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Observational study of anaesthesia workflow to evaluate physical workspace design and layout

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Abstract

Background: The safety and efficiency of anaesthesia care depend on the design of the physical workspace. However, little is known about the influence that workspace design has on the ability to perform complex operating theatre (OT) work. The aim of this study was to observe the relationship between task switching and physical layout, and then use the data collected to design and assess different anaesthesia workspace layouts.

Methods: In this observational study, six videos of anaesthesia providers were analysed from a single centre in the United States. A task analysis of workflow during the maintenance phase of anaesthesia was performed by categorising tasks. The data supported evaluations of alternative workspace designs.

Results: An anaesthesia provider's time was occupied primarily by three tasks: patient (mean: 30.0% of total maintenance duration), electronic medical record (26.6%), and visual display tasks (18.6%). The mean time between task switches was 6.39 s. With the current workspace layout, the anaesthesia provider was centred toward the patient for approximately half of the maintenance duration. Evaluating the alternative layout designs showed how equipment arrangements could improve task switching and increase the provider's focus towards the patient and visual displays.

Conclusions: Our study showed that current operating theatre layouts do not fit work demands. We report a simple method that facilitates a quick layout design assessment and showed that the anaesthesia workspace can be improved to better suit workflow and patient care. Overall, this arrangement could reduce anaesthesia workload while improving task flow efficiency and potentially the safety of care.

Keywords: anaesthesia; human factors; operating room; task analysis; task switching; workflow; workspace design

Editor's key points

- Intraoperative anaesthesia care is complex and requires multitasking.
- As complexity has increased and the number of tasks has grown, new task-related equipment such as computer terminal and electronic drug dispenser, has been incorporated in the anaesthesia workspace without considering the impact on workflow or patient safety.
- Ideal workspace layout should be designed such that the focus is patient care and monitoring, with an overarching goal of vigilance and safety.
- This study demonstrates through a task–workspace analysis that the current anaesthesia workspace configuration promotes inefficiency and potential distraction from patient care.
- Alternative workspace designs are proposed that could promote more sustained attention on the patient and improve both efficiency and safety.

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Modern anaesthesiology practice benefits from a range of operating theatre (OT) devices and technologies. Recent regulatory changes mean that healthcare devices are more carefully designed to accommodate the users.[1] However, few studies have explored the arrangement and integration of multiple technologies within the anaesthesiology workspace, or used evidence-based OT design strategies that account for the complexity of OT work. The majority of published and anecdotal evidence for OT design focuses on issues in the overall OT.[2–6] Some research has investigated the impact of the physical environment on the workflow of OT nurses[7–9] and surgeons' preferences regarding OT design[10]; however, systematic investigation and evaluation of anaesthesia workspace design and functionality are lacking.

The anaesthesia workspace is defined here as the area where anaesthesia providers perform their work. This is often a small area with limited, and often cluttered, work surfaces[2] that is shared by multiple team members and contains several pieces of fixed or moveable equipment. It usually has an anaesthesia machine, electronic medical record (EMR) computer, infusion pumps, and drug storage and preparation areas. Because anaesthesia providers frequently switch between tasks,[11] the spatial arrangement of different devices can critically affect their patient awareness, their ability to monitor physiological values, the efficiency and timeliness of responses, and fatigue; it can also predispose them to a range of disruptions, such as bumping into equipment or tripping over wires.[4,7,9,11] Anaesthesia provider vigilance and work performance can be hindered by new technologies that are not integrated or connected into the anaesthesia workspace without a thorough analysis of how new pieces of equipment and their locations within the anaesthesia workspace influence the provider's workflow. Thus, it is necessary to evaluate whether or not the workspace design and arrangement of equipment support the work demands. A better understanding of the relationship between anaesthesia work, current and future equipment locations, and the demand to switch between tasks might help to define anaesthesia workspace configurations that improve awareness and efficiency while reducing fatigue and disruptions.

The aim of this study was to observe the relationship between task switching and physical layout during the maintenance phase of anaesthesia, and then use the data to inform anaesthesia workspace design and explore different hypothetical anaesthesia workspace layouts. We hypothesised that (i) observations of anaesthesia providers at work would allow us to quantify the time spent on and switching between tasks, and (ii) these data could be superimposed on alternative anaesthesia workspace designs to explore effects on awareness and workflow. Our goal was to identify configurations that would better fit task demands, allow continual monitoring of the patient, reduce instances in which the anaesthesia provider had their back to patient, and reduce the frequency and distance involved in task switching.

Methods

In this observational study, we examined the relationship between workflow and physical layout in the anaesthesia workspace. We first used video data to analyse the time that anaesthesia providers spent on each task during the maintenance phase of anaesthesia. Next, tasks were paired to explore the frequency and direction of task switching. Finally, these data were used to test theoretical configurations of different workspaces and assess the relationship between anaesthesia workspace layout and workflow. This study was performed at The Medical University of South Carolina, a 700-bed academic hospital system in Charleston, SC, USA, after Institutional Review Board (Pro00048787) approval was obtained. All anaesthesia providers in the study completed the informed consent process with the research team.

Study design and setting

A convenience sample series of cases (n=35) were video recorded as part of a larger study on OT design (RIPCHD.OR; Agency for Healthcare Research and Quality: P30HS24380). For all cases, four video cameras were used, such that four views in the OT could be observed simultaneously (Fig. 1). Videos were included in this study if they were (i) recorded in the same OT to control for the size and available space in the OT, (ii) with the same anaesthesia workspace layout to control for any differences in the physical environment (e.g. same surgical table orientation and same general equipment in the OT), and (iii) with one anaesthesia provider present during the maintenance phase of anaesthetic care (i.e. no care transitions) to control for differences in task management with multiple providers. The maintenance phase of anaesthesia in all surgical videos was defined by the pinning and unpinning of the surgical draping, which provided a consistent visual cue.

Task analysis

Six videos met the inclusion criteria and were analysed by two researchers independently using the Noldus Observer XT 12 software. In evaluating the six cases, we reached observational saturation in regard to our research objective, meaning no more information would be gained with more videos. The surgeries were a laparoscopic inguinal hernia repair, laparoscopic gastric bypass, laparoscopic cholecystectomy, gastrostomy tube replacement, laparoscopic cholecystectomy, and an exploratory laparotomy. Using the surgical videos and based on previous work,[11] the researchers coded the specific tasks the provider performed at every second of the maintenance phase of anaesthesia. Codes included patient interaction, visual displays interaction, EMR interaction, retrieving supplies, preparing supplies, infusion pump interaction, handoff, not in workspace, and non-medical tasks. The task categories are operationally defined in Table 1.

All of the task categories were mutually exclusive and comprehensive of the observed work done. Consensus building was used to ensure reliable coding, and all discrepancies between the two researchers were discussed until an agreement was reached. The task data from all surgeries in the sample were extracted into R version 3.2.2 and were first analysed for the distribution of time spent on each task and the frequency of switching. We plotted the tasks as a horizontal timeline plot to visualise the progression of tasks throughout the maintenance phase of anaesthesia and assess how often tasks are switched.[11] Inherent in the categorisation scheme was the performance location of each task. Coupling task with location enabled us to use the data to understand the relationship between physical layout and workflow.

Task switching

The tasks observed from beginning to end of the maintenance phase of anaesthesia were broken down into pairs, which

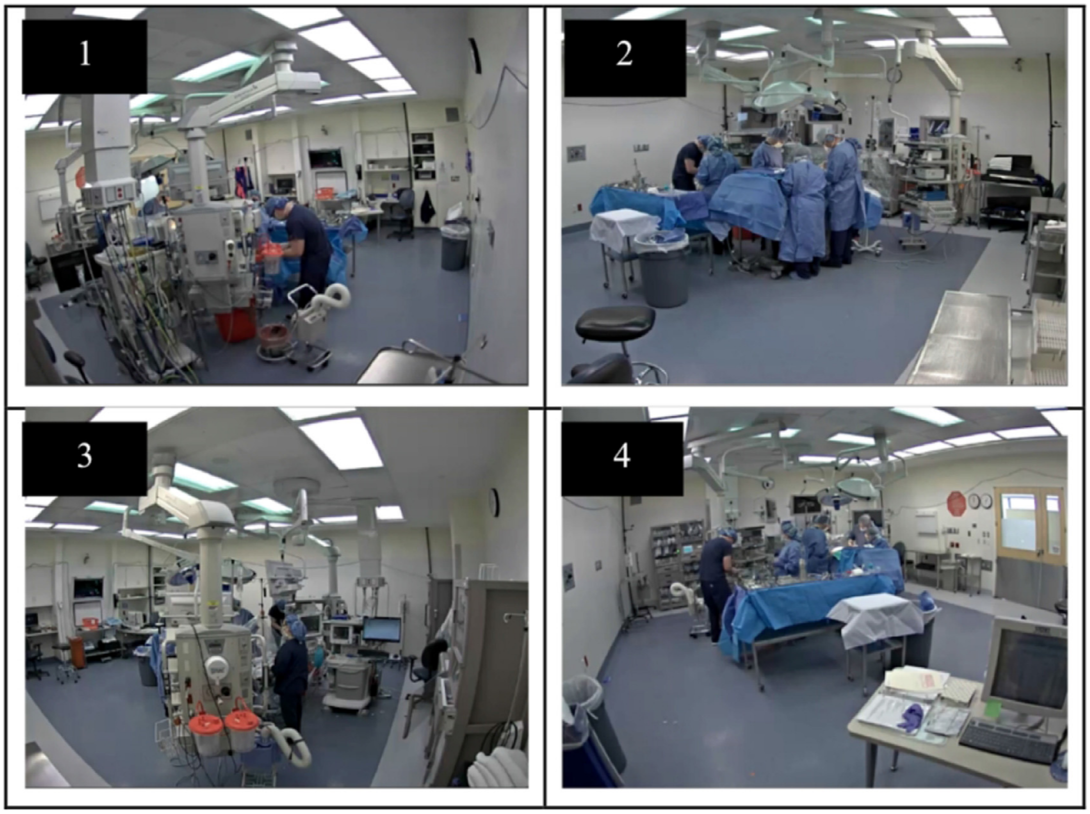

Fig 1. Noldus Observer Video Feeds in the operating theatre.

provided a step-by-step-progression of workflow by conveying which task an anaesthesia provider was currently performing and to which task they switched. We then plotted the task-pair data on a diagram of the anaesthesia workspace layout (i.e. the physical movement from one task to the next) to assess the relationship between workflow and layout design. Each task pair was plotted as a line connecting the task locations. For example, if the anaesthesia provider performed a series of tasks, such as 'patient → visual displays → EMR → patient', then the task pairs would be 'patient–visual displays', 'visual displays–EMR', and 'EMR–patient'. This sequence showed that the anaesthesia provider moved from the patient bed, to the anaesthesia cart, to the EMR computer, and back to the patient bed. Lines were plotted onto the layout diagram according to this movement. The weight of the line corresponded to the frequency of the task pair; a thicker line on the diagram corresponded to task pairs that occurred more frequently. Thus, this approach yielded a figure that showed a step-by-step progression of tasks in a surgery, a visual representation of task switches, and the relationship between tasks and layout design. All six surgeries were evaluated separately.

Anaesthesia workspace design assessment

It is desirable to have a workspace layout that facilitates the primary task of continually monitoring the patient's oxygenation, ventilation, circulation, and temperature.[12] Using these task-switching data, we compared the existing workspace layout (Layout A) with three alternative designs based on (i) reducing the distance between frequently performed task pairs and (ii) centring tasks towards the patient and patient displays. Layout B assessed the effect of moving the EMR closer to the head of the patient bed by placing it next to the infusion pumps. Layout C incorporated an extended work surface attached to the anaesthesia cart that is intended for preparing supplies, instead of the back of the anaesthesia workspace in the storage area. Layout D included the extended work surface and integrated the EMR with the patient displays on the anaesthesia cart to reflect one display. Layout D was based on the recommendation that information systems in the OT could be integrated to reduce alarm distractions and improve a provider's ability to process information coming from multiple sources.[13] These four design iterations are shown in Figure 2 and were assessed by replotting the task pairs derived from observations with Layout A onto each of the three new layouts.

Results

The architectural floor plan of the OT where the six surgeries occurred is illustrated in Figure 3 with the anaesthesia workspace further described. The anaesthesia machine and patient monitor are located to the right of the patient's head on the anaesthesia cart, and the infusion pumps are located to the left of the patient's head. The EMR computer system is attached to the right side of the anaesthesia machine. Anaesthesia supply

Table 1 Task categories used for video coding and their operational definitions. Modified from Betza and colleagues.[11] EMR, electronic medical record.

Task category	Operational definition
Patient	Observing the patient, positioning the patient, talking to the patient, administering drugs intravenously, and generally interacting with the patient
Visual displays	Interacting with or facing the visual displays on the anaesthesia cart, including observing the patient or anaesthesia displays, changing the gas flows, and gathering supplies on the anaesthesia cart
EMR	Using or facing the EMR system; includes documenting, reading, and observing data on the EMR monitor
Retrieving supplies	Opening the doors and drawers, and retrieving supplies from both the short and tall storage cabinets
Preparing supplies	Preparing supplies on top of the short storage cabinet
Infusion pumps	Interacting with the infusion pumps, including observing, controlling rates, and handling i.v. bags
Handoff	The overlapping period of time of two providers, in which one anaesthesia provider enters the operating theatre and a different provider leaves within 15 min of the other entering provider
Not in workspace	Any period of time when the anaesthesia provider is outside of the anaesthesia workspace
Non-medical task	Any task, in which the anaesthesia provider is waiting or idle and not actively observing the patient, anaesthesia cart, EMR, or infusion pumps; this time includes throwing away trash, using a cellular phone, and reading physical papers

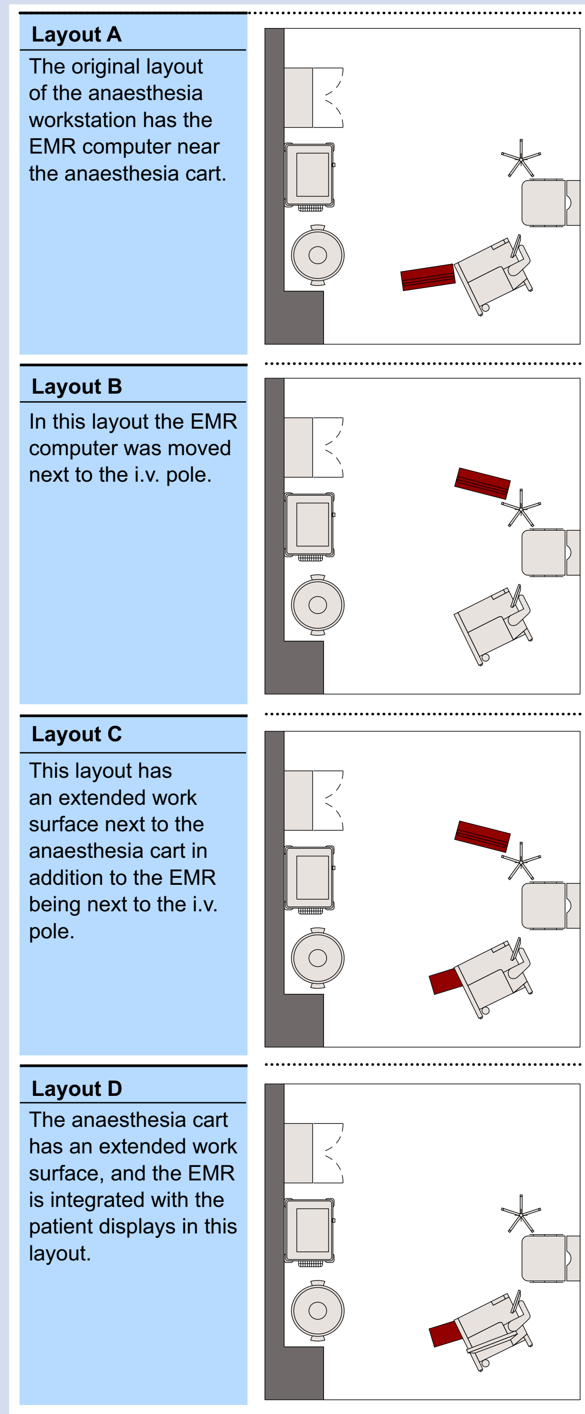

Fig 2. Anaesthesia layout design alternatives. EMR, electronic medical record.

cabinets are located behind the anaesthesia workspace and include a tall cabinet and a short cabinet. The top of the short cabinet serves as a supply preparation area.

Task analysis

The six surgeries had an average maintenance duration of 65.98 (standard deviation: 19.83) min. The shortest maintenance duration was 36.92 min and the longest maintenance duration was 91.57 min. The three tasks that occupied most of an anaesthesia provider's time were patient, EMR, and visual display tasks. These tasks took 30.0%, 26.6%, and 18.6% of the total time, respectively. Short handoffs and the anaesthesia provider being physically absent from the workspace occurred at an average of 0.1% and 0.6%, respectively, of the total maintenance duration, thus have a minimal impact on the overall task flow. The least frequently performed tasks were retrieving supplies, interacting with the infusion pumps, preparing supplies, and performing non-medical tasks at 4.4%, 4.7%, 7.0%, and 8.2% of the total maintenance duration, respectively.

Figure 4 shows the horizontal timeline of tasks for the six surgeries. The width of each coloured bar corresponds to the duration of the task. It is clear that a large amount of task switching occurred throughout the surgery, as very few tasks were long in duration (i.e. very few bars have a large width). On average across all surgeries, a task switch occurred every 6.39 s.

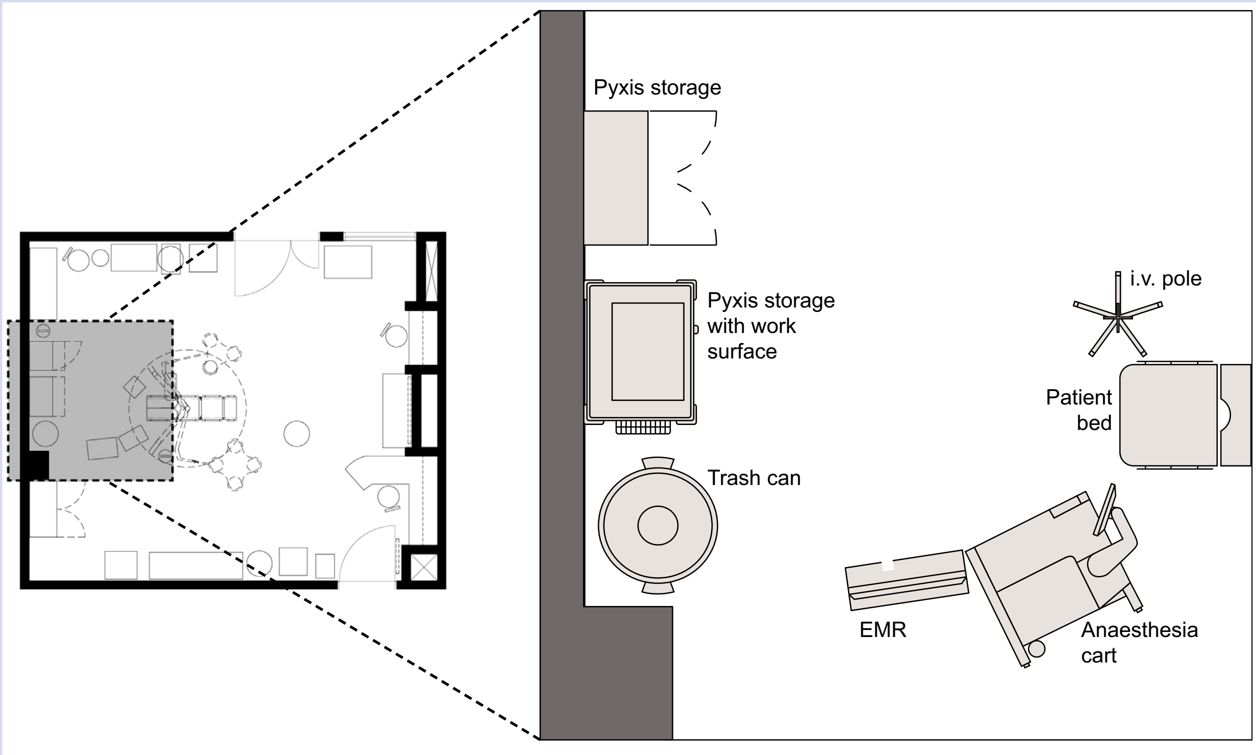

Fig 3. Floorplan of operating theatre with detailed anaesthesia workspace. EMR, electronic medical record.

Workspace layout assessment

Figure 5 shows the results of the task–layout analysis of the original layout and the three design alternatives. In general, all six surgeries showed a consistent pattern of task movement; thus, we chose two surgeries to show in Figure 5 for ease of interpretation. The two surgeries correspond to Surgeries 2 and 3, and they are the cases with the longest and shortest maintenance durations, respectively.

The current workspace layout, Layout A in Figure 5, shows many line crossings of task pairs with the focus of tasks near the centre of the anaesthesia workspace. The spread of task-pair lines throughout Layout A emphasises the volume of movement required to transition between tasks, especially considering that the anaesthesia provider switches tasks approximately every 6 s. The anaesthesia provider is centred towards the patient when performing tasks related to the infusion pumps, visual displays, or the patient. The anaesthesia provider must turn away and disengage from the patient when performing the other tasks (e.g. EMR, handoff, non-medical tasks, not in workspace, preparing supplies, and retrieving supplies), and from the task analysis data, this set of tasks required 46.7% of the total maintenance duration across all surgeries. Thus, the anaesthesia provider was facing the patient (i.e. performing patient, visual displays, or infusion pump tasks) for about half of the duration of the maintenance phase of anaesthesia.

EMR tasks consumed the second largest proportion of time (26.6%) according to the task analysis, and the original layout revealed a lack of focus of tasks towards the patient and visual displays. Moving the EMR computer next to the infusion pumps in Layout B (Fig. 5) allowed for the centre of tasks to be shifted more towards the patient and patient displays in comparison with Layout A. However, it still required the anaesthesia provider to turn away from the patient when preparing and retrieving supplies. Layout C, with extended work surface for preparing supplies, further improved the centring of tasks towards the patient. Integrating the EMR with the visual displays in Layout D allowed for the anaesthesia provider to continually monitor the patient and patient displays while interacting with the EMR computer. In both Layouts C and D, the anaesthesia provider would still need to turn their back and travel away from the patient when retrieving supplies, but these actions account for only 4.4% of the total maintenance duration. In comparison to Layout C, where there was a physical separation between visual displays, patient, and EMR, Layout D was based on the recommendation that information systems in the OT should be integrated to reduce alarm distractions and improve a provider's ability to process information coming from multiple sources.[13] The anaesthesia provider would only need to disengage from the patient and visual displays when retrieving supplies in the Layout D design. Thus, Layout D theoretically improves the centring of tasks around the patient and, by reducing the time the anaesthesia provider spends with their back to the patient, should enable greater awareness than is possible with the original layout and other alternatives.

Discussion

Observational analysis of videos showed the task patterns performed by anaesthesia providers. Most of the provider's

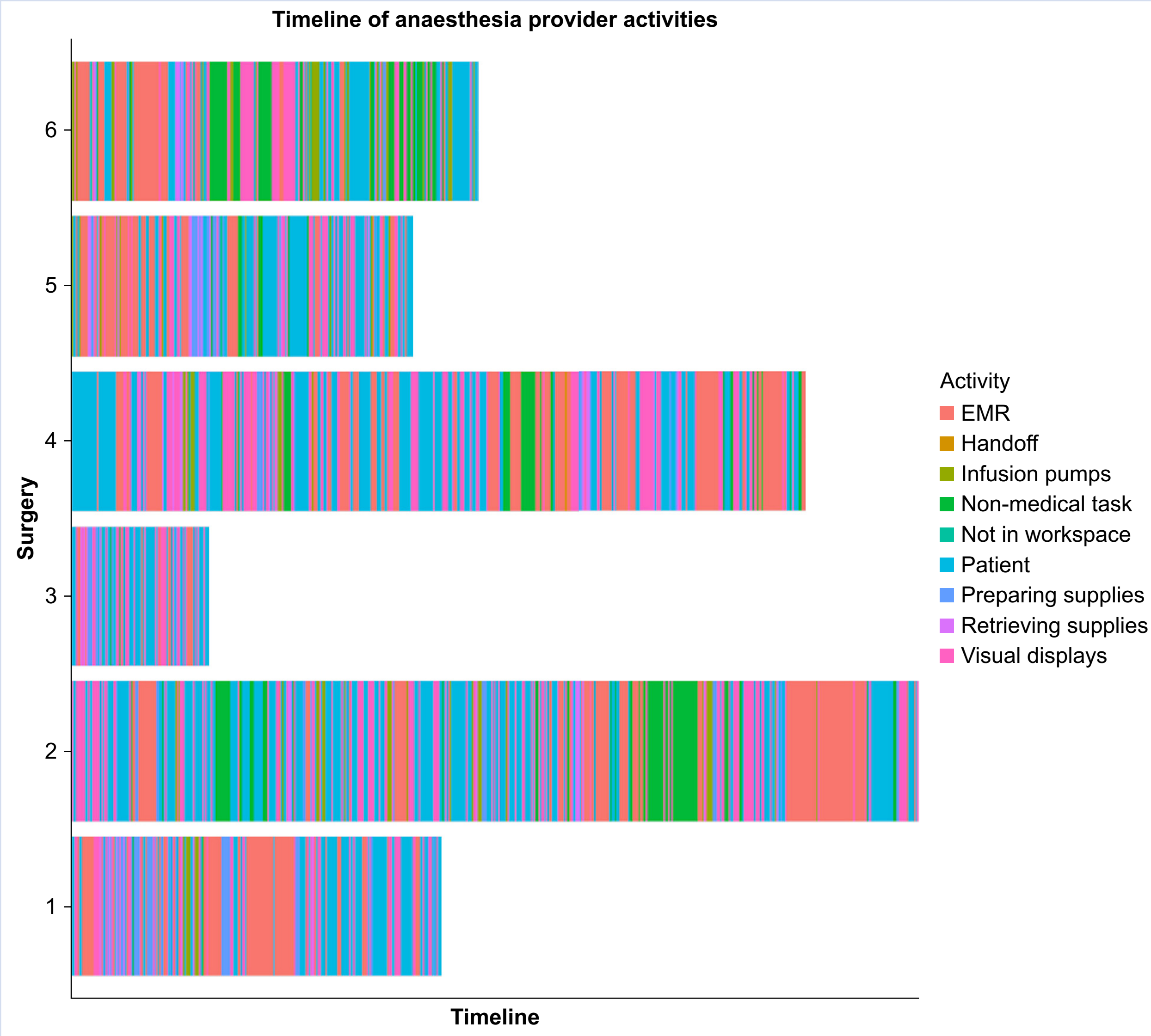

Fig 4. Plots of task switches for each surgery. The width of each color bar corresponds to the duration of the task. EMR, electronic medical record.

time was spent interacting with the patient, visual displays, and EMR, with task switches occurring approximately about every 6 s during the maintenance phase of anaesthesia. Creating pairs that defined the switch from one task location to another illustrated that the attention of the anaesthesia provider may be directed away from the patient and patient displays with the current workspace layout. The design alternatives sought to reduce the distance between frequent task switches and to improve focus towards the patient and patient displays. The analysis showed that Layout D, which included an extra working surface attached to the anaesthesia cart and a display that integrated the EMR with the patient displays, appeared to be the best design alternative of those assessed.

The task analysis showed that the anaesthesia provider spent a large proportion of time interacting with the patient and visual displays, as it is recommended that anaesthesia providers continually monitor the patient's physiological variables during the maintenance phase of anaesthesia.[12] However, any time the provider turns away from the patient, the provider's attention is being divided between the primary task of monitoring the patient and a secondary task. Being engaged in secondary tasks at the EMR or with supplies may impact the provider's cognitive resources being allocated to monitoring the patient and using the EMR or preparing or retrieving supplies. If the provider's cognitive resources are split between tasks, then this may result in reduced awareness and attention to the patient and could potentially lead to errors. Furthermore, the location of the EMR in the current configuration required the provider to turn away from the patient. Although previous studies have suggested that record-keeping consumes up to 15% of intraoperative care,[14]

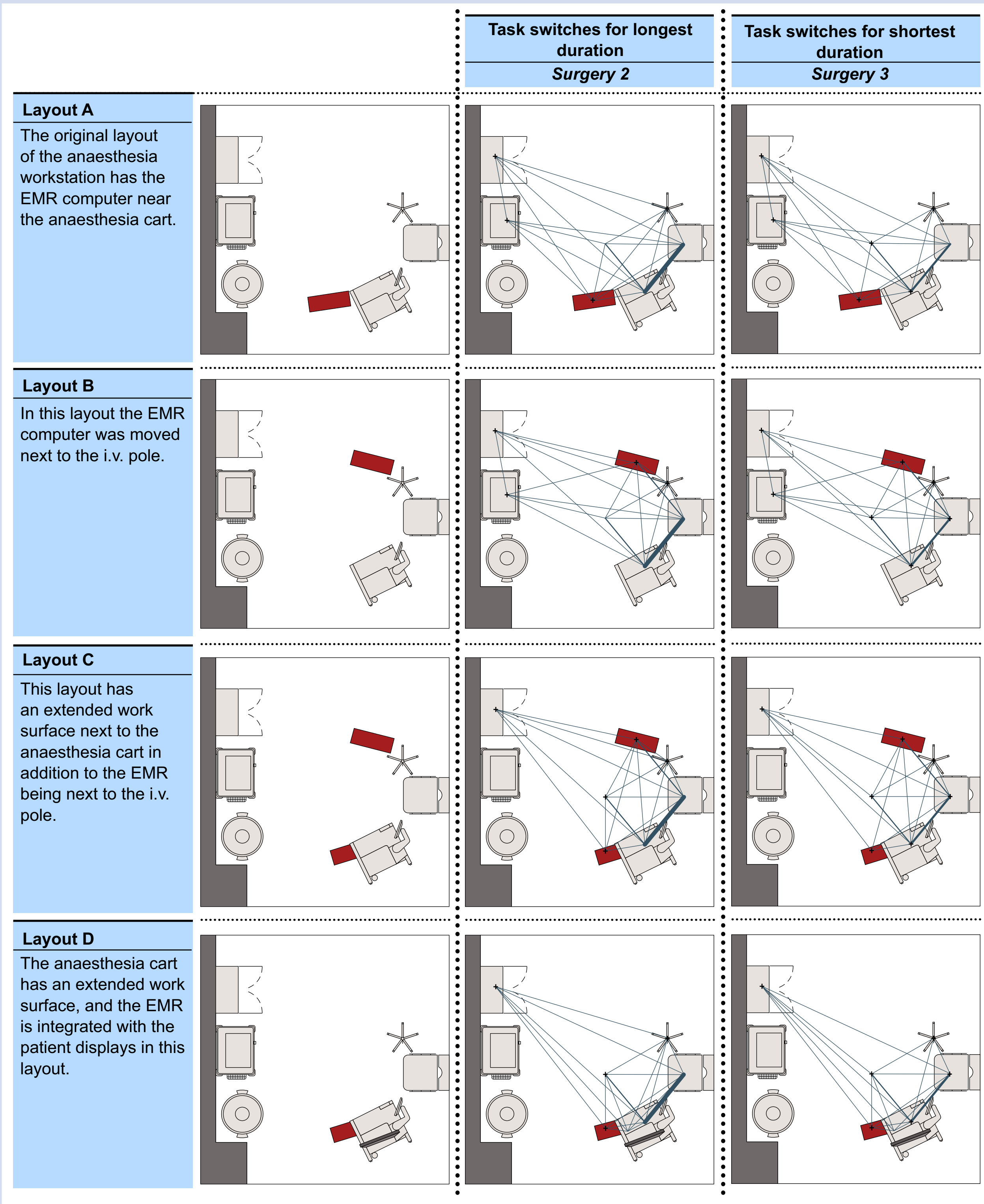

Fig 5. Task switches for shortest and longest maintenance phase durations for layouts A–D. EMR, electronic medical record.

our study showed that almost 30% of the maintenance phase of anaesthesia was spent at the EMR, which is placed perpendicular to the patient. This finding suggests that the EMR location and frequency of use might have a substantial impact on the situational awareness of the anaesthesiologist, and thus can potentially detract from patient care. Although the integration of the EMR into the patient displays in Layout D is a minor physical change, the combined display would reduce the need to move away from the patient to perform the second most frequently performed tasks, EMR tasks.

The task analysis performed also showed that the anaesthesia provider switched tasks approximately every 6 s. Task switching analysis is valuable, as it helps in understanding workflow, efficiency, quality, and safety,[15] and it can be used to improve productivity.[16] Task switching itself can negatively impact performance. For example, response times are reduced and error rates are increased immediately after a task switch.[17] These 'switch costs' can increase from benign to detrimental as task complexity increases.[18] The costs of switching between different anaesthetic tasks under different conditions (e.g. surgery types, multiple anaesthesia providers, and different OT shapes and sizes) have not yet been studied; however, with almost 600 task switches per hour in our sample, there is a clear incentive for further study.

In this study, we were able to investigate workflow and the impact of alternative workspace designs. Our results suggest benefits of integrated display technology, and that this approach can be used to evaluate and validate technology integration into anaesthesia workflow. Additionally, integrating different types of technology into one single workstation could decrease the workstation clutter and keep the patient at the centre of the anaesthesia workstation. Every component of a work system—tasks, tools and technologies, person, environment, and organisation—is interdependent, and changes to one component will affect the entire work system.[19,20] Thus, testing OT layout designs via pre-emptive simulations can help research teams and designers avoid expensive and potentially dangerous design errors.[13] Our proposed methodology is valuable in that it allows a pre-emptive discussion of future design changes between both clinicians and designers, and our methodology is low cost and quick to use. Our methodology is capable of being adopted at other institutions seeking to quickly understand the impacts of potential design changes. The method is similar to other process improvement tools, such as spaghetti diagrams, that allow researchers to understand a person or object's route and distance travelled. Our approach differs in that we are not interested in total distance travelled or the route of the provider, but rather which paths (e.g. patient to visual displays) are most heavily travelled to better determine how to rearrange workspace to minimise movement away from the patient and visual displays. Our approach is a relatively quick, noninvasive, and low-cost way to analyse future designs, and could be used simultaneously with other process improvement and design tools. A task–workspace analysis, such as this, has not been applied in the anaesthesia domain. This approach can be used to further evaluate the anaesthesia workspace and has the potential to improve anaesthesia workflow.

This study was descriptive, and the six cases that met our inclusion criteria reached saturation in regard to our research objective. No more information would be gained with observing more surgical videos, and the six cases were sufficient to describe how the anaesthesia workspace affects workflow. The current work can be expanded to investigate anaesthesia work patterns during other types of surgeries, other OT layouts, and different phases of surgery. The current study investigated the task patterns of one provider; however, there is often more than one anaesthesia provider present during a surgical case, especially in teaching hospitals. Thus, future work can benefit from studying the allocation of tasks and work when there is more than one provider present, or when there is a care transition between providers. Our study demonstrated a task–layout relationship based on data that were elicited in a single OT, and it will be important to study the impact on task flow when the same providers are exposed to multiple layout designs. Therefore, this work can be expanded in the future to evaluate how task patterns and task switching adapt as the layout design changes. Task switching in anaesthesia may be impacted by other stimuli, such as auditory alarms; thus, there is an opportunity to study the effects of visual and auditory information on task switching and directing attention.[21] Another aspect that needs to be considered as this work expands is assessing the entirety of the work system, as other work system factors may influence workspace design in the OT, such as designing for infection prevention and the design of the built environment. For example, the storage cabinets in the current study were fixed, but because of the recent prevalence of mobile storage units, it is important to study how mobilisation and modularisation of equipment impact task switching across different phases of surgery.

One result of our study identified that the anaesthesia providers spend nearly half of the time facing away from the patient. If the provider is facing away from the patient and patient monitors, they are typically engaged in tasks related to the EMR or supplies; thus, being engaged in these secondary tasks may impact the provider's cognitive resources allocated to monitoring the patient. Facing away from the patient does not conclusively indicate that there is reduced awareness or attention; however, when cognitive resources are divided between the patient and secondary tasks, then the competition for cognitive resources may indirectly impact the provider's ability to monitor the patient and could potentially lead to errors. The results suggest that different layouts may modify the fit between physical space and the requirements for frequent task switching. Given the proportion of time spent on EMR tasks, integrating the EMR and anaesthesia workspace would decrease the amount of time that the provider is turned away from the patient. Performance improvements might be observed by moving visual displays closer and providing an additional space for working with materials and supplies. We have thus demonstrated that the anaesthesia workspace can be designed for better task flow and patient care using a simple approach that allows relatively swift, low-cost prototyping. If the anaesthesia workspace redesign can improve efficiency of workflow, there are potential implications for better attention to tasks, thus potentially reducing the information access cost for multitasking and consequently reducing errors and provider fatigue. Overall, a workspace redesign could reduce anaesthesia workload while improving the efficiency of task flow and potentially the safety of care in the OT.

Authors' contributions

Study design: all authors
Data acquisition: all authors
Data analysis: KAJ, DMN
Data interpretation: all authors
Writing of first draft of paper: KAJ
Critically revising of drafts: all authors
All authors approved the final version to be published and agreed to be accountable for all aspects of the work.

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Declarations of interest

The authors declare that they have no conflicts of interest.

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