Review Article

The effect of overlapping surgical scheduling on operating theatre productivity: a narrative review

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Summary

This article reviews the background to overlapping surgery, in which a single senior surgeon operates across two parallel operating theatres; anaesthesia is induced and surgery commenced by junior surgeons in the second operating theatre while the lead surgeon completes the operation in the first. We assess whether there is any theoretical basis to expect increased productivity in terms of number of operations completed. A review of observational studies found that while there is a perception of increased surgical output for one surgeon, there is no evidence of increased productivity compared with two surgeons working in parallel. There is potential for overlapping surgery to have some positive impact in situations where turnover times between cases are long, operations are short (<2 h) and where `critical portions´ of surgery constitute about half of the total operation time. However, any advantages must be balanced against safety, ethical and training concerns.

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Introduction

Operating theatre scheduling is rarely the focus of federal lawsuits or US Senate hearings [1, 2], but one of the world's leading hospitals, the Massachusetts General Hospital (Boston, MA, USA) has paid out > £26 million ($33 million, €31 million) (without liability) to settle cases in relation to its operating theatres scheduling policy and use of overlapping surgery. Any financial gains conceived by that policy have been wiped out several times over, and the reputational damage, reduced staff morale and fractured working relationships remain ongoing challenges. The unredacted emails show how the concerns of many clinicians went unheard by their senior management team [3].

Overlapping surgery involves organising surgical lists in parallel, with a single senior surgeon moving across two operating theatres with the aim of eliminating turnover or gap time between successive cases, thereby maximising `touch time´ (the total amount of clinician-patient contact time). This is facilitated by inducing anaesthesia in a second operating theatre and a junior surgeon commencing non-critical parts of surgery, while a senior surgeon in the first operating theatre completes critical parts of surgery on another patient. Reducing turnover time and maximising touch time are among the goals of NHS operating theatre efficiency drives, especially in the context of > 6 million patients now waiting for surgery after the COVID-19 pandemic [4–6] An overlapping scheduling policy, at least in some form, may be considered by NHS hospitals, with several now trialling versions as high-intensity theatre (HIT) operating lists [7].

Billing via the Medicare and Medicaid systems in the USA requires the surgeon to be present at `critical periods´, so overlapping surgery potentially constitutes billing fraud, which was the basis for the lawsuits referred to above. Generally, non-critical periods are assumed to be incision/exposure of the operative site and closure but are ill-defined. Haemostasis is arguably more important than the primary surgery in preventing later complications, and careful closure of layers and skin avoids wound dehiscence, so both these can be viewed as critical; yet these are exactly the moments in overlapping surgery when the primary surgeon would leave to attend to the parallel operating theatre. Other definitions are also important. `Concurrent´ or `simultaneous´ surgery are extensions of overlapping surgery, where the senior surgeon literally oversees two operations in their entirety, including for critical periods. Several national surgical societies have criticised this practice [8, 9], but the uncertainties of defining `critical´ mean that the various models for parallel surgeries must be viewed as a continuum.

We will critically examine if overlapping surgery is productive, first from a theoretical standpoint, and then assess the evidence in clinical practice. We will also touch on the ethical issues (such as consent) that have been raised in relation to overlapping surgery [10].

Theoretical analysis of overlapping surgery models

The drive for adopting overlapping surgery operating theatre schedules is to improve productivity. From the earliest quantitative analyses of operating theatre efficiency, turnover time (the gap between the previous patient arriving in recovery and induction of anaesthesia in the next) has been regarded as non-productive [11–13] and is embedded in metrics such as the productivity index as something that reduces operational performance [14]. Thus, the UK `Getting It Right First Time´ (GIRFT) initiative has set explicit targets for specialties to achieve a certain number of operations, through reductions in turnover time, on certain `high-volume, low-complexity´ lists [5, 6]. If overlapping surgery reduces or eliminates turnover time, then the theory is that productivity should increase.

However, turnover time, expressed as a percentage of scheduled list time, sets the limits of what any scheduling method can theoretically achieve. Since it is well-established from NHS data [6, 15] and independent research [16] that median turnover times across lists approximate 15% of the total list time, this is the maximum improvement in additional operating time that is achievable. This equates to only 72 min in an 8-h list, which generally is at best sufficient for just one additional case.

Theoretical analysis shows that eliminating turnover time by adopting overlapping surgery cannot achieve productivity gains. Using real timing data, Padegimas et al. showed that for a shoulder arthroplasty lasting 180 min, non-surgical time was approximately 60 min, with an additional 45 min in turnover time [17]. They then correctly argued that this block of 225 min meant only three cases could be completed in a day's schedule of 642 min (with around a 12 min under-run and the final case not needing any turnover). The way to envisage this is shown in Fig. 1a, and two neighbouring operating theatres are shown with these same statistics. Note that the neighbouring operating theatre also performs three cases, so in this conventional setup, there are six cases being performed in total across this two-theatre suite. Padegimas et al. argued that overlapping surgery in a two-theatre model, with what they describe as a 30 min `stagger´ or overlap, would enable a total of four cases to be completed (Fig. 1b). What is clear is that the overlapping scenario (Fig. 1b) yields fewer cases than in the original model (Fig. 1a). The error in logic made by the authors is to compare the two-theatre overlapping list performance of four cases as an improvement on a single list of three cases. The correct method is a comparison with two conventionally scheduled lists with six cases in total.

Independently, but without referring to the examples above, Morris et al. presented theoretical schedules that resemble Fig. 1b, confirming that overlapping surgery generally results in fewer cases than two separate operating theatres could complete. At best, overlapping surgery will result in an equivalent number of cases compared with two separate operating theatres, but will never do more [18]. This fundamental error of comparing the productivity of two theatres vs. one theatre permeates through much of the literature supporting the overlapping surgery model; the erroneous emphasis being to maximise the surgeon's contact time with the patient, not with completing the maximum number of operations.

In general, the main contributors to turnover include: operating theatre cleaning; mandatory (electronic) paperwork; and equipment preparation (with laparoscopic, laser or robotic surgeries taking longer) [19]. In some hospitals,

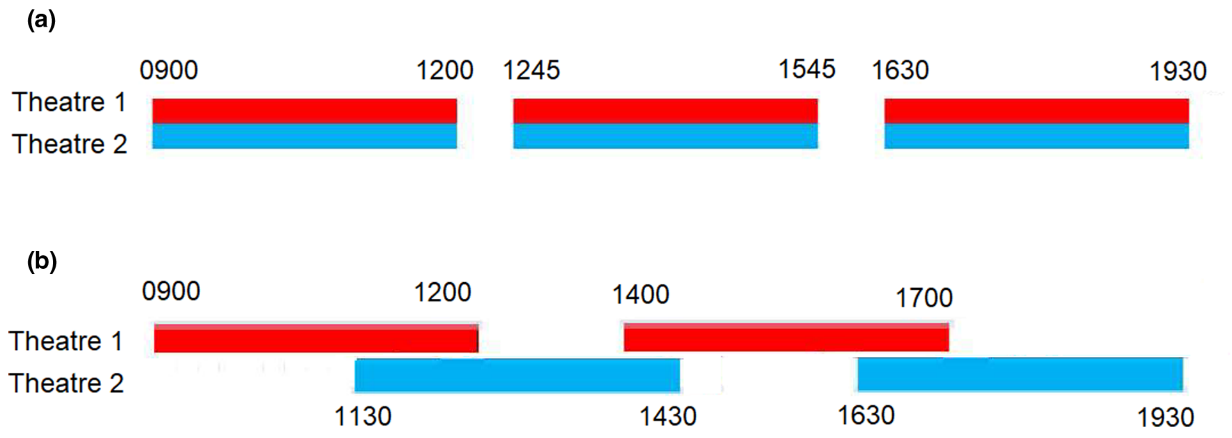

Figure 1 Data from Padegimas et al. [17] for their examples of (a) two parallel, independent operating lists (Theatre 1 (red) and Theatre 2 (blue)) each with three cases of 3-h duration and a turnover time between cases of 45 min and (b) an overlapping model where the Theatre 1 (red) list resembles that in (a) and the cases in the Theatre 2 (blue) list are staggered such that anaesthesia commences to enable the senior surgeon from the Theatre 1 (red) list to start Theatre 2 (blue) surgery after the critical portion in Theatre 1 (red) is complete. Note that this overlapping model can, within the time available, only deliver four completed cases vs. six in the conventional model shown in (a).

regulatory requirements demand minimum time periods between cases (around 15 min) to facilitate sufficient air changes in the operating theatre to prevent cross-infection (especially important in the era of COVID-19), making it impossible to eliminate this time entirely [20]. None of these will be affected by the scheduling method, and in turn they will limit any positive impacts of overlapping surgery. Turnover delays can also occur because of the physical layout of the hospital or staff shortages on the ward; in these situations, simply scheduling operations to overlap does not rectify these more fundamental issues. In addition, none of these factors are influenced by use of separate anaesthesia theatres, as is common in the UK. Even if anaesthesia is induced in the next patient before surgery is complete in the first (`overlapping anaesthesia´ [21]), the operating theatre will still need to be cleaned, equipment prepared, etc. To this extent, there is still a tangible turnover time.

Several factors could theoretically influence whether overlapping surgery will have any impact on the number of cases completed. Where turnover times are absent, then overlapping surgery is, by definition, not required. Conversely, the longer the turnover times, the greater the predicted benefit. Although self-evident, this was proved mathematically by Batun et al. using a complex, novel two-stage stochastic mixed-integer programming simulation model [22].

A second factor determining operating theatre productivity is the proportion of the operation regarded as `critical´. If this is zero (i.e. the operation does not require a senior surgeon at all) then by definition overlapping surgery is unnecessary; the senior surgeon can simply have their own parallel list, next to the resident or surgeon-in-training's solo list. Equally, if the entire operation is regarded as critical then overlapping surgery is impossible. Therefore, the optimum situation is where the non-critical portion of surgery constitutes about half of the surgical time for the operations being scheduled. Again, Batun et al. provided formal mathematical proof of this readily understood concept, where they modelled `parallelisable time´ as a proportion of hypothetical operations in their simulation model [22]. Related to this, very long operations are not amenable to overlapping surgery as there is no theoretical gain possible where the entire list can only be occupied by a single case. Studies have confirmed that any benefits of overlapping surgery are likely to be confined to operations of < 2 h duration [23, 24].

Even from first principles, it is difficult to see how overlapping surgery could increase productivity of case numbers; at best this is predicted to be no worse than two independent parallel lists. Figure 2 shows a conventional arrangement in two neighbouring operating theatres where successive cases are planned independently in a 9-h (540 min) schedule. The operations are each of 90 min duration including: 15 min for anaesthesia induction; 15 min for awakening/tracheal extubation); and a middle 30 min portion which is `critical´, requiring the presence of the senior surgeon. The turnover time is consistently 30 min between each case. Table 1 shows the performance metrics for this conventional arrangement. An overlapping arrangement for the same cases is shown in Fig. 3, where a

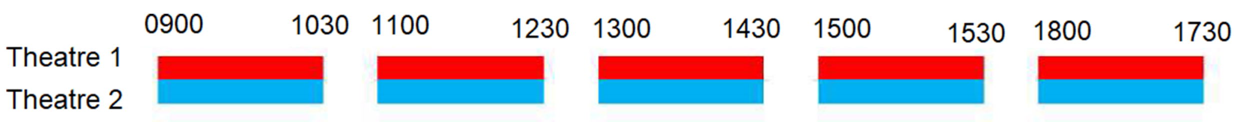

Figure 2 Two hypothetical 9-h lists (Theatre 1 (red) and Theatre 2 (blue)), conventionally scheduled, with duration of each operation 150 min and turnover 30 min. The times of operations (start and end) are shown and as a percentage of the total scheduled list time. The performance metrics are shown in Table 1.

Table 1 Performance metrics associated with Fig. 2. The table shows the relevant data from this model for each operating theatre (Theatre 1 (red) and Theatre 2 (blue)) separately and in combination. Utilisation is calculated continuously from the time of start of first case to the end of the last case, such that `touch time´ would be this minus the total of turnover time. The individual contact times of the staff groups are shown (note that theatre staff are working continuously). Values are number (proportion).

Theatre	Total utilisation; min	Turnover time; min	Late start time; min	Early finish time; min	Surgical time; min	Anaesthesia time; min	Staff contact time; min	Number of cases
1	510 (94%)	120 (22%)	-	30 (6%)	240 (44%)	360 (67%)	540 (100%)	5
2	510 (94%)	120 (22%)	-	30 (6%)	240 (44%)	360 (67%)	540 (100%)	5
Total	1020 (94%)	240 (22%)	-	60 (6%)	480 (44%)	720 (67%)	1080 (100%)	10

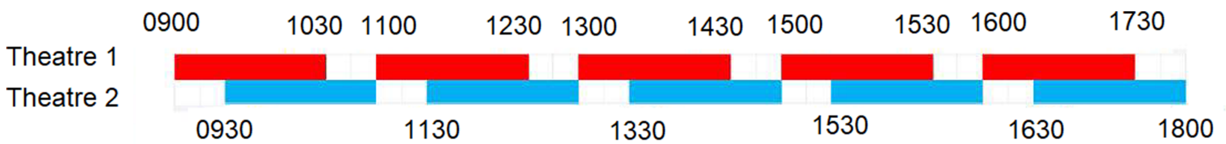

Figure 3 Two hypothetical 9-h lists (Theatre 1 (red) and Theatre 2 (blue)), with overlapping scheduling, with duration of each operation 150 min and turnover 30 min. The times of operations (start and end) are shown. The performance metrics are shown in Table 2.

Table 2 Performance metrics associated with Fig. 3. The table shows the relevant data from this model for each operating theatre (Theatre 1 (red) and Theatre 2 (blue)) separately and in combination, with the last row representing the two theatres viewed as a whole. Further details as per Fig. 2 and Table 1. Values are number (proportion).

Theatre	Total utilisation; min	Turnover time; min	Late start time; min	Early finish time; min	Surgical time; min	Anaesthesia time; min	Staff contact time; min	Number of cases
1	510 (94%)	120 (22%)	-	30 (6%)	240 (44%)	360 (67%)	540 (100%)	5
2	510 (94%)	120 (22%)	30 (6%)	-	240 (44%)	360 (67%)	540 (100%)	5
Total	1080 (100%)	-	-	-	1080 (100%)	1080 (100%)	1080 (100%)	10

single surgeon can only start the parallel case (shown in blue) after the critical period of the first (shown in red) is completed; anaesthesia is commenced in the blue case earlier to facilitate this. There is nothing that can be done about the turnover times within each operating theatre (dependent as they are on the fixed delays discussed earlier) but note that the arrangement results in no overall delay between cases when the two operating theatres are viewed as a whole. From the perspective of each theatre separately (Table 2), the new metrics are unchanged from those shown in Fig. 2 and Table 1. However, when the two operating theatres are viewed as a single unit, turnover time has been eliminated and surgeons/anaesthetists are always in contact with the patient. Yet, there has been no increase in the number of cases completed. Morris et al. expressed this concept succinctly, noting that in overlapping surgery models there is always a gap (`downtime´) at the start of one operating theatre (see Theatre 2 in blue in Fig. 3) and at the end of the other (see Theatre 1 in red in Fig. 3) which is impossible to fill, and which constrains any true productivity gains [18]. So, overlapping models can never be more efficient than a well-planned, one-surgeon-per-theatre model. Rather, the `gain´ is in terms of individual perceptions; with no down times, surgeons feel busier.

Separate from case numbers, which are at best unchanged and at worst reduced, there are two potential sources of financial gain with overlapping surgery. In systems like in the USA, where the value of surgeon `billable hours´ (i.e. their patient contact time) is high and over-rides that for other staff groups, maximising these billable hours is profitable. Second, there is the cost saving in the expense of employing a second surgeon. This may be important in healthcare settings where the cost of employing surgeons is disproportionately higher than for other staff (as in the USA). However, these factors do not apply to environments as in the NHS, and moreover, reducing the surgical workforce does not seem to be the main driver behind the overlapping surgery initiative.

The operations shown in Fig. 2 are idealised as having no variance and being of identical duration. For the conventional scheduling model shown in Fig. 1, the optimum means of scheduling cases of different durations uses the mean and variance [25] and is well-established as being accurate [26, 27]. However, it is not known how to optimally schedule a parallel, overlapping list for a series of operations of variable duration. Another issue, which adds to variance in total (as opposed to surgical-specific) operation time, is the requirement to plan accurately the start of anaesthesia time for overlapping surgery. Except for truly low complexity patients in which induction time is reliably short, anaesthesia times will vary. Koenig et al. showed that there is always a defined probability of either the surgeon having to wait because anaesthesia is not yet complete, or the patient enduring unnecessarily long anaesthesia while awaiting the surgeon's arrival from the other operating theatre [28]. This importance of low variance is emphasised in overlapping surgery studies showing increase in case productivity. Duffy showed a dramatic four-fold increase in caseload for arthroscopies over 4 y, with reliable tourniquet times of 35 min for a single surgeon in an overlapping model [29]. Natchiar et al. showed a similar increase for low-complexity, short duration, low-variance cataract surgery [30].

In summary, theory predicts that overlapping models will not yield real increases in productivity (number of operations completed) unless: original turnover time is high; low variance, reliable operations of relatively short duration are selected; and the operations consist of a `critical portion´ that constitutes about 50% of the surgical time. Even then, productivity may be no higher than that in two independent operating theatres. We will now examine the evidence supporting the extent to which these theoretical predictions are borne out.

Observational and trial evidence of overlapping surgery

Safety, training and ethics

A surgeon operating in overlapping surgery may not be devoting their entire attention to a single patient or be free at times when urgently needed. It is therefore reassuring that, despite this, many studies find no evidence of worse safety outcomes. Ponce et al. reported retrospective data from an academic centre (>26,000 patients), with no differences found between overlapping and standard models [31]. This has been confirmed in other, smaller studies [32–36]. However, none of these studies clearly defined `overlapping´, and they often included relatively brief (approximately 30 min) periods of overlap in the context of induction of anaesthesia or placement of regional block in the next patient in an anaesthesia or block room, rather than a parallel commencement of surgery. The Hawthorne effect may also have contributed to better outcomes in the overlapping group [37].

Theriault et al. analysed 18 studies involving overlapping surgery and found just four outcomes were commonly reported: mortality; re-operation rates; readmission rates; and duration of stay. None of these significantly differed between overlapping and traditional models [38]. However, cases were grouped by retrospectively judging as to whether the patient had overlapped another. The studies did not assess the impact of overlapping surgery when implemented as an intervention, and then compare this with outcomes from a traditional model. Thus, the studies in the review by Theriault et al. were not assessing the outcomes when an overlapping model is implemented but rather the outcomes when a given case slightly overlaps another.

In contrast to these reassuring findings, a Canadian study examined outcomes after hip surgery and showed overlapping surgery for hip fracture and hip arthroplasty had a greater risk of complications (hazard ratio 1.85 (95%CI 1.27–2.71) and 1.79 (95%CI 1.02–3.14), respectively) [39]. Moreover, the authors showed a strong relationship between the probability of complications and degree of overlap, especially for hip fracture surgery, consistent with the theoretical discussion above. The greater the overlap, the more risk there is of overlap impinging on the `critical portion´ of the surgery and therefore, the greater the risk of harm. This was emphasised in a large analysis of > 60,000 cases, which reported statistically significantly higher complication rates for overlapping surgery in specific surgery types including: total knee and hip arthroplasty; spinal surgery; craniotomy; and coronary bypass surgery [40]. This underlines the need to define `critical´ portions of each operation, especially for more complex types of surgery where the critical period might reasonably extend all the way to skin closure.

Related to safety are issues around training quality and ethics, especially consent [10, 41]. Training involves progressing from direct supervision to distant observation and then independent, but supervised, performance. A pertinent, but unanswered, question is whether overlapping surgery permits appropriate supervision [42]. Patients need appropriate consent that makes clear what overlapping surgery means, its risks and how these might be mitigated [43]. Paediatric overlapping surgeries may be especially emotive, as are operations in other vulnerable groups or in patients who cannot directly consent to treatment [44]. However, it is unclear how proper consent can be taken when the demarcations between `overlapping´, `concurrent´ or `simultaneous´ surgeries are blurred. The US Senate found compelling evidence of operations in which surgeons divided their attention between two operating theatres over several hours, failed to return to the operation when residents or fellows needed assistance, or failed to arrive on time for operations, leaving residents or fellows to perform them unsupervised or resulting in patients under anaesthesia for prolonged periods [2]. However, these could have been exceptions indicating poor practice rather than inevitable consequences of overlapping surgery. It is not the focus of this article to discuss further these training or ethical aspects, which have been discussed elsewhere [10, 41–44].

Productivity and costs savings

Although the main drivers for overlapping surgery have always been to increase operating theatre productivity and reduce costs, the literature seems sparse on these points. Nevertheless, some studies celebrate the result that `surgeon contact time´ with patients is increased [34–36], but these conclusions are highly skewed because anaesthesia and positioning time are overlooked even though these are inherent parts of the surgical procedure. Thus, only two of 18 studies reviewed by Theriault et al. analysed anaesthesia times [38]. When the correct metric of total operation time (i.e. including anaesthesia and positioning time) is measured, there is consensus that this is consistently increased for each operation in overlapping surgery (by up to 35% [33]), mainly due to anaesthesia often being induced earlier than necessary [36, 45]. There is also the not uncommon need for the primary surgeon to revisit the first operating theatre, prolonging surgery in the parallel theatre.

These factors may in part underlie the other consistent finding that overall costs are higher with overlapping surgery. Zachwieja et al. found staff costs to be higher by £1200 (US$1500, €1420) and total costs by £8007 (US $10,000; €9467) per list [35]. These costs may be offset by doing additional cases in a payment-by-results model as happens in the USA, and hence some other studies have found no impact on overall service profitability [46]. However, the NHS has recently moved away from payment-by-results [47] to a block-funding model wherein additional activity over and above what is agreed is a financial risk that brings no additional income [48]. Coupled with the reality that operating theatre costs within the NHS are unknown [49], there are real uncertainties around the financial viability of an overlapping surgery model in the UK.

In terms of overall productivity, many studies point to the increase in number of cases that a single surgeon completes with overlapping surgery [34–36]. But, as discussed above, it is inevitable that if an extra operating theatre is available, the absolute number of cases completed will always be higher; the real question is how productivity of one surgeon working across two overlapping operating theatres compares with two surgeons focused on their own lists. In other words, if one operating theatre is scheduled conventionally there are x cases completed, then we can expect that in the neighbouring operating theatre scheduled the same way for the same operations, there will also be x completed, making a total of 2x cases. For overlapping surgery to prove better than conventional scheduling, it needs to demonstrate significantly >2x cases completed. Yet, Zachwieja et al. [35], championing overlapping models in hip and knee surgery (one of the specialties highlighted by Sun et al. [40] as carrying a higher risk of complications with overlapping), concluded that the mean total number of cases a surgeon could perform in an 8-h block increased by just one case (i.e. the gain in cases was just x + 1; not 2x). In the knee arthroplasty data from Murphy et al., a single surgeon completed 3.76 cases per day in a single operating theatre but only 5.01 per day when overlapping; much less than the expected 7.52 for two separate parallel surgeons [33]. Interestingly, in a survey of surgeon's attitudes to overlapping surgery, Perez et al. reported recognition of scheduling the parallel operating theatre being a specific challenge, with unpredictably increased fallow time identified as a concern [50].

Comparison of different healthcare environments

The potential for a beneficial impact of overlapping surgery, and which stakeholders it might or might not benefit, depends on the healthcare environment. In systems like the UK NHS, there is generally a limited number (fixed capacity) of operating theatres within each hospital [51]. Each operating theatre is already allocated to a team (surgeon) and implementing overlapping surgery means reallocating a theatre from one surgeon/team to another. This may balance out if, for example the team benefitting from this reallocation on one day suffers a reallocation in the reverse direction on another day or another week. But organising this in the system becomes ever more complex and requires strong justification that performance improvement will result from such radical organisational change. As we have seen above, there is little or no expectation or evidence that it will.

In healthcare systems like the USA, things may be different. Surgeons or teams do not necessarily have a fixed allocation of operating theatre space; rather they are allocated theatres in accordance with their varying workload [52]. Thus, in hospitals that have spare or unused operating theatres on any given day, it may be rational to use these to support overlapping surgery for a given surgeon or team with the higher workload. Overlapping surgery might also be used as an active strategy to retain high-volume surgeons who bring in profits to the hospital, especially if the surgeon in question perceives greater satisfaction in being allocated two parallel operating theatres where they can work uninterrupted for the entirety of their visit to the hospital. In this manner, `profitable´ surgeons could trump the `unprofitable´ but more productive ones: even under the old NHS payment-by-results system, it was recognised that some operations were inherently profitable even when assessed on a per-minute of operating time basis [47].

In conclusion, despite the lack of evidence that overlapping surgery increases surgical productivity (case numbers), there may be discrete situations where it may offer some benefit, as compared with assigning two separate teams to parallel operating theatres. In hard-to-recruit specialties, waiting list demands may require multiple operating theatres to be allocated to that specialty but with insufficient surgeons to staff them; an overlapping model may offer a temporary solution until recruitment is achieved. Overlapping surgery may be suitable for extra weekend initiative lists, where only one surgeon has volunteered for the additional duty. However, an overlapping model will never yield greater productivity than two independent, well-planned lists, so should not be preferred if two surgeons have volunteered. Overlapping surgery should not be confused with separate, independent interventions to reduce turnover time. Reducing turnover time will increase the potential productivity of a conventionally booked list as much (or as little) as it will that of an overlapping list.

Ultimately, any perceived benefits of introducing overlapping surgery should be balanced against the perhaps small, but very real risks it can present to patient outcomes, safety, training and patient autonomy. The experience of Massachusetts General Hospital underlines that there should be advanced agreement and buy-in of all specialties and stakeholders, including patient or lay representatives, before overlapping surgery is introduced. This should be coupled with a programme of education (in the background theory) and training (in the practical workflow changes required) for all staff involved.

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