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Getting going on time: reducing neurophysiology set-up times in order to contribute to improving surgery start and finish times

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ABSTRACT

At the Walton Centre we conduct a relatively large number of complex and lengthy elective (booked) spinal operations. Recently, we have had a particular problem with half or more of these sessions finishing late, resulting in staff discontent and greater use of on-call staff.

These operations require patient monitoring by neurophysiology clinical scientists. Before the surgeon can start the operation, in-theatre neurophysiological measurements are required to establish a baseline. We reasoned that reducing this set-up time would reduce the risk of surgery starting late, and so the whole session finishing later than expected.

In this project we redesigned the neurophysiology parts of in-theatre patient preparation. We conducted five Plan-Do-Study-Act cycles over 3 months, reducing the duration of pre-surgery preparation from a mean of 70 min to around 50 min. We saw improvements in surgical start times and session finish times (both earlier by roughly comparable amounts). The ultimately impact is that we saw on-time session finishes improve from around 50% to 100%. Following this project, we have managed to sustain the changes and the improved performance.

The most impactful change was to conduct in-theatre neurophysiology patient preparation simultaneously with anaesthesia, rather than waiting for this to finish; when we performed this with a pair of clinical scientists, we were able to complete neurophysiology patient preparation by the time the anaesthetist was finished, therefore not introducing delays to the start of surgery. A final change was to remove a superfluous preparatory patient-baseline measurement.

This is a very challenging and complex environment, with powerful stakeholders and many factors and unpredictable events affecting sessions. Nevertheless, we have shown that we can make improvements within our span of influence that improve the wider process. While using pairs of staff requires greater resource, we found the benefit to be worthwhile.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Late starts and finishes to surgery have been much studied, but the impact of the lengthy in-theatre neurophysiology preparation for complex spinal operations has not been investigated in the literature.

WHAT THIS STUDY ADDS

⇒ This study has demonstrated the impact of neurophysiology preparation, and that improving this process (in particular by deploying a second neurophysiology clinical scientist for the preparation stage) can materially and reliably improve on-time surgical starts and session finishes.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ This paper highlights that physiology clinical scientists can conduct quality improvement work, within their span of influence, that can improve overall operating theatre session efficiency.

PROBLEM

Regular late finishes of long operating theatre sessions lead to staff fatigue and can reduce work satisfaction; ultimately staff may refuse to continue with that extra commitment. Reducing late starts would be expected to have some impact on this as well as making work schedules more predictable for theatre staff and patients.

The Walton Centre NHS Foundation Trust is a large specialist hospital on the outskirts of Liverpool providing comprehensive neurological, neurosurgical and pain management services to patients from across northwest England and north Wales, and also receives some referrals from all other parts of the UK. It is a designated major trauma centre, receiving emergency neurological trauma transfers from across the region. The Neurosurgery Division is one of the largest in the UK, conducting approximately 3000 elective and 2000 emergency surgical cases per year, together with 1000 day-case procedures.

Following a regional merger of adult spinal deformity services, over the last 5 years we have experienced a significant increase in the number of surgical cases finishing after 17:00. Many complex operations last from 7 to 10 hours (so occupy a full day in theatre: three-session cases), placing additional pressure on staff to work late. Surgical cases are

scheduled based on their complexity. Most spinal elective procedures that require neurophysiology monitoring are planned as three-session cases (all-day cases). They are classified as Short, Medium or Long, with anticipated (planned) finish times of 19:00, 20:00 or 20:30, respectively. Elective cases that finish after their planned finish time are classed as finishing late.

Due to ongoing shortages of theatre staff, and staff unwillingness to work beyond their shift finishing time there has been an increase in the use of on-call theatre staff to cover those cases that finish after 19:00. In addition, X-ray and two-dimensional and three-dimensional CT scan imaging elective service provision is reduced after 17:00, with limited cover until 20:00 and thereafter an on-call service (primarily to cover emergency cases). In the neurophysiology department we have a limited number of staff able to work beyond 17:00 and we do not operate an on-call service. Furthermore, neurophysiology monitoring is at its most intensive at the very end of the procedure when staff fatigue is at its highest. There are thus many negative consequences of later-than-planned surgery finishes.

The ultimate issue is late finishes (over-runs) of surgical sessions. This is a very difficult area to do quality improvement (QI) in, as there are many contributing factors and a lot of unpredictable variation. We focused on what is in our span of influence in neurophysiology. This led us to concentrate on the duration of in-theatre pre-surgery preparation (ie, prior to knife-to-skin)—the period during which the patient is anaesthetised and we (neurophysiology scientists) conduct a range of baseline measurements to set up for patient monitoring during the surgery. Excessive durations here will delay the start of surgery and so, it would be logical to assume, would tend to impact on the overall finish time.

We used the Model for Improvement and its Plan-Do-Study-Act (PDSA) cycles.[1] Our (stretch) aim was to reduce pre-surgery duration to 45 min, and so, contribute to on-time starts and consequently, we hoped, to on-time session finishes, within the 3 months of our QI project. We capture the cause-effect logic of the project in an action effect diagram[2] in online supplemental figure S1.

BACKGROUND

Operating theatre facilities and teams are expensive resources and a constraint to the volume of treatment that healthcare systems can provide, so a lot of attention has been paid in the literature to attempting to improve efficiency.[3] Late starts and finishes have been a particular focus.

Much academic work has been done on examining the trade-off between theatre utilisation and the risk of over-run (late finish).[4–7] As the modelling in some of these studies would predict, a trial in an NHS Trust found that switching to longer sessions (from 4 hours to 4.5 hours) allowed more patients to be treated with fewer over-runs.[8] It found that staff satisfaction was unaffected, though noted that for some staff the impact on their lives (eg, childcare and travel) would be serious enough to affect well-being and retention.

Although there is some evidence that late start of surgical sessions is not a good predictor of late finishes,[9 10] such tardiness continues to be a considerable focus for research internationally, with of the order of 50% of sessions found to start late in studies in the USA,[11] the Netherlands[12] and Germany.[13] 'Downtime' when theatre delays prevent the anaesthetist or surgeon working on the patient have been estimated to be of the order of 12% of the planned session time and identified as an opportunity for improvement.[14 15] In our case we are considering single-case sessions, so we might expect there to be less scope to make up for time 'lost' from a late first-case start than in the multi-case sessions generally considered in the literature.

The recent US study found incidence and general causes of late starts in neurosurgery to be similar to other specialties.[11] Searching the literature, we found no work considering the specific contribution of neurophysiology to these issues. However, there is recognition that there is a great deal of variation in practice in neurosurgery, as is common across surgical specialties.[16]

Unsurprisingly, there is also research evidence that evening working leads to worse patient outcomes, with factors being staff availability, skill mix and fatigue.[17] In addition to impact on quality of care, late finishes also take a toll on staff. Several NHS organisations are going beyond the widely-adopted Triple Aim of healthcare[18] to add staff experience and well-being, to pursue a Quadruple Aim (improving population health, patient experience and team well-being, while reducing costs).[19–21] In our case, as often, our problem impacts all four of these key dimensions of healthcare delivery. On top of this, the pandemic has prompted renewed focus on staff well-being.

MEASUREMENT

Figure 1 shows the relevant steps in theatre set-up and neurophysiological patient preparation for an operation, together with the metrics we developed for this project. Our ultimate outcome metric (OM) is the percentage of on-time finishes (OM1) in cases within our scope of interest (three-session surgery cases involving neurophysiology). Since a percentage is an aggregate pass/fail metric that can hide important detail, we also set the actual individual finish time versus the target time (which would be negative for minutes early and positive for minutes late) to be another outcome metric (OM2).

Our focus was what *we* (neurophysiology) could do to reduce late finishes, specifically our part in delayed starts to surgery (knife-to-skin clock time). We set the clock time of start of surgery as a process metric (PM) (which ended up being coded as PM3), with an (internal) target of 10:30.

Root cause analysis using fishbone diagrams[22] and Pareto charts[23] of recent cases suggested a number of

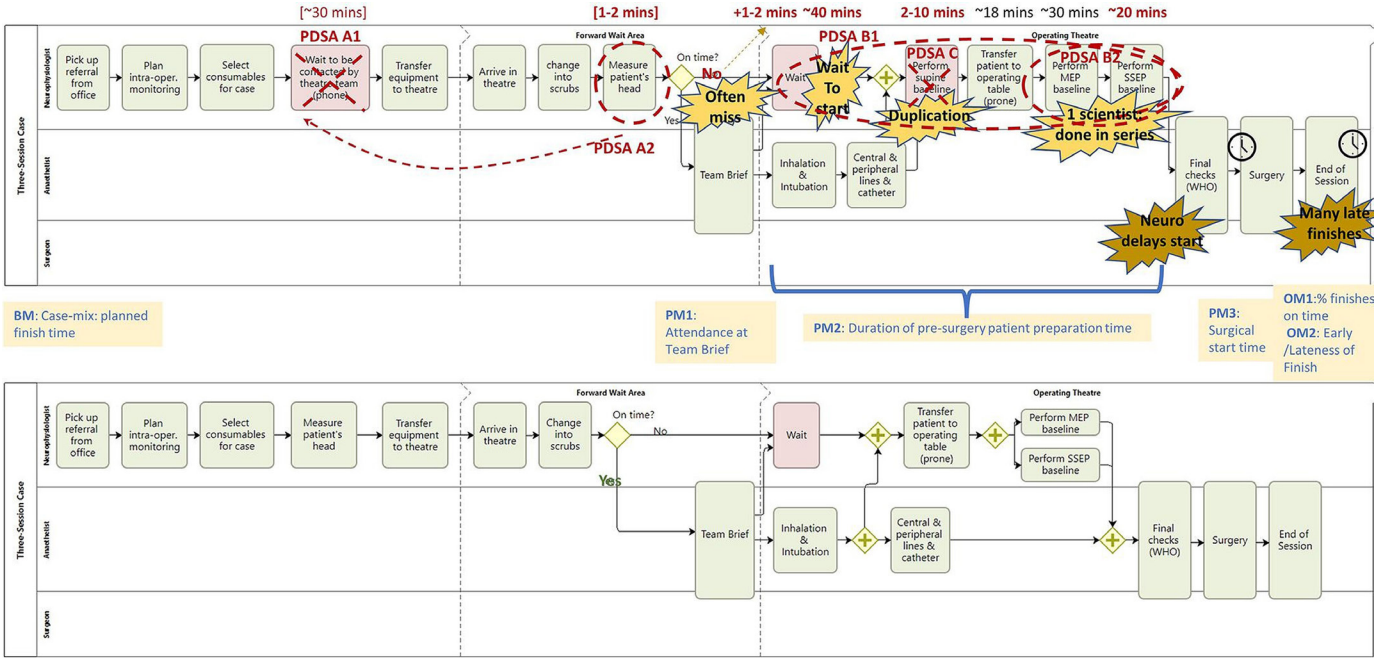

Figure 1 'As-is' process map, focusing on the neurophysiology input to the process. It shows value (green) and waste (red) steps, problems identified and metrics used in this project. BM, balancing metric; MEP, motor evoked potential; OM, outcome metric; PDSA, Plan-Do-Study-Act; PM, process metric; SSEP, somatosensory evoked potential.

potential causes. See the (online supplemental figures S1-S4) for some of the higher-level analyses, and the annotation on the process map (figure 1). In particular, this suggested three sets of issues. First, that that the neurophysiology scientist conducting the set-up for the operation frequently missed the surgical team brief that morning. These meetings of the surgical team include the surgeon and anaesthetist, and discuss and agree the action plan for the forthcoming operation. Missing the brief means having to spend time during the in-theatre neurophysiology patient set-up discussing procedures. We therefore set attendance by the neurophysiology scientist at this briefing as another process metric (PM1). This is also related to the wait to be contacted by theatre staff before setting off to the theatre.

The second set of issues was to do with the duration of pre-surgical patient preparation. This consists of both anaesthesia and (for cases in scope) neurophysiological set-up. A preliminary analysis of a set of recent cases showed us that when neurophysiological set-up was involved this increased the total pre-surgery patient preparation duration from 45 to 50 min to over 50 min. This total pre-surgery patient preparation duration is the most obvious metric of our contribution to late finishes (see online supplemental figure S1)—so was our main project focus as another process metric (PM2). From experience, we decided a suitable target duration would be 45 min. Retrospective analysis (see Results section) shows this to have been a remarkably good judgement!

The root cause analyses highlighted that neurophysiological set-up could not start until anaesthesia was finished, and that having only one scientist in the theatre meant that the lengthy baseline measurement steps had to be done in series (as shown on the process map in figure 1). The third issue was to question whether measurements were necessary with the patient in both supine and prone positions. Online supplemental figure S1 is an overview of the logic and metrics.

Having set these metrics, we then collected baseline values for all of them. This was during a period of low elective activity as COVID-19 impacted on throughput volume, so it took 10 weeks to collect this data set of 12 three-session cases.

Where appropriate, we set up Statistical Process Control (SPC) charts[23–25] to explore the data and be ready to examine potential impacts of the change interventions (see figure 2). The lower three charts use the NHS Excel template for XmR SPC charts[26] to plot data for successive individual patients. The XmR pair of charts (the individual data points plus moving ranges) are appropriate for this type of data. To save space, only the X charts (the data points themselves) are shown here. The top chart simply shows the percentage in the period between each set of vertical-dotted intervention-time lines. There are insufficient data to use the p-chart SPC format for percentage data. For this we would have needed around 10+ data points in each period, *each* representing around 30+ data points as a denominator for that estimate of the underlying percentage.

We adapted copies of the XmR template to show successive case numbers on the X axis rather than dates and, for PM3, to have the time of day on the Y axis, which is valid since, internally, Excel uses decimal time for the calculations of mean and ranges. The horizontal dashed grey lines on the SPC charts are the process limits (also known as control limits), which are the expected range

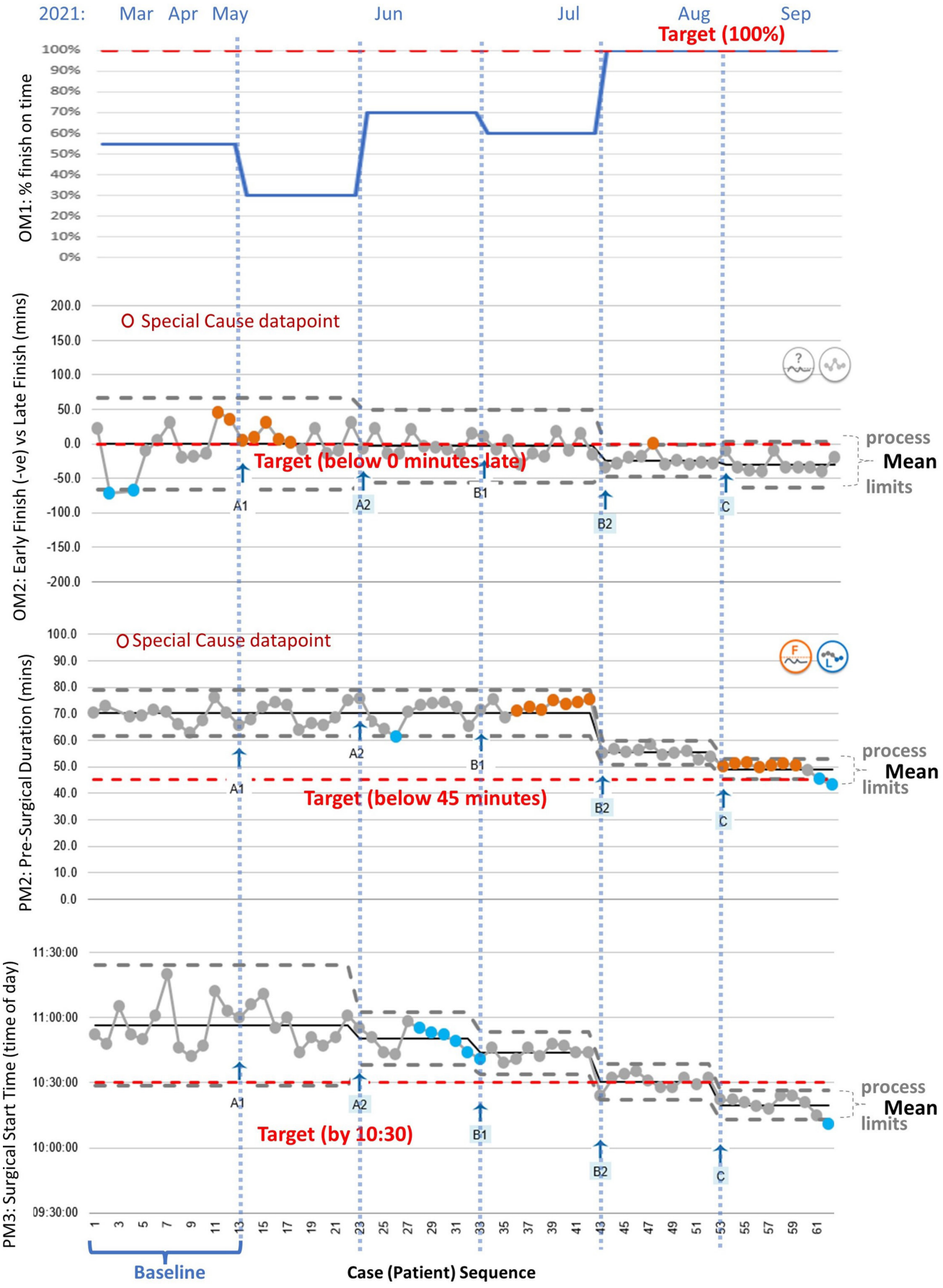

Figure 2 Main performance metrics over baseline and five cycles of Plan-Do-Study-Act (A1 to C). OM, outcome metric; PM, process metric.

of random process variation around the mean solid horizontal lines. The red dashed lines are the target levels of performance on each metric. If, as for the metrics on our three SPC charts, the aim is to be below the target, then if the upper process limit is below the target line (so within the target range), we can say the process is statistically capable of meeting the target: random behaviour alone is very unlikely to breach the target.

For the baseline period (12 cases), 50% finished on time (OM1). We were able to attend none of the preoperation team meetings (PM1). The pre-surgery patient preparation (PM2) had a mean duration of 72 min, with high variation and all were over the 45-min target, see figure 2. A potential special cause (SC) case, far above the upper process limit (UPL), was observed. This was a very difficult patient case, related to a large set of unusual administrative gaps and patient circumstances (Removing this SC case from OM1 makes the baseline 55% of the remainder finishing on time, as shown in figure 2.)

The mean surgical start time (PM3) was 10:56; all were later than 10:30. Again a high value was a potential SC (>UPL), linked to anaesthesia being delayed, though this was much less extreme.

As noted earlier, the operations of interest have three categories of expected duration. The mix varies, so we recorded this as a balancing metric (BM). In the baseline period there were 3 'Short' (planned 19:00 finishes), all of which finished on time; 3 out of 5 'Medium' finished on time and 0 of 4 'Long' (so, in shorthand: S:3/**3**, M:3/**5**,L:0/**4**) (online supplemental figure S5 shows this graphically).

DESIGN

The project was led by the first author (MP) with support from three other neurophysiology scientists (those named in the acknowledgements). These four senior clinical scientists work closely together. MP collected and analysed the data, and all reviewed the process map and root cause analysis data and were involved in identifying and implementing the change ideas. Surgeons and anaesthetists were also consulted on potential clinical impacts. For each patient, the procedures to be undertaken in theatre are discussed at the theatre Team Brief (see figure 1). These procedures included the new ways of working trialled, and so the theatre staff (in particular the surgeons and anaesthetists) were, essentially, also part of the wider QI (intervention) team.

Reviewing the issues identified in the root cause analyses and process mapping in figure 1 (see the previous section) and the, online supplemental figures S1-S4 the neurophysiology team identified and agreed three sets of change ideas:

1. Do pre-theatre set-up earlier and do not wait for contact by the theatre time to go to theatre, so that we could manage to attend the team brief.
2. Do in-theatre patient neurophysiology preparation in parallel with anaesthesia rather than after waiting for it to be completed.
3. Cease redundant components of in-theatre neurophysiological patient preparation (supine patient baseline measurement).

To determine the order in which to test these with PDSA cycles, the neurophysiology team considered the benefits and ease-of-implementation, agreeing simple scores on simple 0–4 scales (see online supplemental table S1 and figure S5), as well as taking into consideration the prerequisites among the changes.

Idea A was the most straightforward, involving moving some planning to a day or more before and setting off for the theatre earlier on the morning of the operation to allow more time for set-up and then attend the team brief. We decided to try this first.

Idea B would require discussion and approval from the anaesthetist, a high-power stakeholder in the surgical team who must agree case-by-case. Therefore, attendance at the team brief to discuss and agree the plan of action prior to the patient's arrival was a prerequisite. If we could achieve a high level of briefing attendance, we would try this second.

Idea C arose from a reconsideration of the steps in the later stages of the process shown in the process map (figure 1). It is not uncommon for such 'waste-spotting' from 'as-is' process maps to reveal steps that are no longer necessary (they have become non-value adding, being a legacy of past requirements in a system that has since evolved).[27 28] Here, we determined there was redundancy in the neurophysiological baseline recordings.

Recording initial patient baseline readings is important in deciding when to trigger clinical alerts once surgery starts.[29] However, there is no consensus in the national and international standards on whether the patient should be prone or supine during these readings. We had been doing both (see figure 1), following the working practices of the surgeons who had first developed the surgical procedures at our specialist trust.

The current BSCN (British Society of Clinical Neurophysiology) standards for spinal cord monitoring and ISIN (International Society of Intraoperative Neurophysiology) standards both state that baseline recordings should be recorded but do not state in which position.[30 31] An experienced reader would assume prone. Further, recent categorisation of the range of different MEP (motor evoked potential) baseline phenotypes were all obtained from prone positions.[32]

The literature on MEP measurement contains limited evidence on the role of prepositioning (supine) measurement in non-degenerative spines prior to prone positioning for surgery. A debate[33 34] concluded with the clear view that in degenerative cervical spinal surgery neurological injury may occur during positioning of the cervical spine in either prone or supine positions[34] and could be considered as a high-risk procedure for neurological positional injury. Researchers argue that,

in orthopaedic deformity surgery, the greatest risks associated with positioning are ulnar nerve injury, brachial plexus injury or postoperative vision loss, which are all rare and a direct result of prolonged positioning rather than initial positioning.[35]

Another study reported that the prone position frequently used in posterior fossa procedures (lumbar spine) is often associated with attenuation changes of transcranial MEP results, which are normalised following the return to a supine position.[36] These authors attribute this to a range of causes which include hypotension, hypothermia and effects of intravenous anaesthesia, and argue that in healthy adults, flexion of the lumbar spine in the prone position leads to an overall increase in the area of the spinal canal and dural sac with minimal changes on the diameter of the spinal canal.

In summary, the literature supports the importance of initial *prone* MEP baseline measurement, with *supine* prepositioning MEP measurement merely acting as controls prior to prone positioning. While supine measures may be relevant for patients at high risk of positional neurological injury, it adds little additional information in low-risk patients and under this circumstance could be considered as a *duplication* in the process. Supine baselines take an additional 2–10 min or pre-surgery preparation time in the operating theatre.

Decisions on whether it is necessary to undertake supine (as well as prone) prepositioning baseline studies should be based on a clinical risk assessment rather than remaining as standard practice. The patients in our study are undergoing spinal deformity surgery, spinal tumour or neuropathic pain dorsal root entry zone surgery; they are at low risk from neurological positional injury.

In addition, opinion on the UK forum on neuromonitoring indicate agreement that supine baseline recordings are not necessary when monitoring is undertaken by experienced teams.[37] (Supine baseline practices appear to now reflect inexperienced surgeons or teams new to neuromonitoring, except for monitoring paediatric neuromuscular patients; our clinical practice is in adult patients.)

Our core team has much experience (including the lead author's over 20 years of experience in neurophysiology and 15 years in intraoperative monitoring), and we are confident that the prone baselines are sufficient. This change (Idea C), to remove the supine measurement step, however, involves a change in clinical practice, so would require the agreement of the surgeons. Meetings would therefore be needed between the neurophysiology scientists and surgeons to explain the rationale and discuss the implications. We also considered it potentially less impactful than Idea B, so we chose to pursue this last.

STRATEGY

To test and refine our three change ideas (A, B and C), we ended up doing five PDSA cycles (summarised in table 1). The changes are illustrated on figure 1 and the results on the metrics are shown in figure 2.

Our first target (Change Idea A) was to attend all preoperation team briefings. The first test (PDSA cycle A1) with the next 10 three-session cases was disappointing. We were still unable to attend any team briefings. (As would be expected, the other metrics were also materially unchanged.) We therefore decided to refine and repeat this (cycle A2) by changing the time of departure for the theatre from 08:30 to 08:15 and also performing the measurement of the patient's head on the ward (between 08:00 and 08:15, before the patient leaves for theatre) rather than in the theatre waiting area. We tested this with the next 10 cases. We now managed to attend all team briefings. The impact on the other metrics was small, but variation was reduced. However, this change was also a prerequisite for further changes (which involved agreement on case planning with the anaesthetists and surgeons), so we decided to retain this change. We were also strengthening our belief that pre-surgery set-up delays were important.

The next change (B) was to start neurophysiology patient preparation in parallel with anaesthesia (after intubation, and with agreement of the anaesthetist during the case planning). A first test (cycle B1) still failed to have much impact on the metrics, in particular the OMs. The pre-surgical patient preparation duration (PM2) remained unchanged and still always over 45 min. Importantly, neurophysiology often took longer than anaesthesia, so still caused delays to surgical starts (knife-to-skin times). To cut the neurophysiology duration, we now tried deploying a second clinical scientist, so that two steps (MEP and somatosensory evoked potential (SSEP), taking roughly 30 and 20 min, respectively) could be done in parallel (see figure 1). Testing this (cycle B2) finally shifted pre-surgical patient preparation duration (PM2) and the OMs. While not achieving 45 min on PM2, there was a material improvement, we were sometimes achieving 10:30 surgery starts (PM3) and we were finally achieving 100% finishes within time (OM1)—see figure 2.

The final cycle (C) was to remove the redundant supine-position baseline patient measurements, having gained agreement from the surgeons (who had previously specifically asked for them). With this, we further improved PM2 and the OMs, and achieved reliable 10:30 starts (PM3).

RESULTS

As figure 2 and table 1 summarise, we did not quite reach our target (45 min pre-surgery duration) on our most obvious metric (PM2), but came close (and achieved all the others!). In fact, a retrospective statistical analysis of PM2 versus OM2 (finish time vs schedule) data (see online supplemental appendix) shows that 45 min turns out to be an appropriate target to provide a 1-in-20 (5%) risk of over-run. However, while 5% is a standard target level in

Table 1 Improvement cycles

PDSA cycle	Plan/prediction	Do	Study	Act
A1	If cases planned and leave dept at 8:30 (instead of waiting to be contacted) then *will* have time to attend team briefing (PM1). This will improve PM2 and OMs.	10 May 2021. Next 10 cases. Plan case at least 24 hours before, prepare consumables and equipment. Leave dept at 08:30 for theatre, **attend team brief**.	OM1: ☒ 30% of cases finished on time (worse!). OM2: ☒ Mean around 0 (on-time only on average), with wide variation (±>1 hour); no material change. PM1: ☒ 0% (no team briefs attended) (no change). **PM2**: ☒ Mean=70 min, with high variation (±9 min), all CC (no material change). PM3: ☒ Mean 10:56 (no material change), 1 potential SC identified—linked to anaesthesia delay time. BM: S:3/**5**, M:0/**2**, L:0/**3.**	OM1: 'Long' case consistently finish after their planned finish time. PM1: Conclude: leaving at 8:30 had no impact on PM1 (attending brief), PM2 or PM3. **Unsuccessful: refine**. Leave earlier, move head measurement task from WA. Tentative pattern emerging: PM2 delay important factor in delaying surgical start time.
A2	If have done head measurement on the ward and leave earlier (08:15) then *will* have time to attend team briefing (PM1).	1 June 2021. Next 10 cases. As above PLUS. Measure the patient's head **on the ward.** And leave department at **08:15.**	OM1: ☒ 70% finished on time. OM2: ☒ Mean around 0 (on-time); no material change, but reduced variation (±50 min). PM1: ☑ 100% (all 10 team briefs attended: target met). **PM2**: ☒ No material change: mean=70 min. PM3: ☒ Mean 10:50 (small improvement), reduced variation. Consistent pattern emerging due to NP having to wait for anaesthesia to finish. BM: S:3/**3**, M:4/**4**, L:0/**3.**	Conclude: attendance *may* have some impact on 'Short' and 'Medium' cases; 'Long' still problematic. Little impact on PM2 and PM3, but prerequisite for B and C: **retain**. Anaesthesia delay continues to impact PM3. Conclude: **next** focus on NP impact on pre-surgery prep duration.
B1	If simultaneous NP set-up with anaesthesia, then reduce pre-surgery delays, so PM2, PM3 and OMs.	24 June 2021. Next 10 cases. As above PLUS. Do **set-up simultaneously with anaesthesia** (after intubation).	OM1: ☒ 60% finished on time. OM2: ☒ No material change. PM1: ☑ 100% (all 10 team briefs attended). **PM2**: ☒ No material change. PM3: ☒ Mean 10:44 (small improvement): All 10 cases started before 10:50. All CC. BM: S:2/**2**, M:4/**4**, L:0/**4.**	Long cases still problematic. No change to PM2 likely linked to NP theatre duration sometimes > anaesthesia duration. **Conclude**: want NP duration ≤ anaesthesia duration to avoid delays to surgical start.

Continued

Table 1 Continued

PDSA cycle	Plan/prediction	Do	Study	Act
B2	If NP set-up in pairs then NP duration ≤anaesthesia duration: PM2 reduced, so PM3 and OM1 reduced.	20 July 2021. Next 10 cases. As above PLUS. Do set-up in **pairs**.	OM1: ☑ 100%. All cases finished within planned finish time. OM2: (☑) Mean = −24 min (ie, early);~capable PM1: ☑ 100% (all 10 team briefs attended). **PM2**: ☒ Mean=55 min (process range 50–60 min). Material reduction in mean and variation (±4 min), all CC PM3: ☒ Mean=10:30 (=target) but above on ~50% of occasions! So not capable. BM: S:5/**5**, M:4/**4**, L:1/**1.**	Setting up in pairs has a significant impact on PM2: 40% cases within target, but still >target (45 min). **Conclude**: needs further reduction in NP time. Possible impact on 'Long' cases, BUT limited data in this cycle (one case).
C	If we only perform prone intraoperative baselines, we can remove duplication from the system.	11August 2021. Next 10 cases. As above PLUS. **Cease supine** baseline recordings.	OM1: ☑ 100%. All cases finished on time again. OM2: (☑) Mean = −29 min (early); ~capable. PM1: ☑ 100% (all 10 team briefs attended). **PM2**: ☒ Mean=49 min. Low variation (±3 min). One case (of these last 10) within the 45-min target. PM3: ☑ Mean=10:20. All 10 cases were within the 10:30 target, UPL within target. BM: S:6/**6**, M:1/**1**, L:3/**3.**	Removing baseline duplication within the system significantly improved PM2 and PM3 (now capable of meeting target). Three-session cases now consistently finish before their planned finish times, even 'Long' cases.

☑: Target met; ☒: Target not met.
BM, balancing metric; CC, common cause (ie, random) variation; L, long; M, medium-length; NP, neurophysiology; OM, outcome metric; PM, process metric; S, planned (relatively) short duration operations; SC, special cause variation; UPL, upper process limit (also known as upper control limit); WA, theatre waiting area.

most management analyses, it may be more exacting than necessary in the NHS theatre over-run context. Changing the resultant risk to 10% in the statistical analysis would correspond to a PM2 target of around 50 min—the mean achieved in the final PDSA cycle (cycle C).

This is borne out by success on the overall finish times (the OMs). Over five improvement cycles we managed to improve on-time finishes from around 50% to 100% for the final two cycles (n=20 cases). We can see (figure 2: OM2) that the process is now just about capable of finishing on time (the UPL coincides with the target line indicating finishing 0 min late). From figure 2, we see that this major improvement coincided with the material reduction in PM2 in PDSA cycle B2. This was when we made renewed efforts to fit the neurophysiology patient preparation duration within the (parallel) anaesthesia time, so removing our (neurophysiology) impact on delayed surgical starts. We also note that the process is now capable of allowing us to attend all briefing meetings (PM1) and of surgical starts by 10:30 (PM3).

We are happy that we have materially improved our impact on on-time finishes, but of course we are part of a multidisciplinary team and there are many factors outside our own specialism's control and influence.

The online supplemental figure S6 shows a graph of the case mix (our BM) in each phase, categorised by planned finish times of 19:00, 20:00 or 20:30, corresponding to cases expected to be 'Short', 'Medium' or 'Long', and whether they were actually finished by this time. (NB: this categorisation and setting of planned finish times is not done by neurophysiology.)

Though the numbers in each category are small, we see some suggestions of trends. The 'Short' cases (due to finish by 19:00) were rarely a problem even before our QI project bore much fruit—there were two late finishes, requiring on-call staff, both during the PDSA A1 period.

The 'Medium' expected length cases were often problematic until we moved to early preparation and were able to attend meetings (A2); and it was not until the big improvements from in-theatre reorganisation (B2) that we overcame the problems with the longest category of case.

We consider the additional staffing (for the parallel neurophysiology MEP and SSEP shown in the lower process map in figure 1) worthwhile, and have managed to sustain it. We have also recently embarked on training three new neurophysiology scientists, which will strengthen our ability to maintain pair-working. All the changes trialled and refined in the PDSAs are now our standard practice. However, adding the new scientists to the team has introduced training requirements, including during theatre sessions, impacting on the pre-surgery durations in the short-term.

Since this QI project finished (September 2021), there has been another winter of COVID-19 disruption and a change in caseload, related to a change in the surgical team and the start of a new spinal service (endoscopic spinal deformity), but of the 17 cases following those in figure 2 (to mid-June 2022):

- OM1: 94% have finished on time (one case involving training over-ran)
- OM2: We have continued to finish around 40 min before the scheduled end of sessions.
- PM1: We have attended all (100%) of the pre-surgery briefings.
- PM2: This has improved: pre-surgical preparation time exceeded the 45-min target on only eight occasions: three times before training sessions started (and by a maximum of only 4 min); five times during sessions with training (all by longer, and four of them are the four times surgery was delayed, ie, started after 10:30).
- PM3: Surgery started by the 10:30 target for all but four sessions (all with training).

LESSONS AND LIMITATIONS

We conducted this QI project during the COVID-19 period of reduced throughput, so although cases were similar, the volume of cases was lower than previously, and so data built up fairly slowly. This forced a trade-off between volume of data collection and progress on QI. Though each PDSA cycle consisted of only 10 cases, each required about 3 weeks to generate that many data points. While QI usually aims for rapid feedback on the impact of changes, this issue of slow build up of data are one that many face in highly-specialist (and so low volume) branches of healthcare. A consequence of small numbers here is that we have noticeable fluctuations in our case mix (online supplemental figure S6), our balancing metric. There was a marked drop (from 3 or 4 to 1) in the problematic 'Long' cases during our cycle B2, when we had the marked improvement in performance. However, this was back up to three cases for the final cycle (C) and the performance improvement was maintained.

In retrospect, we might have conducted a more-detailed data analysis of the timings of each step on the as-was (upper) process map (even if just a snapshot), to more-rapidly home in on the value of redesigning our neurophysiology process so that it would not introduce delay to surgery start time by conducting it in parallel with anaesthesia and to be finished first. We might also have had a greater focus on the issue of the long-planned-duration cases, and set up more PMs.

It would also have been useful to collect comparative data (maybe quantified) about staff experience before and after the changes—in particular from the three staff groups most affected (theatre staff, imaging (X-ray and CT) staff and neurophysiology staff). We could have used a short questionnaire or interview.

We have also acknowledged that we are working in teams with high-power stakeholders (including surgeons and anaesthetists) and focused just on our own contribution to the overall problem; there are (of course) many factors outside our spans of control and influence that can affect the final surgery finish time.

Although our changes require a bit more staff input time (pairs of neurology scientists for set-up), we consider this worthwhile and have been able to sustain it; further, we have been able to justify and obtain an enlargement to our team.

CONCLUSION

We now have a reliable process for attending pre-surgery meetings, plus agreements with anaesthetists to do our neurophysiology patient preparation in parallel with anaesthesia and with surgeons to dispense with supine baseline patient neurophysiological measurements. We have a stable pre-surgery set-up duration (PM2), though the 45-min target may have been overly ambitious: our UPL (the maximum expected duration) in the last PDSA cycle was around 52 min. However, the improvements we made were sufficient to make a material contribution to on-time starts (PM3) and finishes (the OMs OM1 and OM2), as clear in figure 2, and performance on PM2 has subsequently improved (though is currently reduced again due to the temporary additional training requirements for the new staff).

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REFERENCES

1 Langley GJ, Nolan KM, Nolan TW, *et al*. *The improvement guide: A practical approach to enhancing organizational performance*. San Francisco: Jossey-Bass, 1996.
2 Reed JE, McNicholas C, Woodcock T, *et al*. Designing quality improvement initiatives: the action effect method, a structured approach to identifying and articulating programme theory. *BMJ Qual Saf* 2014;23:1040–8.
3 Bello C, Urman RD, Andereggen L, *et al*. Operational and strategic decision making in the perioperative setting: meeting budgetary challenges and quality of care goals. *Best Pract Res Clin Anaesthesiol* 2022;18.
4 Westbury S, Pandit M, Pandit JJ. Matching surgical operating capacity to demand using estimates of operating times. *J Health Organ Manag* 2009;23:554–67.
5 Pandit JJ, Tavare A. Using mean duration and variation of procedure times to plan a list of surgical operations to fit into the scheduled list time. *Eur J Anaesthesiol* 2011;28:493–501.
6 Proudlove N, Hine A, Tavare A, *et al*. Improvements and corrections to estimating probabilities in the formula for planning a list of operations to fit into a scheduled time. *Eur J Anaesthesiol* 2013;30:633–5.
7 Dexter F. Hours of cases to schedule to rarely have overrun (correspondence and author reply). *Eur J Anaesthesiol* 2012;29:108–9.
8 Herron JBT, French R, Gilliam AD. Extended operating times are more efficient, save money and maintain a high staff and patient satisfaction. *J Perioper Pract* 2018;28:231–7.
9 Pandit JJ, Abbott T, Pandit M, *et al*. Is 'starting on time' useful (or useless) as a surrogate measure for 'surgical theatre efficiency'? *Anaesthesia* 2012;67:823–32.
10 Dexter F, Epstein RH, Penning DH. Late first-case of the day starts do not cause greater minutes of over-utilized time at an endoscopy suite with 8-hour workdays and late running rooms. A historical cohort study. *J Clin Anesth* 2020;59:18–25.
11 Hicks KB, Glaser K, Scott C, *et al*. Enumerating the causes and burden of first case operating room delays. *Am J Surg* 2020;219:486–9.
12 van Veen-Berkx E, Elkhuizen SG, Kalkman CJ, *et al*. Successful interventions to reduce first-case tardiness in Dutch University medical centers: results of a nationwide operating room benchmark study. *Am J Surg* 2014;207:949–59.
13 Schuster M, Pezzella M, Taube C, *et al*. Delays in starting morning operating Lists: an analysis of more than 20,000 cases in 22 German hospitals. *Dtsch Arztebl Int* 2013;110:237–43.
14 NHS Improvement. Operating theatres: opportunities to reduce waiting Lists NHS Improvement; 2019. https://allcatsrgrey.org.uk/wp/download/surgery/Theatre_productivity_report__Final.pdf. [Accessed 20 Sept 2021].
15 Pandit JJ. The NHS Improvement report on operating theatres: really 'getting it right first time'? *Anaesthesia* 2019;74:839–44.
16 Fuller G. Neurology: GIRFT programme national specialty report NHS Getting It Right First Time (GIRFT) Programme; 2021. www.gettingitrightfirsttime.co.uk/medical-specialties/neurology/ [Accessed 20 Sept 2021].
17 Kelz RR, Freeman KM, Hosokawa PW, *et al*. Time of day is associated with postoperative morbidity: an analysis of the National surgical quality improvement program data. *Ann Surg* 2008;247:544–52.
18 Berwick DM, Nolan TW, Whittington J. The triple AIM: care, health, and cost. *Health Aff* 2008;27:759–69.
19 Bodenheimer T, Sinsky C. From triple to quadruple AIM: care of the patient requires care of the provider. *Ann Fam Med* 2014;12:573–6.
20 Sikka R, Morath JM, Leape L. The quadruple AIM: care, health, cost and meaning in work. *BMJ Qual Saf* 2015;24:608–10.
21 Arnetz BB, Goetz CM, Arnetz JE, *et al*. Enhancing healthcare efficiency to achieve the quadruple AIM: an exploratory study. *BMC Res Notes* 2020;13:362–62.
22 Best M, Neuhauser D. Kaoru Ishikawa: from fishbones to world peace. *Qual Saf Health Care* 2008;17:150–2.
23 Provost LP, Murray SK. *The health care data guide: learning for data improvement*. San Francisco, CA: Jossey-Bass, 2011.
24 Mohammed MA, Worthington P, Woodall WH. Plotting basic control charts: tutorial notes for healthcare practitioners. *Qual Saf Health Care* 2008;17:137–45.
25 Mohammed MA. Using statistical process control to improve the quality of health care. *Qual Saf Health Care* 2004;13:243–5.
26 NHS England. Statistical process control tool, 2021. Available: www.england.nhs.uk/statistical-process-control-tool [Accessed 20 March 2021].
27 May F, Pepperall J, Davies E, *et al*. Summarised, verified and accessible: improving clinical information management for potential haematopoietic stem cell transplantation patients. *BMJ Open Qual* 2021;10:e001605.
28 Boaden R, Harvey G, Moxham C, *et al*. *Quality improvement: theory and practice in healthcare*. NHS Institute for Innovation and Improvement, 2008. www.england.nhs.uk/improvement-hub/wp-content/uploads/sites/44/2017/11/Quality-Improvement-Theory-and-Practice-in-Healthcare.pdf
29 Kim J-S, Jang M-J, Hyun S-J, *et al*. Failure to generate baseline muscle motor evoked potentials during spine surgery: risk factors and association with the postoperative outcomes. *Clin Neurophysiol* 2018;129:2276–83.
30 Grover H, Walsh P, Sanders B, *et al*. *Updated ANS/BSCN guidelines for neurophysiological recordings of the spinal cord during corrective spinal deformity surgery*. British Society for Clinical Neurophysiology, 2018. www.bscn.org.uk
31 MacDonald DB, Dong C, Quatrale R, *et al*. Recommendations of the International Society of intraoperative neurophysiology for intraoperative somatosensory evoked potentials. *Clin Neurophysiol* 2019;130:161–79.
32 Wang S, Ren Z, Liu J, *et al*. The prediction of intraoperative cervical cord function changes by different motor evoked potentials phenotypes in cervical myelopathy patients. *BMC Neurol* 2020;20:221.
33 Epstein NE. The need to add motor evoked potential monitoring to somatosensory and electromyographic monitoring in cervical spine surgery. *Surg Neurol Int* 2013;4:383–91.
34 Harel R, Knoller N, Regev G, *et al*. The value of neuromonitoring in cervical spine surgery. *Surg Neurol Int* 2014;5:120.
35 Kamel I, Barnette R. Positioning patients for spine surgery: avoiding uncommon position-related complications. *World J Orthop* 2014;5:425–43.
36 Apostolakis S, Karagianni A, Chiotaki E, *et al*. Attenuation of motor evoked potentials following prone. *Iran J Neurosurg* 2020;6:29–34.
37 Neuromonitoring UK. Available: www.neuromonitoringuk.org [Accessed 20 Sept 2021].