Consequences of running more operating theatres than anaesthetists to staff them: a stochastic simulation study

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Background. Numerous hospitals implement a ratio of one anaesthetist supervising non-medically-qualified anaesthetist practitioners in two or more operating theatres. However, the risk of requiring anaesthetists simultaneously in several theatres due to concurrent critical periods has not been evaluated. It was examined in this simulation study.

Methods. Using a Monte Carlo stochastic simulation model, we calculated the risk of a staffing failure (no anaesthetist available when one is needed), in different scenarios of scheduling, staffing ratio, and number of theatres.

Results. With a staffing ratio of 0.5 for a two-theatre suite, the simulated risk that at least one failure occurring during a working day varied from 87% if only short operations were performed to 40% if only long operations performed (65% for a 50:50 mixture of short and long operations). Staffing-failure risk was particularly high during the first hour of the workday, and decreased as the number of theatres increased. The decrease was greater for simulations with only long operations than those with only short operations (the risk for 10 theatres declined to 12% and 74%, respectively). With a staffing ratio of 0.33, the staffing-failure risk was markedly higher than for a 0.5 ratio. The availability of a floater for the whole suite to intervene during failure strongly lowered this risk.

Conclusions. Scheduling one anaesthetist for two or three theatres exposes patients and staff to high risk of failure. Adequate planning of long and short operations and the presence of a floating anaesthetist are efficient means to optimize site activity and assure safety.

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the theatre. We considered three types of critical periods: induction, recovery, and crisis. A crisis was defined as an event requiring an emergency intervention by an anaesthetist during surgery because of haemorrhage, ventilation-associated problems etc., or because of a delicate step during a scheduled procedure (clamping the aorta or the hepatic pedicle, for instance). We defined a staffing failure as a situation in which an anaesthetist’s presence was required but none was immediately available. This failure was equivalent to an interval with more critical periods in the operating suite than available anaesthetists. The main endpoint of the study was the frequency of a staffing failure during an 8-h working day. We examined the effect of staffing ratio, the number of theatres in use, and type of surgery performed. We also tested the effect of adding a floating anaesthetist to cover the whole suite on the risk of a staffing failure.

**Simulation framework and assumptions**

We only studied planned surgery. We did not address the case of emergency surgery which is another topic with different management issues. We considered a suite of several operating theatres located in the same site. An anaesthetist could work in any theatre (but was assigned to a particular one at the start of the workday). An additional floating anaesthetist could be assigned to the suite, to handle the staffing failure but not to start operations. We assumed a zero transit time of anaesthetists between theatres, that patients were always immediately available, and that surgeons and all medical staff were fully available when required. We simulated an 8-h working day in a suite consisting of between 2 and 18 operating theatres with one nurse anaesthetist in each theatre. The ratio of anaesthetists per theatre was varied from 0.33 to 1.

1. Throughout this paper, the duration of an operation (long or short) includes both induction of anaesthesia and the waking of the patient at the end of surgery, as the former starts before and finishes after the latter. Our assumptions and parameters are summarized in Table 1.

   The six-step simulation of the anaesthetist’s working day in one operating theatre was run minute-by-minute using real values derived from French hospitals (described later).9

   1. In a given theatre, an operation started as soon as an anaesthetist was available.

   2. The duration of the first operation was generated at random from a specified log-normal distribution of operation durations, which in turn provided the termination time. The mean duration is specific to the type of surgery. The log-normal distribution has been shown to provide a satisfactory fit to reported data.10 The distribution was left-truncated because in the real world, each operation cannot be shorter than a minimum duration.

   3. An anaesthetist performed induction, and its duration was fixed at 10 min.

   4. Whether or not a crisis occurred during surgery was determined at random from a Bernoulli distribution; the probability of its occurrence increased with the duration of surgery. The time at which any such crisis started was randomly selected from a normal distribution, truncated at the time induction ended, and recovery started. A crisis could be initiated only after induction ended and could not continue beyond the start of recovery. The crisis duration ranged from 10 min for short operations up to 45 min for the longest as described in Table 1. The anaesthetist’s presence was required throughout the entire duration of the crisis period. A crisis had no influence on the recovery.

   5. An anaesthetist supervised recovery, which lasted for a fixed time of 10 min.

   6. Only induction was scheduled and it could be postponed should no anaesthetist be available.

At the end of the recovery, there was a 30-min turnover period, after that induction of anaesthesia for the next operation was started as soon as an anaesthetist became available with a minimum time lapse of 0 min between two inductions started by the same anaesthetist (meaning that the second induction was started as soon as the first finished). The process was repeated in all theatres concomitantly until the end of the 8-h workday. Towards the end of the day, a new operation was started only if its expected duration was within the time remaining in the anaesthetist’s workday. As a result, some theatres were idle towards the end of the day, whereas some operations exceeded 8 h because the randomly generated duration was longer than expected.

Monte Carlo simulation of the whole suite was repeated 1000 times to determine the average risk of a staffing failure. Similar sets of simulations were performed for various different scenarios. Simulations were carried out with a program developed in S-PLUS (Insightful®).

**Sources of input data**

Model parameters were obtained from two sources. The database constructed during the French 3-day study9 gave a snapshot of anaesthetists’ practices in France in 1996 in different types of hospitals and provided the average durations of various types of surgery (Table 2). An internal study in the Department of Anaesthesiology at Beaujon University Hospital (20 operating theatres) provided the missing information for the critical periods in different surgical procedures by subspecialty. Over a 1-month period, anaesthetists completed a self-administered questionnaire about the type of surgery, the time each procedure started and finished, and the times at which all
critical periods started and finished. In that department, each theatre benefited from the presence of a dedicated anaesthetist (staffing ratio=1).

**Scenarios modelled**

Various situations were investigated. The scenarios involved suites of 2–18 theatres typical of teaching hospitals, with all-short or all-long duration operations (the first two scenarios), or a 50:50 mixture of the two (half long and half short duration) (scenario 3). We also considered a suite with a mixture of nine different surgical activities (scenario 4), again typical of French teaching hospitals. We examined the effect of increasing the ratio of number of anaesthetists per theatre from 0.33 to 1. We also examined those scenarios with a floating anaesthetist. The parameters for these scenarios are given in Table 2.

**Output variables and statistics**

A wide range of statistics could be derived from the model; the key output measure was the risk of a staffing failure (expressed as a percentage), that is, the risk that no anaesthetist was available during a critical period at least once during the 8-h day. We also derived the frequency of staffing failures throughout the workday, how long they lasted, theatre occupancy achieved (total case hours divided by total theatre hours in a day), and the average daily time of critical periods requiring an anaesthetist. With 1000 simulations, crisis probabilities of 0.1, 0.5, and 0.9 were used to estimate the risk of a critical period occurring at least once during the 8-h day.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Type of activity</th>
<th>Mean (min)</th>
<th>Median (min)</th>
<th>10th–90th percentiles (min)</th>
<th>Minimum duration (min)</th>
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<tbody>
<tr>
<td>1</td>
<td>Suite with only short-duration operations</td>
<td>60</td>
<td>47</td>
<td>20–120</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>Suite with only long-duration operations</td>
<td>200</td>
<td>190</td>
<td>125–285</td>
<td>50</td>
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<tr>
<td>3</td>
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<td>47</td>
<td>20–120</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Short</td>
<td>60</td>
<td>47</td>
<td>20–120</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Long</td>
<td>200</td>
<td>190</td>
<td>125–285</td>
<td>50</td>
</tr>
<tr>
<td>4</td>
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<td>70</td>
<td>30–185</td>
<td>20</td>
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<tr>
<td></td>
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<td>18–400</td>
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<td>150</td>
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<td>70</td>
<td>25–200</td>
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<tr>
<td></td>
<td>Plastic</td>
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<td>130</td>
<td>60–270</td>
<td>25</td>
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<td></td>
<td>Ophthalmology</td>
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<tr>
<td></td>
<td>Vascular</td>
<td>96</td>
<td>80</td>
<td>40–175</td>
<td>25</td>
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</table>
0.7 were estimated with respective 95% confidence intervals of plus or minus 0.02, 0.03, and 0.03.

**Sensitivity analysis**

To investigate the impact of slight modifications of parameters and hypotheses, we performed sensitivity analyses. The following system parameters were sequentially changed: risk of a crisis occurring and its duration, mean and standard deviation of the distribution governing the starting time of a crisis, durations of induction and recovery, and time interval between two interventions by the same anaesthetist.

**Results**

As an example, Figure 1 illustrates one simulation of one scenario; the progression of the operations in four theatres with two anaesthetists for 8 h is calculated every 5 min. Thick lines indicate periods when an anaesthetist was required (induction, crisis if any, recovery). On the x-axis, the block represents the minutes with a staffing failure.

Mean rates of theatre occupancy, for all combinations of scenarios, numbers of theatres, and staffing ratios were clustered around 78%, which is close to the maximum capacity of 80%, obtained for a staffing ratio of 1 regardless of the number of theatres and of the scenario.

Delayed starts of an operation because an anaesthetist was not available were negligible. In the worst situation of short operations with a 0.5 staffing ratio, the mean total accumulated delay was less than 6 min theatre$^{-1}$ day$^{-1}$.

For 10% of the simulations, this total accumulated delay exceeded 12 min theatre$^{-1}$.

Durations of staffing failures were short, for example, for a staffing ratio of 0.5 they lasted a mean(SE) of 4(2.4) min, and decreased as the ratio and the number of rooms increased. This trend was relatively independent of the scenario.

We examined the risk of a staffing failure occurring at each minute of the day and how this varied with time throughout the day for a staffing ratio of 0.5. Figure 2 shows that there was a sharp peak near the beginning of the day, lasting 10–20 min. At this time anaesthesia had been induced in patients undergoing surgery in half of the theatres in the suite and all the anaesthetists were occupied.

**Fig 1** Example of the simulation process in theatres 1–4 with two anaesthetists over 8 h. Thick lines represent critical phases during which an anaesthetist is required: induction (I), recovery (R), or crisis (C). The black box on the x-axis denotes a staffing failure period.

**Fig 2** Simulations of the risk of a staffing failure (expressed as a percentage), defined as an anaesthetist needed in two theatres simultaneously, during the workday, in scenarios 1–3, all with a staffing ratio of 0.5. (A) Scenario 1 (short operations) with two theatres. (B) Scenario 1 with 10 theatres (note the different y-axis scale). (C) Scenario 2 (long operations) with 10 theatres. (D) Scenario 3 (mixed durations of surgery) with 18 theatres. (E) Scenario 2 (long operations) with 18 theatres. The percentage risk of a staffing failure occurring somewhere in the suite was calculated for each minute of the workday.
inducing anaesthesia in the second half of the theatres, so none was available in the event of an early recovery or a crisis occurring in any of the first half of the theatres. Furthermore, the more theatres in the suite, the greater the risk was during this critical period that an anaesthetist would be needed in one of the theatres of the suite. This failure is illustrated in Figure 2B (10 theatres), where the initial peak was much higher than in Figure 2A (two theatres), both with short operations (note the different y-scale in Figure 2B). A sharp and sudden decrease in risk occurred at 20 min because, at that time, the second set of inductions had been completed, so all anaesthetists became available to respond to any urgent need in any theatre. From then on, the risk of a staffing failure varied little over time until it began to decrease towards the end of the workday as some theatres became idle. In Figure 2A (short operations, two theatres), the risk of a staffing failure varied little over time until it began to decrease towards the end of the workday as some theatres became idle. In Figure 2A (short operations, two theatres), the risk of the staffing failure in each minute after the initial peak was 3%. It was further reduced to 1% when there were 10 theatres with short operations (Fig. 2a), and even lower for 18 theatres with mixed-duration operations (Fig. 2d). Risk was lower because, with only two theatres and one anaesthetist, only two critical periods had to coincide to result in a staffing failure. With 10 theatres and 5 anaesthetists with short operations (Fig. 2b), although the chance of concomitant critical periods was higher, a failure occurred after 20 min only when more than five critical periods occurred simultaneously, yielding a risk of only 1%. With long operations (Fig. 2c), the risk declined further because critical periods formed a smaller fraction of the operation. Risk decreased yet again with 18 theatres because nine anaesthetists were available to handle up to nine simultaneous critical periods (Fig. 2e). In this situation (scenario 2 with 18 theatres), the peak amplitude was limited because it was highly unlikely for recovery from anaesthesia to occur at the same time as induction.

An alternative way of looking at staffing failure was to determine the risk that at least one failure occurred somewhere in the suite at some time during the working day. Figure 3 shows for scenarios 1–3, with a staffing ratio of 0.5, that this risk decreased as the number of theatres in the suite was increased, at least up to 10. The risk diminution effect was sharpest for scenario 2 (long operations), from 40% to 12%, and for scenario 3 (mixed durations), from 64% to 14%. For scenario 1 (short operations), the curve was flatter and started to increase when there were more than 10 theatres. That profile could be explained by the higher initial peak amplitude of minute-to-minute risk when there were more than 10 theatres (Fig. 2). That profile could be explained by the higher initial peak amplitude of minute-to-minute risk when there were more than 10 theatres (Fig. 2) that outweighed the decrease of the subsequent low-level risk. The very mild U-shape of the distribution, therefore, resulted from two contradictory effects: the risk of a staffing failure was dependent on the operation duration, but the longer the operation, the smaller the risk. This dichotomy is clearly reflected by the percentage of time an anaesthetist had to be present, which decreased as the duration of the operation increased. In our model, an operation lasting less than 60 min required the presence of an anaesthetist for a mean of 20.2 min, whereas his presence was required for 35 min for the longest operations (more than 120 min). Finally, suites with theatres dedicated to either short or long operations had a lower risk of at least one staffing failure occurring during the workday (15% above 14 theatres).

Figure 4 illustrates that the risk of a staffing failure declined sharply with an increasing staffing ratio. Slopes did not strongly depend on the number of theatres, regardless of the scenario.
The presence of a floater to assure support in the case of a staffing failure strongly reduced the risk for at-risk scenarios (1, 3, and 4) with a staffing ratio of 0.5 (Fig. 5A and B). Even for 18 theatres, a floater available to act in the case of any staffing failure, reduced the risk from 80% to 40% for short operations (scenario 1). This gain was even greater for long operations (scenario 2, not illustrated).

When looking at situations with a more stringent staffing ratio (0.33) as in Figure 5c, similar risk reductions were obtained with the adjunction of a floater. The benefit of the floater maybe became smaller for suites with 15 or 18 theatres. Incidentally, with this staffing ratio, the risk of a staffing failure was higher than with a staffing ratio of 0.5. For example, in scenario 3, a floater limited the risk of a staffing failure to 12% in 18 theatres.

Results were globally robust to parameter variations. Table 3 shows that the risk of a staffing failure always changed in an expected direction and that even halving some input parameters never did appreciably more than half the resulting risk. A fixed period of 5 min between the first two inductions performed by the same anaesthetist increased the risk, because critical periods could overlap, which was not the case with the original model, according to which inductions could be postponed should no anaesthetist be available.

Discussion

The results of this study showed that the risk of not having an anaesthetist available for any patient (staffing failure) when anaesthetists supervise two or more theatres was high. This risk was greater for short-duration operations. Scheduling a floating anaesthetist for the whole suite to ensure coverage during critical periods reduced the risk of a staffing failure. Our findings are relevant because organization with one anaesthetist supervising two or more theatres is now implemented in many institutions, because of economic and demographic considerations.1–7 The emergence of the concept of non-medically-qualified anaesthetist practitioners shows that this is an increasing trend, mainly for reducing costs.61 1 1 2 Thus, much energy has been devoted to examining strategies for organizing operating theatre assignments or for scheduling subspecialty allotments, in order to increase cost-effectiveness of operating theatres.12–15 Saving 15 min is considered a major improvement in operating-theatre efficiency.11 The impact of improving the cost-effectiveness on safety has not been clearly evaluated. The occurrence of critical periods during the working day not only increases the immediate risk of an accident for the patient but also puts the whole team under greater stress. Although the association of stress with morbidity and mortality remains controversial, it has been shown that this stress tends to precipitate crises and inadequate medical responses.16 17 It has been shown that production pressure can be responsible for frequent violations of safety rules in real life.16 Understanding and characterizing risk is essential to improve scheduling of operating theatre use (personnel management) for planning operations so as to alleviate problems and avoid crises.
This simulation study evaluates the risk that an anaesthetist would be required in two theatres simultaneously according to different scenarios. Three main conclusions can be drawn. First, the period during which the risk of a staffing failure is the highest is the beginning of the day and cautious scheduling for operating-theatre assignments is required. With a 0.5 staffing ratio, starting the second half of inductions as soon as the first inductions have been completed may not be the safest strategy. Previously reported results\(^{14} \text{15}\) showed that a certain time interval should be respected to improve operating-theatre efficiency. Our data also indicated that such a delay would also improve risk management, because a model with a fixed period between inductions performed by the same anaesthetist increased the risk when compared with a model in which induction could be postponed in the case of a problem. Second, a higher number of centralized theatres decreased the risk of a staffing failure for a given ratio, at least when much longer operations are planned. Construction of new units should take this observation into consideration. However, the gain becomes negligible above a certain threshold, depending on the surgical subspecialty; for instance, 10 theatres for scenarios 1 and 2. Mixing subspecialties may help to meet the combined requirements of reducing the risk of a staffing failure and maintaining the availability of anaesthetists. Optimization of scheduling and theatre assignments is crucial as shown by the non-uniformly distributed risk and the impact of choosing mixed operation durations. Last, the strategy of adding a floating anaesthetist to a 0.5 or 0.33 staffing ratio improves the safety of the overall functioning of the suite, assuring coverage of mixed-duration operations with at-risk procedures. Even if such a gain was reduced for suites with a large number of theatres, considering floaters should be recommended.

This study has important strengths and limitations. Among its strengths are the ability of stochastic simulations to investigate complex situations and quantify risks resulting from multiple parameters. A clinical trial would be hard to set up. Likewise, comparisons between different hospitals with different management strategies and options would be of doubtful validity, owing to the impact of internal management issues on operating-theatre use.\(^{18}\)

Despite the controversy surrounding this issue, it has been suggested that the presence of an anaesthetist is associated with a lower risk of mortality.\(^{18} \text{19}\) In addition, studies including large numbers of patients showed that minor perioperative incidents and events are associated with postoperative complications.\(^{20}\) Our results show that the risk of anaesthetist unavailability can very simply be reduced by scheduling an additional floating anaesthetist. Nevertheless, the major pitfall of such simulations is the necessary simplifications and the assumptions that are made. This study was essentially based on national results through a nationwide survey, but it seems to be similar to that observed in most western European and North

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**Table 3** Sensitivity analysis: changes of the risk of a staffing failure (%) in scenario 4 with a staffing ratio of 0.5, as a function of different modifications of the original parameters introduced into the simulation study

<table>
<thead>
<tr>
<th>Parameter</th>
<th>10 theatres</th>
<th>18 theatres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original parameters</td>
<td>33</td>
<td>37</td>
</tr>
<tr>
<td>Crisis probability halved</td>
<td>28</td>
<td>34</td>
</tr>
<tr>
<td>Crisis duration halved</td>
<td>26</td>
<td>34</td>
</tr>
<tr>
<td>Crisis probability and duration halved</td>
<td>26</td>
<td>32</td>
</tr>
<tr>
<td>No crisis</td>
<td>20</td>
<td>26</td>
</tr>
<tr>
<td>Induction duration halved</td>
<td>16</td>
<td>19</td>
</tr>
<tr>
<td>Recovery duration halved</td>
<td>15</td>
<td>17</td>
</tr>
<tr>
<td>5 min between the first two inductions performed by the same anaesthetist</td>
<td>42</td>
<td>44</td>
</tr>
</tbody>
</table>
American countries, Australia, and New Zealand. Limiting this method to specific situations or conditions (particular types of operations, anaesthesia, or specifically adapted units, such as maternity wards) would provide us with different results and their comparisons might be meaningless. The risks estimated here reflect the units in which the baseline data for the simulations were collected. We do not provide confidence intervals because they would be relevant only under the assumption that our model accurately reflects universal reality. This is clearly not the case.

We have not considered the effect of disease severity. An ASA III patient will require the presence of the anaesthetist more frequently than for an ASA I patient. Similarly, the invasiveness of surgery has an important impact on the risk. The specific risk in each institution should be determined according to the case-mix and to the observed duration and complexity of surgery in that institution.

Our objective was to provide an evaluation of different scenarios and to give an accurate idea of the evolution of the risk of a staffing failure as a function of certain parameter changes. In particular, we wanted to make clear the implication of different choices regarding the number of anaesthetists. Adding new assumptions would make the model more sophisticated and the situations more various. They might modify the slope of risk evolution, increase or decrease the average level, but should not invalidate the present conclusions. With slight modifications, this computer tool can be used to evaluate specific situations. Adding hypotheses or making them more flexible is easy to implement. For example, a possible extension is to include the expected time of the end of the operation. This time could be updated throughout the operation, becoming more and more precise as the real end approaches. Similarly, anaesthetic techniques can be refined to match specific situations. For example, the presence of an anaesthetist during an operation is not, in principle, dependent on operation duration, as we assumed here. We chose this as a pragmatic approach based on clinical experience. Nevertheless, if figures for the duration of crises according to the type of operations are available, it is straightforward to include them in our model.

In conclusion, the ratio of the number of anaesthetists to the number of theatres is a crucial element in terms of patient safety. The occurrence of a staffing failure does not systematically entail an adverse event, but it is likely to have an overall effect on both safety and quality of the operation. An adequate cost-safety balance should take concurrent critical periods into account. We think our model could be an important component contributing to the evaluation of such a balance. These promising results warrant further investigations; first, with more complex models to refine specific hypotheses and ultimately, with the design of a clinical study. However, an immediate organizational management consequence of our findings is that a floating anaesthetist markedly lowers the frequency of anaesthetist unavailability in situations at-risk.

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