternative medicine that is of lower quality and may be organized as a quick fix.

On the other hand, the hospital administration puts much emphasis on minimizing costs. Surgeons rely on the quick supply of instruments to perform their procedures and are interested in having a stock of material and technical equipment that can be accessed without delay [19,20]. A lack of stock resulting in emergency supply orders may in fact lead to treatment delays, additional costs, and life-threatening situations [21]. By identifying mutual goals, such as cost reduction, creating highly efficient workflows and helping maintain patient safety and quality of care, limitations on developing system-based inventories can be overcome [22], even in times of financial pressure.

Apart from a misalignment of interests, a high level of unawareness of costs among OR users was identified as a limitation to cost-conscious equipment use [18]. Standardization of draping, surgical tray setups, or surgical preparation shows positive effects on cost and patient safety (fewer surgical site infections in orthopaedic trauma surgery) [18]. The nonexistence of such standards and a lack of comparative data on the setup of surgical carts [23] are key factors limiting the implementation of change. A reduction in the number of instruments on a standard surgical tray, as proposed by Toor et al. [24] could lead to significant economic savings. Quality of care and patient outcome could be safeguarded if such measures were conducted under the control of surgeons and mathematical models [24]. In the absence of such standardizations, a fear of displeasing the surgeons may lead to dangerous “workarounds” by other OR staff members. Instead of speaking up, they tend to accept the frustrating but routine interruptions that are created when supplies are missing, and even borrow items from the next patient's cart to maintain harmony within the OR team [4]. However, such a strategy not only decreases surveillance of the patient during the procedure but also initiates a “snowball effect” cascading through the next and all other following procedures [4]. Adequate information about alternative materials and instruments needs to be shared among OR workers, such that in a collaborative approach, decisions on the elimination of or changes to highly expensive or unused items on a surgical tray may result, while overcoming concerns of change based on mistrust [23,25,26]. This can additionally help create a basis for a more respectful and appreciative approach among all team members in the OR [27]. Furthermore, the additional implementation of programs to teach resource management could lead to a reduction in the amount of supplies wasted [28].

Despite mutual awareness of the expense of certain equipment, collaboration might be the best if not the only sustainable option [29,30]. Such collaborative strategies might not be limited to one surgical subspecialty, but consist of pools of equipment.

For instance, Pasin et al. [31] showed that the pooling of equipment among Montreal regional community service centres led to overall benefits, despite the initial resistance to change. The big losers were centres with previously high overcapacity whose SCM would have been unsustainable over the long run [31]. Therefore, such a systematic approach might be beneficial for the greater good — even in large-scale pools. In short, the focus can be switched back from managing equipment emergencies with a short-lived silo mindset to the main task only in a team-based approach by optimizing patient flow in a safe and qualitatively outstanding and sustainable way [15].

Optimizing the materials (drug supply)

Drug shortages are common in low-, middle- and high-income countries alike and may affect all groups of drugs [32]. Antimicrobial stewardship is not enough to tackle such challenges, as other essential medications such as insulin, sedatives, anaesthetics, or opioids can become short in stock, as was apparent during the COVID-19 pandemic [33,34].

Adverse patient outcomes may result from anaesthesia drug shortages [35,36]. Drug shortages, therefore, may potentially influence patient safety and outcome, even affecting PACU stay or demand for intensified postoperative care, such as an ICU stay. In this setting, bottlenecks are inevitable.

Patients should be informed about drug shortages and be given the opportunity to decide on postponing elective surgery. This was shown by Hsia et al. [37], who investigated the effect of neostigmine shortages. In their study, more than 50% of patients asked for further information, which led to the postponement of elective cholecystectomy in a significant number of cases [37].

Postponing surgery may again lead to more bottlenecks due to long-term accumulation of patients on waiting lists, with so-called overstocking leading to a backlog of elective surgical patients [21].

A strategy applied in the COVID-19 pandemic was to adapt treatment standards wherever possible. For example, due to shortages in intravenous anaesthetics, volatile anaesthetics were used to treat patients with the acute respiratory distress syndrome in the ICU [38]. However, such approaches are usually not evidence based and might lead to adverse patient outcomes [34].

A plausible solution is to find strategies to help reduce the incidence and impact of drug shortages in the future. Implementing national surveys that assess the number and type of anaesthesia provided and keeping track of such data over the long run allows drug supplies to be managed — also in case of a pandemic [39]. Through the implementation of such a national survey, countries such as Switzerland could use projections of annual drug consumption based on historical data for types of anaesthesia. Sustainable replenishment could be organized on a nationwide basis, even during the COVID-19 pandemic [39]. Meanwhile, in France, drug distribution among ICUs was also organized based on a centralized approach during the pandemic [40]. Propofol, midazolam, and paralytic agents were distributed among hospitals based on the number of resuscitation beds they had during the pandemic. Such strategies require strong collaborative networks among institutions, anaesthesiologists, intensive care physicians, and pharmacists alike [40] and are paramount for efficient decongestion of the supply bottlenecks.

Optimizing the communication

The flow of information is key in all steps of the perioperative process. The implementation of a coordinated communications system within the perioperative supply chain by centralized decision-making and IT-enabled intraoperative prompts was introduced in a US academic medical centre where over 33,000 surgical cases were studied [41]. Simply having such a centralized decision-making location led to a 3.4% reduction in preoperative processing time, and when combined with IT-enabled prompts, a 10.8% overall reduction could be achieved [41].

Setting boundaries for the flow of such information is aggravated by hierarchical management styles, cost designations used by the financial accounting system, remote locations of departments, and silo thinking of individual staff members [4]. Communication in written form, in person, or over the telephone is typical in such lethargic systems [4]. A lack of "in-time" information and a lack of coordination among internal functions inevitably leads to disruptions such as missing laboratory values, unavailable radiology technicians, missing equipment, material, etc. [4].

It is imperative to keep timely information among all team members to ensure workflow optimization and enable the best quality of care. It has been previously shown that among the most common attributable causes for delays in perioperative care (up to 62% of all procedural delays) are either the surgeon running late — often due to lack of communication — or interruptions in the flow of information to the ward or outpatient care centres [4]. Such disruptions in information flow may even lead to interpersonal conflict, further delaying the OR schedule [4].

A possible solution for such communication difficulties is so-called "link practitioners" [21]. Link practitioners are mediators between the wards, ORs, and associated staff. They act as patient advocates, ensuring timely readiness for surgery. Such a role requires a high understanding of all processes involved in the perioperative setting and a solid understanding of all key stakeholders' interests. Senior healthcare practitioners who specialize in perioperative care (e.g. anaesthetists) might be well suited for such a role and help achieve an adequate flow of perioperative information, leading to efficient and safe patient treatment [21].

Optimizing the postoperative care system

Bed availability (ICU, PACU, and ward) can be a significant cause of surgical delay [42]. It may lead to case cancellation and reduced operative capacity [43]. Additionally, in one study, it negatively affected patient satisfaction, resulting in an exponential increase in indirect costs and losses [42].

In most cases, the patient is transferred to the PACU after emergence from anaesthesia [44]. It is well known that PACU economics cannot be affected by the type of anaesthesia alone [45]. For example, length of stay in the PACU was not associated with local or general anaesthesia [46]. The main driver of PACU costs was the distribution of admissions [45]. Nowadays, the PACU serves as a multi-function zone and not simply a "wake-up" area [47]. Preparing patients for surgery already in the PACU or holding patients with epidural anaesthesia under surveillance can increase efficiency and safety in the perioperative workflow [47]. A structured postoperative care system has to be established in order to avoid long-term accumulation of patients waiting in the PACU for surgery or delays in transferring postoperative patients from the emergence rooms to the PACU [4]. Overstocking, therefore, directly impacts OR-related patient flow [4].

In order for patients to be able to leave the PACU after surgery, in-house bed planning comes into play. In contrast to the PACU, general ward capacities, as well as ICU or intermediate care units, are used for many different patients and are not limited to the elective surgical program or OR setting. They may be needed for patients undergoing urgent or emergent non-OR procedures such as thrombolysis, decompensating patients from the general wards, or some specialized surgical cohorts, such as post-cardiac or neurosurgery patients [48]. This complexity makes it difficult to specify exact times from admission to patient discharge for each individual patient [49].

It is in the interest of all stakeholders to avoid the situation of fully occupied ICU or ward beds, which can lead to elective case cancellation or long-time PACU stay [48]. Therefore, information on weekday trends in admissions must be gathered and taken into account when scheduling cases in the OR [48]. The capacities and capabilities of enhanced care systems are institution-specific [48]. Planning for ICU-bound elective surgery patients needs a solid understanding and adequate estimation of their expected length of stay in the ICU. Since both empty and overbooked beds create costs, shorter estimated stays (e.g., 1–2 days) should lead to scheduling early during the week, while longer predicted stays (3–4 days) benefit from end-of-week scheduling, so that the weekend can be used for patient recovery [48].

Kim Seung-Chul et al. [50] investigated different bed reservation systems in an ICU. They showed that despite using computer simulation, there was no perfect solution that met all the needs of ICU physicians, surgeons, and other practitioners who asked for ICU beds for their patients. Also, the type of patient population admitted to the ICU is highly dependent on the type of institution making the referral [48]. New patient safety tools allow continuous postoperative monitoring (e.g., of respiratory function) also in the setting of intermediate care units and, in some institutions, even in a general ward, and may help decrease congestion due to limited intensive care capacity while keep patients safe [51]. Providing a buffer stock upstream through adequate monitoring of ICU admissions and time spent in the ICU and other postoperative care locations is paramount for a well-functioning postoperative care system and to avoid congestion in this bottleneck.

Optimizing the staff

Staffing takes place on a strategic, tactical, and operational level [12]. Several factors, such as healthcare legislation or shortages in nursing staff, complicate adequate scheduling. Wright et al. [52] developed a simulation model optimizing nurse scheduling based on health-care legislation and were able to reduce the number of shifts without creating additional costs. The staffing model used by ICUs also depends greatly on the institution, as nurse-to-patient ratios vary from 1:1 to 1:4, even for patients in a critical care setting [53].

Not all staffing models attempting to reduce the number of nurses are tolerable when it comes to maintaining patient safety. Complication rates, length of stay [53,54], and risk-adjusted mortality [55] were higher in settings with more patients per nurse. Reducing shifts cannot be the solution for the postoperative care bottleneck if it compromises patient safety. Alternative measures such as regionalization, higher flexibility in bed allocation, and rationing of beds should be considered to contain costs [56]. Such options need to be based on international standardization of needs and definitions of critical care institutions in order to prevent improper comparisons among different institutions [56].

Apart from increasing the number of employees in times of high workload, intensified training should be offered to produce flexible and highly skilled staff [57]. Such measures also promote a growth culture that creates team spirit. Resilience and a “multi-brainpower” attitude may help in times of crisis and staff shortages, when workload can become intense [58]. Moreover, a well-established feedback culture, sound team spirit, and functional clarity can help contribute to safety in the perioperative setting [59].

Besides internal optimization, staffing may also be collaborative, creating a staff pool with members from several institutions instead of fixed specialty-associated teams. Individuals trained for different settings can work in the ICU or PACU when needed [60]. Apart from the number of staff, building efficient teams is paramount. One inefficient team can lead to stalled production and a bottleneck, resulting in lost capacity [4,61]. This may increase pressure on other teams and negatively impact employee morale [4].

Team constellations are highly important for maximal efficiency. Ebadi et al. [62] studied the effect of a method that pools information about surgical complications with team constellations. They used historical data on specific team performance and patient characteristics (body mass index and comorbidity scores) to arrange and schedule the best treatment team setups for reaching maximal patient safety and output [62]. Models designed to improve teamwork in an ICU, such as those established by Sjöberg et al. [63] in an ICU, may also help additionally to reduce delays. They have shown that despite the promotion of interprofessional teamwork, hierarchical structures in the ICU were maintained by individual team members, negatively impacting team performance and nurse retention [64]. Such structures must be minimized on an institutional level in order to be able to consider new technologies such as proposed by Ebadi et al. [62] Focusing on individual training and stressing respectful teamwork can help maintain patient safety and staff health in times of high financial pressure on the healthcare system.

Optimizing the preoperative patient pathway

Case cancellations due to patient-related factors are frequent. Apart from absenteeism, suboptimal preoperative evaluations and healthcare issues are key drivers for cancellations. One approach to reduce cancellations was the introduction of preoperative consultations at drop-in anaesthesia outpatient clinics and ambulatory care centres, where surgeons immediately provided anaesthetists with dictated notes for the preoperative assessment, and patients who were cleared for surgery were immediately sent to the laboratory for blood tests [65]. The patients in this study also received a phone call two days prior to surgery instead of a simple letter. Such interventions led to higher patient satisfaction due to a feeling of increased autonomy, and the focused patient-centred approach led to a reduction in cancellation rates [65]. Apart from structural optimization, education may help reduce case cancellations. The use of telemedicine for preoperative scheduling, preparation, and assessment may further reduce cancellations and delays in the perioperative care that follows [66]. Finally, the role of the preoperative nurse in patient education should be emphasized. On the one hand, preoperative calls by nurses can adequately identify patients who need to be assessed as part of an anaesthesiology-supervised process in order to guarantee patient safety and keep cancellation rates low. Also, preoperative patient education by qualified nursing staff was beneficial for postoperative recovery, as it eased patient anxiety [67]. Such strategies may lead to lower cancellation rates and improved quality of care and increased efficiency, thus reducing those bottlenecks in the perioperative setting [68].

Conclusion

Successful management of bottlenecks in the perioperative setting can be achieved using a multidisciplinary approach that includes aligned strategic decision-making, tactical planning, and operational adjustments. Bottlenecks limit the maximum output of a system. Therefore, it is in the interest of all participating disciplines and teams to reduce such congestions.

Several factors may result in disturbances in the perioperative throughput of patients. Among these are infrastructure, architectural design and limitations, inefficient equipment and material supply chains, communication-related limitations on the flow of information, and system-related, patient-related, or staff-related factors associated with postoperative care. This has a tremendous effect not only on economic factors but also on staff satisfaction, patient safety, and patient outcome. Further studies are needed to identify bottlenecks in the future and maintain workflow by forecasting instead of reacting to acute disruptions.

Key points

- Reducing bottlenecks is important for an economically efficient perioperative workflow for patients, staff, and key stakeholders alike.
- The supply of drugs and equipment for anaesthesia needs to be planned and secured by a centralized pharmaceutical distribution point in advance.
- Scheduling of procedures should take into account a patient's postoperative care needs. The reduced capacity of the postoperative care system should be clearly communicated throughout the interdisciplinary system, so that patient safety can be safeguarded.
- Staff pools should be filled with highly trained and resilient individuals who can work in diverse settings, such as the ICU or PACU. In the future, shared staffing models might include collaboration between hospitals in times of crisis such as pandemics.
- In the interests of a sustainable system, collaboration should be implemented not only for staffing but also for the availability of intensive care beds or staff and patient education.

Research agenda

- Mathematical models to assess the monitoring of perioperative workflows are needed.
- The potential value of feedback tools allowing short-term adjustments of perioperative bottleneck management is to be investigated.
- The benefit of managerial education about perioperative bottleneck management remains widely unknown.

Contributions

Maks Mihalj, Andrea Corona, Lukas Andereggen, Richard D Urman, Markus M. Luedi and Corina Bello wrote the article.

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Declaration of competing interest

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References

[1] Khanna S, Boyle J, Good N, et al. Analysing the emergency department patient journey: discovery of bottlenecks to emergency department patient flow. Emerg Med Australasia (EMA) 2017;29(1):18–23. https://doi.org/10.1111/1742-6723.12693 (In eng).

[2] Marshall JR, Katzer R, Lotfipour S, et al. Use of physician-in-triage model in the management of abdominal pain in an emergency department observation unit. West J Emerg Med 2017;18(2):181–8. https://doi.org/10.5811/westjem.2016.10.32042 (In eng).
[3] Van Der Linden MC, Van Loon M, Feenstra NSF, et al. Assessing bottlenecks in Emergency Department flow of patients with abdominal pain. Int Emerg Nurs 2018;40:1–5. https://doi.org/10.1016/j.ienj.2018.03.006 (In eng).
*[4] Fowler PH, Craig J, Fredendall LD, et al. Perioperative workflow: barriers to efficiency, risks, and satisfaction. AORN J 2008; 87(1):187–208. https://doi.org/10.1016/j.aorn.2007.07.001.
[5] Wu DTY, Barrick L, Ozkaynak M, et al. Principles for designing and developing a workflow monitoring tool to enable and enhance clinical workflow automation. Appl Clin Inf 2022;13(1):132–8. https://doi.org/10.1055/s-0041-1741480 (In eng).
[6] Arora M, Gigras Y. Importance of supply chain management in healthcare of third world countries. Int J Supply Oper Manag 2018;5(1):101–6. https://doi.org/10.22034/2018.1.7.
[7] Jones RL, Plantes K. Cost containment in anesthesiology: a survey of the association of anesthesia clinical directors. J Clin Anesth 1994;6(5):409–10. https://doi.org/10.1016/s0952-8180(05)80012-1 (In eng).
*[8] Stevens GC. Successful supply-chain management. Management Decision. 1990.
[9] Rose J, Weiser TG, Hider P, et al. Estimated need for surgery worldwide based on prevalence of diseases: a modelling strategy for the WHO Global Health Estimate. Lancet Glob Health 2015;3(Suppl 2):S13–20. https://doi.org/10.1016/s2214-109x(15)70087-2 (In eng).
[10] Epstein NE. Multidisciplinary in-hospital teams improve patient outcomes: a review. Surg Neurol Int 2014;5(Suppl 7): S295–303. https://doi.org/10.4103/2152-7806.139612 (In eng).
*[11] Dobrzykowski D, Saboori Deilami V, Hong P, et al. A structured analysis of operations and supply chain management research in healthcare (1982–2011). Int J Prod Econ 2014;147:514–30. https://doi.org/10.1016/j.ijpe.2013.04.055.
[12] Bello C, Urman RD, Andereggen L, et al. Operational and strategic decision making in the perioperative setting: meeting budgetary challenges and quality of care goals. Best Pract Res Clin Anaesthesiology 2022;36:265–73.
[13] Rotondi AJ, Brindis C, Cantees KK, et al. Benchmarking the perioperative process. I. Patient routing systems: a method for continual improvement of patient flow and resource utilization. J Clin Anesth 1997;9(2):159–69. https://doi.org/10.1016/s0952-8180(96)00242-5 (In eng).
*[14] Shao X, Zhong X, Li J, et al. Bottleneck analysis to reduce surgical flow disruptions: theory and application. IEEE Trans Autom Sci Eng 2015;12:127–39. https://doi.org/10.1109/TASE.2014.2329833.
[15] O'Mahony L, McCarthy K, O'Donoghue J, et al. Using lean six sigma to redesign the supply chain to the operating room department of a private hospital to reduce associated costs and release nursing time to care. Int J Environ Res Publ Health 2021;18(21). https://doi.org/10.3390/ijerph182111011 (In eng).
[16] Sandberg WS, Daily B, Egan M, et al. Deliberate perioperative systems design improves operating room throughput. Anesthesiology 2005;103(2):406–18. https://doi.org/10.1097/00000542-200508000-00025.
[17] Friedman DM, Sokal SM, Chang Y, et al. Increasing operating room efficiency through parallel processing. Ann Surg 2006; 243(1):10–4. https://doi.org/10.1097/01.sla.0000193600.97748.b1 (In eng).
*[18] Gurnea TP, Frye WP, Althausen PL. Operating room supply costs in orthopaedic trauma: cost containment opportunities. J Orthop Trauma 2016;30(Suppl 5):S21–6. https://doi.org/10.1097/BOT.0000000000000718.
[19] Little J, Coughlan B. Optimal inventory policy within hospital space constraints. Health Care Manag Sci 2008;11(2): 177–83. https://doi.org/10.1007/s10729-008-9066-7 (In eng).
[20] Rappold J, Van Roo B, Di Martinelly C, et al. An inventory optimization model to support operating room schedules. Supply Chain Forum Int J 2011:56–69. Taylor & Francis.
[21] Doyle GW. Improving perioperative efficiency and patient throughput. Dublin City University; 2022.
[22] de Vries J. The shaping of inventory systems in health services: a stakeholder analysis. Int J Prod Econ 2011;133(1):60–9. https://doi.org/10.1016/j.ijpe.2009.10.029.
[23] Burns LR, Lee JA, Bradlow ET, et al. Surgeon evaluation of suture and endo-mechanical products. J Surg Res 2007;141(2): 220–33. https://doi.org/10.1016/j.jss.2006.11.023 (In eng).
[24] Toor J, Bhangu A, Wolfstadt J, et al. Optimizing the surgical instrument tray to immediately increase efficiency and lower costs in the operating room. Can J Surg 2022;65(2):E275–81. https://doi.org/10.1503/cjs.022720.
[25] Reis JG, Fontaine K. Cutting costs in the OR: a case study. Aorn j 1993;57(2):503–4. https://doi.org/10.1016/s0001-2092(07)64108-8 (In eng).
[26] Ahmadi E, Masel DT, Metcalf AY, et al. Inventory management of surgical supplies and sterile instruments in hospitals: a literature review. Health Syst (Basingstoke, England) 2018;8(2):134–51. https://doi.org/10.1080/20476965.2018.1496875 (In eng).
[27] Donald J. What makes your day? A study of the quality of worklife of OR nurses. Can Oper Room Nurs J 1999;17(4):17–27 (In eng).
[28] Sorber R, Dougherty G, Stobierski D, et al. Cost awareness of common supplies is severely impaired among all members of the surgical team. J Surg Res 2020;251:281–6. https://doi.org/10.1016/j.jss.2020.02.007.
[29] De Blok C, Meijboom B, Luijkx K, et al. The human dimension of modular care provision: opportunities for personalization and customization. Int J Prod Econ 2013;142(1):16–26.
[30] Andereggen S, Zoller FA, Boutellier R. Sharing research equipment to bridge intraorganizational boundaries. Res Technol Manag 2013;56(1):49–57. https://doi.org/10.5437/08956308X5601082.
[31] Pasin F, Jobin MH, Cordeau JF. An application of simulation to analyse resource sharing among health-care organisations. Int J Oper Prod Manag 2002.
[32] Shukar S, Zahoor F, Hayat K, et al. Drug shortage: causes, impact, and mitigation strategies. Front Pharmacol 2021:12. https://doi.org/10.3389/fphar.2021.693426 (Review) (In English).
[33] Siow WT, Tang SH, Agrawal RV, et al. Essential ICU drug shortages for COVID-19: what can frontline clinicians do? Crit Care 2020;24(1):260. https://doi.org/10.1186/s13054-020-02971-x (In eng).
[34] De Oliveira Jr GS, Theilken LS, McCarthy RJ. Shortage of perioperative drugs: implications for anesthesia practice and patient safety. Anesth Analg 2011;113(6):1429–35. https://doi.org/10.1213/ANE.0b013e31821f23ef (In eng).
[35] Sinow C, Burgart A, Char DS. How anesthesiologists experience and negotiate ethical challenges from drug shortages.

AJOB Empir Bioeth 2021;12(2):84–91. https://doi.org/10.1080/23294515.2020.1839596 (In eng).
[36] Rodriguez-Monguio R, Lun Z, Bongiovanni T, et al. Postoperative respiratory events in surgical patients exposed to opioid analgesic shortages compared to fully matched patients non-exposed to shortages. Drug Saf 2022;45(4):359–67. https://doi.org/10.1007/s40264-022-01171-6 (In eng).
[37] Hsia IK, Dexter F, Logvinov I, et al. Survey of the national drug shortage effect on anesthesia and patient safety: a patient perspective. Anesth Analg 2015;121(2):502–6. https://doi.org/10.1213/ane.0000000000000798 (In eng).
[38] Jerath A, Ferguson ND, Cuthbertson B. Inhalational volatile-based sedation for COVID-19 pneumonia and ARDS. Intensive Care Med 2020;46(8):1563–6. https://doi.org/10.1007/s00134-020-06154-8 (In eng).
[39] Hofer CK, Wendel Garcia PD, Heim C, et al. Analysis of anaesthesia services to calculate national need and supply of anaesthetics in Switzerland during the COVID-19 pandemic. PLoS One 2021;16(3):e0248997. https://doi.org/10.1371/journal.pone.0248997 (In eng).
[40] Chapuis C, Collomp R, Albaladejo L, et al. Redistribution of critical drugs in shortage during the first wave of COVID-19 in France: from operating theaters to intensive care units. J Pharm Pol Pract 2022;15(1):28. https://doi.org/10.1186/s40545-022-00425-z (In eng).
*[41] Kistler JT, Janakiraman R, Kumar S, et al. The effect of operational process changes on preoperative patient flow: evidence from field research. Prod Oper Manag 2021;30(6):1647–67. https://doi.org/10.1111/poms.13301.
[42] Al Talalwah N, McIltrot KH. Cancellation of surgeries: integrative review. J Perianesth Nurs 2019;34(1):86–96. https://doi.org/10.1016/j.jopan.2017.09.012.
[43] Koh WX, Phelan R, Hopman WM, et al. Cancellation of elective surgery: rates, reasons and effect on patient satisfaction. Can J Surg J canadien de chirurgie 2021;64(2):E155–61. https://doi.org/10.1503/cjs.008119 (In eng).
[44] Sandberg Warren S, Daily B, Egan M, et al. Deliberate perioperative systems design improves operating room throughput. Anesthesiology 2005;103(2):406–18. https://doi.org/10.1097/00000542-200508000-00025.
[45] Dexter F, Tinker JH. Analysis of strategies to decrease postanesthesia care unit costs. Anesthesiology 1995;82(1):94–101. https://doi.org/10.1097/00000542-199501000-00013 (In eng).
[46] Corey JM, Bulka CM, Ehrenfeld JM. Is regional anesthesia associated with reduced PACU length of stay?: a retrospective analysis from a tertiary medical center. Clin Orthop Relat Res 2014;472(5):1427–33. https://doi.org/10.1007/s11999-013-3336-5 (In eng).
[47] Schad S, Booke H, Thal SC, et al. The recovery room: transition from a sleepy postoperative unit to a vibrant and cost-effective multipurpose perioperative care unit. Clinicoecon Outcomes Res 2021;13:893–6. https://doi.org/10.2147/ceor.S331681 (In eng).
*[48] Weissman C. The enhanced postoperative care system. J Clin Anesth 2005;17(4):314–22. https://doi.org/10.1016/j.jclinane.2004.10.003 (In eng).
[49] Carnes T, Price D, Levi R, et al. An optimization framework for smoothing surgical bed census via strategic block scheduling. Manufacturing Service Operation Management; 2011. p. 488–94.
[50] Seung-Chul K, Ira H. Flexible bed allocation and performance in the intensive care unit. J Oper Manag 2000;18(4):427–43.
[51] Ishikawa M, Sakamoto A. Patient SafetyNet for the evaluation of postoperative respiratory status by nurses: a presurvey and postsurvey study. J Perianesth Nurs 2021;36(1):14–7. https://doi.org/10.1016/j.jopan.2020.03.005 (In eng).
[52] Wright PD, Bretthauer KM, Côté MJ. Reexamining the nurse scheduling problem: staffing ratios and nursing shortages. Decis Sci J 2006;37(1):39–70.
[53] Dimick JB, Swoboda SM, Pronovost PJ, et al. Effect of nurse-to-patient ratio in the intensive care unit on pulmonary complications and resource use after hepatectomy. Am J Crit Care 2001;10(6):376.
[54] Amaravadi RK, Dimick JB, Pronovost PJ, et al. ICU nurse-to-patient ratio is associated with complications and resource use after esophagectomy. Intensive Care Med 2000;26(12):1857–62.
[55] Tarnow-Mordi W, Hau C, Warden A, et al. Hospital mortality in relation to staff workload: a 4-year study in an adult intensive-care unit. The lancet 2000;356(9225):185–9.
[56] Prin M, Wunsch H. International comparisons of intensive care: informing outcomes and improving standards. Curr Opin Crit Care 2012;18(6):700–6. https://doi.org/10.1097/MCC.0b013e32835914d5 (In eng).
[57] Andereggen L, Andereggen S, Bello C, et al. Technical skills in the operating room: implications for perioperative leadership and patient outcomes. Best Pract Res Clin Anaesthesiol 2022. https://doi.org/10.1016/j.bpa.2022.05.002.
[58] Mascha EJ, Schober P, Schefold JC, et al. Staffing with disease-based epidemiologic indices may reduce shortage of intensive care unit staff during the COVID-19 pandemic. Anesth Analg 2020;131(1):24–30. https://doi.org/10.1213/ane.0000000000004849 (In eng).
[59] Healey AN, Undre S, Vincent CA. Defining the technical skills of teamwork in surgery. Qual Saf Health Care 2006;15(4):231–4. https://doi.org/10.1136/qshc.2005.017517.
[60] Hickey S, Mathews KS, Siller J, et al. Rapid deployment of an emergency department-intensive care unit for the COVID-19 pandemic. Clin Exp Emerg Med 2020;7(4):319–25. https://doi.org/10.15441/ceem.20.102 (In eng).
[61] Lam SM. How to create high-performing teams. Facial Plast Surg 2010;26(1):16–20. https://doi.org/10.1055/s-0029-1245059 (In eng).
*[62] Ebadi A, Tighe PJ, Zhang L, et al. DisTeam: a decision support tool for surgical team selection. Artif Intell Med 2017;76:16–26. https://doi.org/10.1016/j.artmed.2017.02.002 (In eng).
[63] Bjurling-Sjöberg P, Wadensten B, Pöder U, et al. Balancing intertwined responsibilities: a grounded theory study of teamwork in everyday intensive care unit practice. J Interprof Care 2017;31(2):233–44. https://doi.org/10.1080/13561820.2016.1255184 (In eng).
[64] Laflamme K, Leibing A, Lavoie-Tremblay M. Operating room culture and interprofessional relations: impact on nurse's retention. Health Care Manag 2019;38(4):301–10. https://doi.org/10.1097/HCM.0000000000000280.
*[65] Hovlid E, von Plessen C, Haug K, et al. Patient experiences with interventions to reduce surgery cancellations: a

qualitative study. BMC Surg 2013;13(1):30. https://doi.org/10.1186/1471-2482-13-30.
[66] Mihalj M, Carrel T, Gregoric ID, et al. Telemedicine for preoperative assessment during a COVID-19 pandemic: recommendations for clinical care. Best Pract Res Clin Anaesthesiol 2020;34(2):345–51. https://doi.org/10.1016/j.bpa.2020.05.001.
*[67] Lee CK, Lee IF. Preoperative patient teaching: the practice and perceptions among surgical ward nurses. J Clin Nurs 2013; 22(17–18):2551–61. https://doi.org/10.1111/j.1365-2702.2012.04345.x (In eng).
[68] Ballon-Landa E, Clavijo R, Gross M, et al. A novel video-based patient education program to reduce penile prosthetic surgery cancellations. Am J Men's Health 2019;13(6):1557988319893568. https://doi.org/10.1177/1557988319893568.