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What is the best workflow for an operating room? A simulation study of five scenarios

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Abstract Parallel induction of anesthesia improves operating room (OR) efficiency. To support decision-making as to optimal facilities and optimal use of resources, we compared the cost-efficiency of several workflow models of parallel induction to that of the traditional model, using discrete-event simulation. For each scenario, average number of procedures performed, surgery time, daily over- and under-utilized time, and staffing costs per operation were assessed. We also studied whether scheduling short and long procedures in separate rooms would amplify the effects of the parallel processing. All parallel work-flow models demonstrated better cost-efficiency than the traditionally sequenced working pattern. Staffing costs per procedure were 7% lower in the best induction model than in the traditional model. When short procedures were scheduled separately, differences between induction models were small.

Keywords Parallel processing · OR management · Efficiency · Workflow · Operating room · Simulation

Parallel processing, mainly concurrent induction of anesthesia, seems to improve operating room (OR) efficiency [1–3]. Several approaches for parallel induction have been suggested: Block rooms for epidurals [4] or brachial blocks [5] before surgery; induction rooms with additional personnel to provide anesthesia inductions for one [2, 3] or several operating rooms [1]; surgeons administering local anesthetics in the holding room while the OR is prepared for surgery [6]. All these models have reduced the non-operative time enough to enable more operations to be performed per day.

Hospital facilities, however, are not always suitable for parallel induction. Administrators redesigning or planning new facilities face the dilemma whether it is necessary to add an induction room to every individual OR, or whether a multiple-bed induction room could serve several ORs with fewer personnel. Even in countries where OR facilities are traditionally designed with dedicated induction rooms [7, 8], they may not always be in optimal use.

To support decision-making as to optimal facilities and resource use, we investigated several workflow models of parallel induction by means of computer simulation. We compared the traditional induction-in-room model with several work-flow models, with respect to their effects on labor costs, number of procedures performed by 3:30 p.m., as well as under- and over-utilized time. We also studied, would short and long procedures scheduled in separate rooms further augment any benefits from the parallel processing.

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1 Materials and methods

The Trauma Operating Unit of the Helsinki University Central Hospital includes four ORs. Of the 5000 annual procedures, 70% are trauma or emergency operations. The ORs are built with individual induction rooms. Alternatively, the holding area of the OR can serve as an induction room. The study protocol was approved by the Internal Reviewer of the hospital.

In contrast to our previous study [3], which compared a particular induction model with the traditional workflow, we lacked the option to compare multiple models in a real life situation. Instead, we used computer simulation, widely used for similar purposes [9].

For the analysis, data on the duration of all procedures performed in one year were obtained from the hospital information systems. These data only included the following time stamps: patient in room, surgery start time, surgery finish time and patient out of room. Therefore, more detailed procedural interval data: durations of surgical preparation, anesthesia induction, dressings, emergence and room clean-up time [3, 10] from our previous study [3], performed during the same year, was used as a supplement for the simulation models. Procedures lasting longer than 9 hours (9 of 4596 cases) were excluded to ensure proper functioning of the model.

The data were entered into the Stat-Fit program (Geer Mountain Software Corporation, South Kent, CT) to determine the best-fitting distribution for each procedural time interval and then exported to a simulation program (Delmia Quest, Version D5R16SP5; Delmia Corp. Auburn Hills, MI)

We studied the following scenarios, in which the number of different professionals needed was based on our real-life experience:

1. Traditional model:

In each OR, a team consisting of one anesthesiologist, one surgeon, one anesthesia nurse, one circulating nurse, and one instrument nurse takes care of the entire surgical process: induction of anesthesia, preparation, surgery, turnover, and transport to the postanesthesia care unit (PACU).

2. Four rooms with induction rooms and additional personnel

Each of our ORs has its own adjacent induction room. As compared to the traditional model, a team of one anesthesia nurse and one instrument nurse is added to each of the four ORs. The anesthesia of the first patient of the day is induced in the OR, and by the end of that case, the additional induction team, with the anesthesiologist assigned to that particular OR, performs anesthesia induction for the next patient. The team takes care of that particular patient until the end of the case, while the original team prepares for the next patient, and so on.

3. Circulating induction team

A team consisting of one anesthesiologist, one anesthesia nurse, and one instrument nurse moves from one induction room to another, performing only anesthesia inductions. Other resources of the four ORs remain the same as in the traditional model.

4. Centralized induction room

A centralized induction room with three beds and additional personnel (two anesthesia nurses, one instrument nurse and one anesthesiologist) serves all four ORs. The number of additional personnel in accordance with national, as well as ASPAN guidelines for perianesthesia nursing and monitoring [11] was determined as follows: Each patient under general anesthesia is individually monitored by an anesthesia nurse while one additional nurse is required to be present. Furthermore, one anesthesia nurse can monitor two or three patients under a regional block, provided that at least one additional nurse is present in the room.

5. Four teams in four ORs for three surgeons—no induction rooms

Four ORs with personnel (each with one anesthesia nurse, two instrument nurses, and one anesthesiologist) are available for procedures scheduled in three rooms and three surgeons. The personnel of the empty room will prepare for the patient of the surgeon expected to finish next.

From the original cases, 50 schedules were randomly formed. Each schedule comprised cases performed in one working day in four rooms. This means approximately 500–700 cases per run. These schedules were run 10 times for each scenario e.g. 5000–7000 cases per scenario.

In the first setting, a short case was scheduled first, as recommended [12], followed by the longest, second longest and so on, corresponding to the local scheduling protocol. To simplify the models, the procedures were distinguished only by their duration, not by the surgical services or individual surgeons. Only direct labor was taken into account.

Working hours in all scenarios were 7:45 a.m. to 3:30 p.m. After 3:00 p.m., inductions were no longer performed outside the OR.

In each scenario, the following parameters were assessed: average number of procedures performed, surgery time, daily overtime and under-utilized time [10], and staffing costs per operation. Staffing costs were calculated based on the average salary for regular hours, including benefits, for each resource, plus overtime costs (calculated as1.75 times the cost of a regularly scheduled hour [13]).

In the second setting, the three most cost-efficient models were selected and short and long cases scheduled in separate rooms. Simulation runs and costs calculations were as above.

Table 1 Main results of the various models

Measure	Centralized induction room	Three surgeons in four rooms	Circulating induction team	Individual induction rooms	Traditional model
Surgeons per OR (overall)	1.00	0.75	1.00	1.00	1.00
Anesthesiologists per OR (overall)	1.25	1.00	1.25	1.00	1.00
Nurses per OR (overall)	3.75	3.00	3.50	5.00	3.00
Number of operations per OR per day	3.3 (32%)	2.5 (0%)	3.2 (28%)	3.4 (36%)	2.5 ± 0.6
Surgery time [min]	86 (−1%)	87 (0%)	88 (1%)	85 (−2%)	87 ± 64
Non-operative time [min]	57 (−43%)	103 (3%)	68 (−32%)	53 (−47%)	100 ± 31
Daily overtime per OR [min]	42 (45%)	28 (−3%)	56 (93%)	35 (21%)	29 ± 41
Daily underutilized time per OR [min]	6 (−81%)	30 (−6%)	1 (−97%)	6 (−81%)	32 ± 49
Staffing costs per operation [€]	318 (−7%)	325 (−5%)	329 (−4%)	329 (−4%)	341 ± 80

Values are presented as mean and mean differences (%) when compared to traditional model. All simulations were repeated sufficiently for $P<0.01$. Data for traditional model are presented as mean ± SD.

The models were validated by comparing the surgery and non-operative times provided by the model to those in the previous study [3]. The measures for traditional model are presented as mean ±SD. All workflow models were compared with each others.

2 Results

All induction models were more cost-efficient than the traditional model (Table 1). Staffing costs per procedure were lowest in the centralized induction team model, being 6.8% lower than for the traditional model. Daily overtime hours were highest in the circulating induction team model.

When short procedures were scheduled separately from the long ones, no statistically significant difference emerged in cost-efficiency between the individual induction room model and circulating induction team model (Table 2.). With this scheduling method, the centralized induction team model was the least cost-efficient.

3 Discussion

In this study, all parallel work-flow models demonstrated better cost-efficiency than did the traditionally sequenced working pattern. Our findings, similar to others [1–3, 14], indicate that doing things in parallel seems to be the key issue, rather than the location or resourcing of the induction team.

As the differences between the induction models were minor, the decision may need to be based on other issues: Short procedures seem to benefit the most from staffed, individual induction rooms [2, 3]. In contrast, when the hospital case mix comprises mostly longer procedures with fewer turnovers, a centralized induction room serving several ORs would be a better solution. In those circumstances, individual induction teams would probably have too much idle time.

Another solution of the double-queue scheduling, as described by Karvonen et al [15], was most recently applied by Harders et al. [16] to augment the effects of parallel

Table 2 Scheduling long and short procedures in separate ORs

Measure	Individual induction rooms	Circulating induction team	Centralized induction room
Surgeons per OR (overall)	1.00	1.00	1.00
Anesthesiologists per OR (overall)	1.00	1.25	1.25
Nurses per OR (overall)	4.00	3.50	3.75
Number of operations per OR per day	3.2 (3%)	3.1	3.1±1.1
Surgery time (min)	88	88	88±65
Non-operative time (min)	63	65 (3%)	63±21
Daily overtime per OR (min)	31 (3%)	35 (17%)	30±31
Daily underutilized time per OR (min)	6 (−14%)	6 (−14%)	7±15
Staffing costs per operation (€)	315 (−2%)	319 (−1%)	323±123

Mean differences (%) = difference compared to centralized induction room model. Data for centralized induction room model are presented as mean ± SD.

processing. Their results confirm our understanding that cases shorter than two hours benefit the most from the parallelism, especially if the preparation time is long, and should therefore be scheduled separately from the long ones. The results of this study indicate that this is also a reasonable option, although may alter the staffing needs in the PACU [17].

When it comes to patient safety, the model that incorporates the best continuity of care probably offers the best option. This is, in our experience [3], best served by a workflow, in which the same induction team follows the patient through the whole process, as in model 2. It also allows the team to take breaks without waiting to be released by anyone, contributing to personnel satisfaction. In institutions with mainly salaried personnel, this may be the only incentive available, along with the avoidance of overtime hours.

The circulating induction team model featured the smallest number of staff for four rooms. That the number of overtime hours was greatest in the circulating induction team model indicates that the team was often occupied at the time when the last case of the day came to the induction room. Hanss et al. [1] in turn, have shown that in their institution one team could easily serve three rooms and yet have time for other tasks.

Despite additional labor costs in parallel models, more procedures were done, which lowered unit costs. Three additional cases performed each day in four rooms correspond to fifteen cases per week or nearly eight hundred additional procedures annually. The model in which three surgeons operated in four ORs produced the same number of operations per day as did the traditional model with four surgeons.

Revenues gained by parallel processing are considered to offset any increased costs [1, 2, 14]. In our publicly funded health care system, incremental revenues are not easy to assess—nor do we strive for a profit. Despite this, any cost reduction is welcome. In our trauma surgery unit, with 70% of the procedures being more or less urgent, every procedure that could be performed during regular hours would bring about cost savings in form of saved overtime and on-call payments.

Even though labor costs explain a major part of the OR costs, additional facilities could lead to additional costs. As we already had the facilities for parallel induction, these were considered as sunk costs. Since capital costs do not exceed one-tenth of Finnish health care costs, incremental costs for additional space are likely to be relatively low. Regarding equipment, we calculated that in our four-OR facility, even adding the most expensive anesthesia workstation in every single induction room would add only about €5 to the cost per procedure. This calculation is based on a €50 000 workstation with a write-off period of 8 years, divided by 1250 annual procedures per OR. In a centralized induction room, both cost components would be even lower. In any case, with all cost components taken into account, it is highly unlikely that costs per procedure would exceed those realized by the traditional workflow.

Parallel processing can cause congestion in the PACU [18], although we did not specifically address that issue. Congestion in the PACU seems, however, to be more dependent on other things, such as the length of the cases and of the number of transporters, rather than on the number of patients [17, 18]. In our case, three additional procedures per day are unlikely to cause any major problems.

It would be difficult to test multiple work flow patterns in a real-life situation, especially in a busy trauma center. Computer simulation is a method previously used for similar purposes, such as determining staffing needs [20, 21] number of beds in the PACU [19] or number of ORs required [22]. Discrete-event simulation is especially suitable for modelling complex systems with variable resource allocations, patient flows, and schedules [23]. The downside of this method is that many assumptions are required to make the model work. It also does not take into account any of the unexpected delays frequently experienced in a real-life situation.

The number of long cases as well as the type of specialty and the proportion of urgent surgeries also affect the resources needed per OR. Our resources per OR were rather generous, because of the academic nature of the institution, as well as the large share (70%) of trauma procedures. In hospitals with predominantly elective surgery, the cost of resources per OR could be reduced. Different resource allocation models should be tested in more detail also in other environments and with variable case mixes such as elective inpatient surgery and outpatient surgery. Furthermore, it should be investigated, how the choice of an anesthesia technique would affect the workflow.

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