Clinical-scientist-led transoesophageal echocardiography (TOE): using extended roles to improve the service

Nikki Kaye,1 Michael Purdon,1 Rebecca Schofield,1 Grazia Antonacci 2,3 Nathan Proudlove 4

ABSTRACT
At the North West Anglia NHS Foundation Trust, we perform transoesophageal echocardiography (TOE), a semi-invasive diagnostic test using ultrasound for high-quality heart imaging. TOE allows accurate diagnosis of serious heart problems to support high-quality clinical decision-making about treatment pathways. The procedure can be lengthy and is traditionally performed by a consultant cardiologist, who typically has multiple commitments. This constrains patient access to TOE, leading to waits from referral to test, delaying treatment decisions.

In this quality improvement project, we improved access by redesigning workforce roles. The clinical scientist, who had been supporting the consultant during TOE clinics, took on performing the procedure as the main operator. We used the Model for Improvement to develop this clinical-scientist-led service-delivery model, and then test and refine it. This increased capacity and frequency of TOE clinics, reducing waits and releasing around 2 days per month of consultant time.

Over five plan-do-study-act cycles, we tested six changes/refinements. Our targets were to reduce the maximum waiting time for TOE to 3 working days for inpatients and to 14 working days for outpatients. We succeeded, achieving reductions in mean waiting times from 7.7 days to 3.0 days for inpatients and from 33.2 days to 8.3 days for outpatients.

TOE requires intubation; when this fails, TOE is abandoned. We believe light (rather than heavy) sedation is helpful for this intubation. We reduced sedation levels (from a median of 3 mg of midazolam to 1.5 mg) and, as a secondary outcome of this project, reduced the intubation failure rate from 13% to 0% (over 32 postchange patients). Following this project, our TOE service is usually performed by a clinical scientist in echocardiography who has British Society of Echocardiography TOE accreditation and advanced training. We have sustained the improved performance and demonstrated the value of enhanced roles for clinical scientists.

PROBLEM
Echocardiography is an important diagnostic technique with high demand. Of the 15 key diagnostic tests monitored in public NHS England data, the echocardiography waiting list is the fourth largest and has the third highest number of 6-week wait breaches, which is the joint highest proportion at 48%. The national target set in 2008 is 1%. As of the end of September 2022, North West Anglia NHS Foundation Trust (NWAF) had a waiting list of over 2800 for echocardiography (most being transsthoracic echocardiography (TTE), but also transoesophageal echocardiography (TOE)) with 69% waiting over 6 weeks.

At the NWAFT Cardiac Investigations Department, TOE has been performed by a consultant cardiologist, a role in short supply and with multiple other commitments, so capacity has been limited. Additionally, sometimes TOE had to be abandoned due to failed intubation, and some appointment slots have been taken up with ‘failure demand’ from inappropriate referrals. The pathway also contained many points of delay (figure 1), causing knock-on effects in other clinics and staffing.
Constrained access has lengthened patient waiting times for TOE, delaying clinical decision-making and so treatment pathways and condition management. For inpatients, it increased their length of stay in beds in our trust’s acute (secondary care) hospitals when patient flow is a particularly severe problem across the NHS. Most inpatient referrals for TOE are ‘query infective endocarditis’ (IE), a condition that should be treated without delay to improve survival. Supporting this, an internal audit of IE at NWAFT found that long waits between inpatient referral for TOE and the TOE procedure itself (and so diagnosis) can affect patients’ prognoses. A further benefit of improved access to TOE would be some patients bypassing the inpatient TTE diagnostic service, saving departmental resources. TTE is a much higher-volume service, so an inpatient could access this more quickly. Therefore, in practice, clinicians may request a TTE even though they believe a TOE will be necessary subsequently.

NWAFT’s vision is based on ‘excellent quality of care’ and ‘delivering outstanding care and experience’.3 We operationalise this through continuous service improvement and redesign initiatives, in particular, new quality improvement (QI) programmes.3

In this project, our QI approach was the Model for Improvement (MfI). At its core it has three questions: Q1: “What are we trying to accomplish?”; Q2: “How will we know that a change is an improvement?”; and Q3: “What changes can we make that will result in improvement?” to guide system exploration and plan-do-study-act (PDSA) cycles.4 The three questions guide a QI team to set aims, establish metrics and design and select change ideas to then test and refine through PDSA cycles. Revisiting the purpose, metrics and set of change ideas, the team decides whether to continue developing and testing further change ideas or to focus elsewhere. Recently, the MfI has been used successfully in another area of echocardiography,5 another physiological sciences specialism, neurophysiology,6 as well as in hospital life sciences specialisms.7–9

Our primary project aim (Q1 of the MfI) was to improve the performance of our department at NWAFT via improving our TOE provision. Within this overall aim, we had four goals (see also the driver diagram4 in online supplemental figure S3):

1. Improve access to TOE by reducing the waiting times to within 3 days for inpatients and 14 days for outpatients, within 6–12 months (our main intended outcome);
2. Improve intubation success rates, so fewer TOE procedures are abandoned;
3. Relieve the consultant cardiologist of the TOE clinic, so they can shift their time to other high-value tasks such as seeing patients who require clinical decisions, and to make use of the greater availability of clinical scientists;
4. Improve the quality of TOE reporting to meet British Society of Echocardiography (BSE) TOE guidelines.10

To try to achieve these, we tested a set of change ideas (Q3 of the MfI) arising from the broad concept of developing and refining a clinical-scientist-led TOE service. To our knowledge, there has been no previous performance analysis of a TOE service, or comparison
of consultant- versus scientist-led provision, in the NHS. Therefore, if successful, an additional objective was to disseminate our findings. To assess our progress (Q2 of the MIF), we established and analysed a set of metrics. See online supplemental figure S3 for an overview of the logic of our project.

BACKGROUND
TOE is a semi-invasive diagnostic test using ultrasound to produce high-quality images of the heart. Unlike in TTE, in TOE the echo transducer that produces the sound waves is attached to a soft, thin, flexible probe inserted through the patient’s mouth and down the oesophagus. This is an uncomfortable procedure and we recommend patients are sedated, usually with midazolam, though they can choose not to be. Ideally, patients are lightly sedated, so they are less uncomfortable but still conscious enough to help with intubation by swallowing. Further sedation can be given if necessary. The relationship between the amount of sedation given during TOE and intubation success is a topic of considerable current interest in the field, but we could find no published papers.

The oesophagus lies close to the upper chambers of the heart and enables the operator to obtain clearer images of the heart and valve structures. TOE allows accurate diagnosis of serious heart problems, important for appropriate treatment and management. TOE is often used to provide information prior to heart surgery, for example, to repair or replace heart valves, and specialist regional (tertiary care) hospitals require TOE images for some patients before they accept their transfer. Some other patients are referred for TTE, but then the operator is unable to image the heart sufficiently clearly, and so they are referred-on for TOE.

Traditionally, the lead operator undertaking TOE has been a clinician, often a consultant cardiologist—an expensive and severely constrained resource in the NHS—as has been the case at NWAFT. However, there is increasing appreciation of the potential value and professionalism of clinical cardiac scientists, and the profession has grown considerably over the past few years, with increased responsibility and workload. Roles are widening, and the number of scientist-led services in echocardiography is growing, including heart valve clinics, stress echocardiography, contrast/bubble echocardiography clinics and (less commonly) TOE services.

The NHS faces severe staffing shortages; as many as 10% of posts are unfilled in some roles and regions. The GIRFT (Getting It Right First Time) report for cardiology highlights that this shortage also extends to consultant cardiologists and cardiac clinical scientists. The report suggests that there should be an Urgent 7/7 TOE service with the support of a nurse. Our trust currently cannot provide this. It also suggests that achieving this coverage requires a national programme to expand the echocardiography workforce. Responding to these pressures, there is a pathway for cardiac physiologists to become clinical scientists and so able to register with the Health and Care Professions Council. This is via MSc-level Scientist Training Programme training positions or equivalence through the Academy for Healthcare Science.

GIRFT also suggests innovative use of the existing workforce, such as expanding the roles of cardiac clinical scientists. The report highlights successful examples of efficiency gains through switching to non-medically led services, with a consultant cardiologist available to support as needed. To take over such roles from consultants, clinical scientists must undergo advanced training. The National School for Healthcare Science has a new 18-month programme, the Echo Training Programme, to increase the number of echocardiographers by enabling cardiac scientists/physiologists to widen their roles, for example, performing more TTE and freeing some clinical scientists to do more specialised work like TOE.

A scientist-led service in TOE is not novel—a number of other NHS hospitals in the UK have instituted this approach. Our informal discussions with cardiac scientists from other trusts suggest these services operate successfully, but that training and standard operating procedures differ somewhat. There is no standardised training protocol for TOE advanced training (we suggest an outline of training for clinical scientists in TOE in online supplemental appendix A). Our literature search found no published studies or data on clinical-scientist-led TOE services.

Within echocardiography services, scientist-led TOE is less established than in other areas such as stress echocardiography or specialist valve clinics. This because TOE is semi-invasive and so carries greater risk. While clinical scientists in cardiac science perform some fully invasive techniques (such as implantation of loop recorder monitoring), scientist-led TOE requires simultaneous responsibility for the patient’s sedation and for analysis and interpretation of the results.

Staff retention is also challenging. In addition to workload pressures, cardiac clinical scientists have been demotivated by limited further career development, progression, research and education opportunities; this has led to an increasing number leaving the NHS to work through agencies or for private-provider companies. One recognised way to improve motivation and retain staff is to extend scientists’ responsibilities through the development of cardiac-scientist-led clinics, as reported to have been done to a greater extent in other echocardiography services. Thus, we believe extending this through TOE services could contribute to the retention of scientific staff in the NHS.

There has been a little use of QI in cardiac science more widely, for example, increasing activity in transthoracic echocardiography, reducing inappropriate echocardiography in paediatrics, patient/carer compliance with follow-up after fitting an implantable device also in paediatrics, increasing efficiency in cardiac catheterisation and improving process of care and outcomes generally in a developing country.

MEASUREMENT

The process flow for the service is outlined using process mapping20–23 in figure 1. Prior to the project, the consultant cardiologist operated the probe in the patient’s oesophagus and I (lead author, NK, cardiac clinical scientist) supported acquiring images on the echocardiography machine. We were supported by a cardiac nurse.

During the COVID-19 pandemic, the TOE service (classed as an aerosol-generating procedure) was temporarily suspended. Once we restarted, it took a while for the system to return to regular pre-COVID-19 operation. It had done so by summer 2021, and we used data from July 2021 to March 2022 for our baseline and root cause analyses.

For goal 1, reducing waits for TOE, we set up two outcome metrics (OMs): OM1in, the time from referral to TOE for inpatients; and OM1out, the same for outpatients (figure 1). Figure 2 shows these in individuals (I or X) statistical process control (SPC) format24 25 Baseline data show mean waits of 7.7 and 33.2 working days (Monday–Friday), respectively, well beyond our self-set targets of 3 and 14 days and with considerable variation. Useful process metrics (PMs) here were PM1n, the number of slots we could schedule for TOEs (capacity), and PM1w, the proportion of these not used for TOE (‘wasted’). The baseline values were PM1n=6 per month (fortnightly lists of 3 TOE slots each), and PM1w=7/54=13% wasted. Waste slots include patient did-not-attend (DNA), but also bookings turning out to be for inappropriate referrals, discovered through review on the day of the procedure (so too late to backfill). However, the reasons for unused slots were not documented, so we were unable to break this down retrospectively.

Goal 2 was to improve the success rate of intubation (OM2), with postulated drivers being the amount of sedation (midazolam) administered (PM2) and the operator (see online supplemental figure S3). Figure 2 shows PM2, in run chart format25 with baseline median=3 mg (mean=2.92 mg), and picks out cases where the patient struggled to tolerate the probe leading to intubation failure (TOE abandoned) or complications (taking extra time and often requiring additional medication such as pethidine). As shown, the baseline intubation failure rate (OM2) was 4/36=11%; adding complications takes this to 17%.

Goal 3 was to free consultant cardiologist time by releasing them from the TOE service. We can estimate the hours consumed. A TOE procedure usually takes around 60 min, including patient preparation (cannulation, consent, checking previous history). Later, time is required for discussing the results with the patient, results reporting and patient discharge. A morning session would typically run 09:00–12:00, that is, 3 hours, but can overrun. The cardiologist would then typically spend the afternoon analysing the cases, reporting, letter-writing, discussing with patients and discharging them—another 3 hours. Therefore, substituting with a clinical cardiac scientist as the main procedure-operator for a list would release approximately a day of consultant cardiologist time. As per PM1n, with the consultant-led service, we were scheduling two lists each month, thus consuming around 2 days of consultant cardiologist time per month.

Goal 4 was to improve reporting. We found that outpatients’ results were reported in a letter, while inpatients’ results were written in the patient’s notes. Examining our baseline data revealed that there was no standardisation in reporting; fewer than half of our TOE investigations were fully documented on the reporting system, meaning other healthcare professionals could not access analysis and results for some patients. No audit or quality assurance system was in place.

I (lead author, NK), as the person most involved with TOE, used a fishbone diagram26 to capture my perceptions on potential root causes of the problem goals 1, 2 and 4 aimed to address (long patient waits, intubation failures and less-than-idea reporting), see online supplemental figure S1. A 4N chart and niggle-o-gram27–29 captures and ranks perceptions gathered from a focus group of clinical scientists and cardiac nurses in the department, see online supplemental figure S2 and table S1. The top ‘niggles’ (from clinical scientists and cardiac nurses) were about long patient waits and access (staff were very aware of the long waits for TOE and TTE, NWAFT figures were noted at the start of this paper), with frustration with inefficiencies in the TOE process flows.

To give an overview of the resulting cause–effect relationships hypothesised, we developed a driver diagram,30 see online supplemental figure S3. This ‘causal map’ naturally was refined during the project, with C1 and C2 being refinements from the basic idea (A) of the scientist taking over operation of the TOE probe. When we changed the patient information leaflet (E), we took the opportunity to include a patient satisfaction questionnaire to check for adverse impacts of the change on patient experience, and to look out for any other potential further changes. We also considered potential barriers and actions that might help overcome them (online supplemental table S2).

DESIGN

This QI project was conducted by a small team consisting of the service manager, consultant cardiologist and cardiac nurse, led by the first author (NK, a clinical cardiac scientist). The team worked closely to enable me to collect the data. All reviewed the baseline data and analyses (figures 1 and 2 and online supplemental file 4).

Reviewing the process map, SPCs and fishbone diagram, it was apparent that there was waste capacity from slots cancelled on the day a booking was found to be an inappropriate referral. On-the-day cancellations can be confusing and distressing for patients.31 We also had some lists with two outpatient TOEs plus one reserved for potential inpatient requests, with the latter sometimes
Figure 2  Metrics over time. PDSAs 3–5 not shown as not targeting these metrics. BM, balancing metric; OM, outcome metric; PM, process metric; PDSA, plan-do-study-act cycle; TOE, transoesophageal echocardiography; TTE, transthoracic echocardiography.
not needed, and also some wasted time in the workflow (figure 1)—which can result in unnecessary list overruns.

The team identified six change ideas (A–E). See also the driver diagram (online supplemental figure S3). (Note: the initial idea driving the project was A; the others came up during the project as opportunities from, or refinements to, the initial idea. They are discussed in the order in which they are labelled on online supplemental figure S3.)

**Change idea A**

A clinical cardiac-scientist replaces the consultant cardiologist as lead for the service and TOE probe operator during sessions.

Frequently, there were long waits for the cardiologist (much in demand for other tasks) (figure 1). Their availability also restricted the service to run a list only fortnightly. If a slot was unused, then that capacity would be wasted.

The core improvement idea was to release the consultant cardiologist with me (NK) stepping-up to be lead operator in their place. I already had the necessary training and experience (see online supplemental appendix A for notes on TOE training and accreditation). Clinical support is available onsite for any serious complication. The cardiac nurse was also deemed competent in delivering sedation through their experience and training. For their further development, the cardiac nurse will be present during the consent process and discussion of the results. To replace me in acquiring the echocardiography images, we would need a second clinical scientist/cardiac physiologist.

We predicted this would have a positive effect on the TOE service in many ways (online supplemental figure S3). Though it would put more pressure on the department by pulling in a second scientist/physiologist, this would be outweighed by the liberated high-value consultant cardiologist time.

No longer being constrained by cardiologist availability, we could run weekly lists, increasing capacity from 6 TOEs per month to 12 (3 TOEs per list), though initially limiting lists to 2 TOEs (so 8 per month) as we develop the service while ensuring patient safety. We aim to perform 12 per month once the consultant cardiologist and the cardiac scientist are satisfied. The greater capacity and shorter gaps between lists should reduce waits. A further advantage of having a scientist lead is that any unused TOE-list time (which was wasted previously) could be used for inpatient TTEs (so these could be done more quickly).

**Change idea B**

Clinical scientist review of TOE referrals before booking.

Previously, the cardiac nurse would book all patients referred to the TOE service. There is patient risk associated with TOE, so it is important for patients to only have the investigation when required. On taking over the service (idea A), I found TOE was not appropriate for several patients arriving for appointments, so I cancelled them, which is poor patient experience and left unused TOE slots, or I performed TTE on them instead.

The change idea was for the cardiac nurse to print off referrals for my review before booking. This would increase activity (used slots), reduce unnecessary risk to patients and also allow me to prioritise inpatients (who are more urgent).

**Change idea C1**

Release the second cardiac clinical scientist.

After taking on the lead role (idea A), I realised we could rearrange the room, putting the echocardiography machine on the same side as the TOE equipment, so I could operate both, without this compromising performance. We could therefore refine idea A, freeing the second scientist for other services—for example, instead of being present for a TOE list they could run a TTE list (approximately five procedures).

I predicted that this would not affect TOE performance metrics. TOE is a core part of my expertise and training, and performing both roles (manipulating the TOE probe and acquiring the images on the echocardiograph) is demanding but feasible, and would be efficient as I know exactly what images I wish to acquire.

**Change idea C2**

Use a nursing assistant.

The above refinement resulted in only two of us in the room for sessions, which we found challenging for patient management. So a further refinement was to obtain support from a nursing assistant during the TOE procedure. (The nursing assistant already performed procedure checks at check-in such as ECG, blood pressure, oxygen saturation.)

**Change idea D**

Reduce patient sedation.

As noted in the Background section, there is interest among TOE specialists in the impact of the degree of patient sedation on the success of intubation (and so of the whole procedure). We shared the view that light sedation tends to be more helpful than heavy. Taking over the service gave me and the cardiac nurse the opportunity to put this into practice.

**Change idea E**

Change patient information leaflet and include satisfaction form.

The patient information leaflets stated that the procedure would be performed by a doctor (consultant cardiologist); we should change this to ‘by a senior clinical scientist in echocardiography or a consultant cardiologist’ to inform them, in advance of consent and to avoid creating confusion or anxiety. To investigate whether the new process was producing poor patient experience, we could also include a patient satisfaction survey and also take the opportunity to ask for experience-improvement suggestions.
The economic impact of the project was not a material consideration in the change and we did not model or evaluate this. However, the difference between the initial service and the final design (from a consultant + a clinical scientist, to a clinical scientist + a nursing assistant) is clearly substantial. A back-of-the-envelope analysis suggests net salary savings of the order of 40%. The future trajectory is for the cardiac scientist specialising in TOE to become a consultant cardiac scientist (this is the purpose of the national Higher Specialist Scientist Training (HSST) programme). With this eventual salary uplift, we estimate the net salary savings would be of the order of 25%.

**STRATEGY**

Over the course of this QI project, we tested and refined the change ideas over five PDSA cycles, summarised in table 1.

Every week, I met with the consultant cardiologist to review the project results, for audit and governance. This helped guide whether further refinement or training was required. I also gathered feedback from the wider team to check their experience.

**PDSA1**

Test change idea A (clinical scientist replaces the consultant cardiologist as lead operator) and change idea D (reduce sedation)—which we predicted would impact on different outcome metrics.

We released the consultant cardiologist, pulling in a second clinical scientist instead, and started weekly lists: capacity (PM1n) increased from six to eight TOEs per month. As shown in table 1, this was successful in reducing waits (OM1in and OM1out) during this cycle, but not sufficiently to meet our targets. We discuss the logic behind the SPC analysis in the Results section and online supplemental appendix C. With the PDSA1 data, there were insufficient data to justify recalculating the SPC limits for OM1in, but there were for OM1out (see figure 2).

We met the intubation target (0% failures). There were many slots wasted during this cycle (7 of 24=29%, see the Results section for discussion). However, my time was ‘less wasted’ as I could move to inpatient TTE work to help reduce these waits (light blue on the bottom graph in figure 2).

We also used lower volumes of sedative (PM2) and observed improved intubation outcomes (OM2).

**PDSA2**

Test change idea B (clinical scientist review of TOE referrals prior to booking).

I took this on, with guidance from the cardiologist when unsure or needing clarification. I predicted that this would solve inappropriate bookings, reducing wasted slots (PM1w). However, this was more of a challenge than I anticipated, with some referrals requiring more clinical input from the cardiologist.

Disappointingly, PM1w remained at the same rate as the baseline (13%). However, as shown in figure 2, it is lower than during PDSA1 and has allowed greater activity, further reducing the waits during this cycle by inpatients (OM1in) to a mean of 2.1 (working) days and by outpatients (OM1out) to 8.3 (working) days, within our targets of 3 and 14 days.

Now there was sufficient evidence and data to recalculate the SPC for OM1in, and we decided to assign the recalculation point to PDSA1, and enough evidence for provisional recalculation for PM1out once again at PDSA2 (see figure 2).

Note: the other PDSA cycles were relatively small refinements to the process, not impacting on the core results.

**PDSA3**

Test change idea C1 (avoid requiring second cardiac clinical scientist).

I took on the task of acquiring the echocardiogram images, so the second clinical scientist was not needed. This avoids the scientist-led TOE service putting more pressure on our other services, in particular TTE.

I predicted that this would not affect the TOE sessions. This proved generally to be the case, but I learnt that I had to ensure everything was in the correct position before starting the procedure and needed to be able to focus on the technical aspects. Importantly, if I needed assistance with the patient (manipulating their head or administering additional sedation if they were not tolerating the TOE probe well), I discovered this put a lot of pressure on the cardiac nurse. We, therefore, requested the support of a nursing assistant to focus on patient safety.

**PDSA4**

Test change idea C2 (use a nursing assistant to help with patient management).

This further refinement to session staffing was agreed. Experience (observation) showed this was satisfactory.

**PDSA5**

Test change idea D (change patient information leaflet and include satisfaction form).

We made it clear in the leaflet that a clinical scientist rather than a doctor (consultant cardiologist) would generally be performing the TOE procedure, and designed a patient satisfaction questionnaire. This change was not designed to impact operational performance. As expected, we did not pick up any patient unhappiness.

**RESULTS**

Our PDSA cycles covered 32 used TOE slots, with 14 of these being under the final process configuration.

Goal 1 was to reduce both inpatient and outpatient waits for TOE. The weekly (rather than fortnightly) lists and increased capacity allowed us to do this. In online supplemental appendix C, we describe how we decided on the SPC analyses of OM1in and OM1out presented in figure 2, as far as possible following methodological
Table 1  PDSA improvement cycles

<table>
<thead>
<tr>
<th>PDSA cycle</th>
<th>Plan/prediction</th>
<th>Do</th>
<th>Study</th>
<th>Act</th>
<th>Time required (months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td></td>
<td></td>
<td>OM1: 7.7 days; OM1out: 33.2 days</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>OM2: 11% intubation failures</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>PM1n: 6 TOE slots per month</td>
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<td></td>
<td></td>
<td></td>
<td>PM1w: 13% slots wasted</td>
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<td></td>
<td></td>
<td></td>
<td>PM2: 2.92 mg of midazolam (median 3 mg)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Institute a clinical scientist led service, extending role (CI A) and reduce sedation (CI D). This will improve OM1 (reduced waiting times due to more capacity, PM1n) and OM2 (greater intubation success rate).</td>
<td>Clinical cardiac scientist as lead operator</td>
<td>Clinical cardiac scientist/physiologist in support (image acquisition)</td>
<td>Clinical cardiac scientist as lead operator</td>
<td>Do not recalculate the SPC limits for OM1in; recalculate for OM1out.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Weekly TOE lists (capacity 6 → 8 TOEs per month)</td>
<td>Weekly TOE lists (capacity 6 → 8 TOEs per month)</td>
<td>Make permanent change: Capacity=8 TOEs per month; Cardiologist 2 days a month released; Continue lower sedative.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Unused slots → TTE</td>
<td>Unused slots → TTE</td>
<td>Inappropriate bookings: institute referral review</td>
</tr>
<tr>
<td>2</td>
<td>Institute review of referrals prior to booking and give priority to inpatients (CI B). This will further improve OM1 (by reducing slots wasted, PM1w, by reducing inappropriate bookings).</td>
<td>Cardiac nurse prints referrals.</td>
<td>Reviewed by clinical scientist</td>
<td>Appropriate cases booked, prioritising inpatients</td>
<td>Recalculate SPC for OM1in, (at PDSA1). Provisional recalculation for OM1out at PDSA2.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Clinical scientist (lead operator) and cardiac nurse share image acquisition.</td>
<td>Do not require a support clinical scientist.</td>
<td>Continue lower sedative.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>No change to performance metrics (success!)</td>
<td>No change to performance metrics (success!)</td>
<td>This will improve OM1 (reduced waiting times due to more capacity, PM1n) and OM2 (greater intubation success rate).</td>
</tr>
<tr>
<td></td>
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<td></td>
<td>Release 2nd clinical scientist from here on. Technical success, but care management is difficult with challenging patients: refine</td>
<td>Release 2nd clinical scientist from here on. Technical success, but care management is difficult with challenging patients: refine</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Reassign roles to avoid need for a support (2nd) clinical scientist (CI C1). Can be done without reducing performance Frees resource for other departmental services.</td>
<td>Clinical scientist (lead operator) and cardiac nurse share image acquisition.</td>
<td>Do not require a support clinical scientist.</td>
<td>No change to performance metrics (success!)</td>
<td>No change to performance metrics (as expected)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Easier patient management—successful</td>
<td>Easier patient management—successful</td>
<td>Patient feedback confirms new process is not upsetting patients</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Worthwhile improvement, additional role justified, retain as permanent change.</td>
<td>Worthwhile improvement, additional role justified, retain as permanent change.</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Add nursing assistant role to help with manipulation of patient’s head and ensure safety is maintained (CI C2). Easier management, especially of challenging patients.</td>
<td>Add nursing assistant role.</td>
<td>Add nursing assistant role.</td>
<td>Discuss with stakeholders.</td>
<td>Discuss with stakeholders.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Easier patient management—successful</td>
<td>Easier patient management—successful</td>
<td>Change the information leaflet.</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Worthwhile improvement, additional role justified, retain as permanent change.</td>
<td>Worthwhile improvement, additional role justified, retain as permanent change.</td>
<td>Include a patient satisfaction form with appointment letter.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Easy way to seek patient ideas for areas of improvements.</td>
<td>Easy way to seek patient ideas for areas of improvements.</td>
<td>No change to performance metrics (as expected)</td>
</tr>
<tr>
<td>5</td>
<td>Add ‘clinical scientist’ as TOE operator on patient information leaflet and institute patient satisfaction form to assess experience and gather patient suggestions (CI E). Patients will be reassured.</td>
<td>Add ‘clinical scientist’ as TOE operator on patient information leaflet and institute patient satisfaction form to assess experience and gather patient suggestions (CI E). Patients will be reassured.</td>
<td>Add ‘clinical scientist’ as TOE operator on patient information leaflet and institute patient satisfaction form to assess experience and gather patient suggestions (CI E). Patients will be reassured.</td>
<td>No change to performance metrics (as expected)</td>
<td>No change to performance metrics (as expected)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Worthwhile information, retain as permanent change.</td>
<td>Worthwhile information, retain as permanent change.</td>
<td>Patient feedback confirms new process is not upsetting patients</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Easy way to seek patient ideas for areas of improvements.</td>
<td>Easy way to seek patient ideas for areas of improvements.</td>
<td></td>
</tr>
</tbody>
</table>

The mean waiting times for inpatients (OM1in) are down from 7.7 days to 3.0 days. This meets the internal target we set (3 days); however, this is the mean, so the system is not capable of reliably meeting the target for each patient. The data may suggest some further improvement following PDSA2, but do not yet have enough data

guidance.25 32 Though we have fewer than the 20 data points recommended to construct the baselines (we have 17 and 19 points, respectively), and would like more data following PDSA2, we are limited by maternity leave and data-system limitations. Nevertheless, we argue in the appendix that our analyses are robust.
to make a robust claim. For outpatients (OM1out), the mean is down from 33.2 days to 8.3 days. Our analysis (online supplemental appendix C) shows that the system has been improved further than it had been in PDSA1, but the limited number of datapoints means that this is a trial or provisional estimate until we have more data (the guidance is 12 data points25). This (provisionally) meets the (internal) targets we set ourselves (14 days) and appears (again, provisionally) to be capable of meeting the target reliably (the upper process limit, which shows the range of expected random variation, does not exceed the target).

We noted earlier that rapid diagnosis for inpatients is particularly important, both for diagnosis and for patient flow through the very-congested acute hospital system. We plan to increase our TOE lists from 2 back to 3 slots, so a capacity of 12 per month. We now have the staff capability and capacity to consider running a second list later in the week if inpatient TOEs arise. This would increase capacity by up to a further 12 per month. It would be covered by a consultant cardiologist, or a second fully TOE-trained cardiac scientist. This would also help cover annual/sick leave. This will give us added reliability in coping with demand peaks.

It is disappointing that the wasted TOE slots (PM1w) after the project remained at 13%, as during the baseline. There will always be some ‘lost’ TOE slots, for example, due to DNAs, late-notice cancellations, on-the-day decision by a patient to refuse TOE but agree to TTE in that slot instead. The jump to 29% during PDSA1 was probably random variation. However, now I am running the service, I can use unexpectedly unneeded TOE time to perform inpatient TTE instead.

Review of referrals late in the week (when I’m not in the department) for the next list (Monday morning) is difficult. We may refine idea B, for example, reviewing such cases by video call or (preferably) by the consultant.

We have been very successful on goal 2, reducing intubation failures from 11% to 0%; including cases with complications gives 17% to 0% (OM2, figure 2). I can use lower sedation levels (from a median of 3 mg to 1.5 mg of midazolam) and get better outcomes. Under the old procedures, the cardiologist would sometime use pethidine and metoclopramide in addition to midazolam. In our prechange baseline, there were cases with 5mg of midazolam and/or additional sedation medications—in three of these, flumazenil had to be used to reverse sedation effects, which is undesirable. Though our sample is fairly small (n=69 with only four failures), and the observational nature of our data means we cannot add the change in operator as a covariate, statistical analysis suggests some tentative evidence of association between sedation volume and intubation success (see online supplemental appendix B).

Intubation failures are something that we aim to make a rare event. The G-chart is a form of SPC chart designed for situations such as this, using the number of successful cases between successive failure cases as its metric.25 This is a tool we plan to use for monitoring in future, and we have constructed one with our current (so far limited) data (see online supplemental figure S4 and accompanying notes).

Goal 3, freeing the consultant cardiologist’s time, has been completely successful. We estimate this is 2 days per month (decreased a little by covering my leave and providing support with assessing some of the referrals.) This high-level assistance of, and even substitution for, consultant-grade doctors’ tasks is the pinnacle of the UK’s Modernising Scientific Careers workforce-development strategy36 and its highest-level training component: the doctoral-level HSST programme.34 We have done this while increasing capacity and without requiring any additional staff input, other than some nursing assistant time.

Goal 4 was to improve BSE reporting-guideline compliance. Since launching our scientist-led service (PDSA1), all TOE cases are reported to BSE standards and promptly uploaded onto the database. Previously, around 20–30 images would be stored from each imaging; now, we store 60+, giving us reassurance that we have much better coverage. We are satisfied there has been no loss of image quality. A formal quality assurance is in place for any new service audit is in preparation: the imaging lead will review all complex cases with the clinical cardiac scientist including patient history/treatment options to ensure the best possible outcome for the patient. This will also provide continuous training and development for the clinical scientist.

As an added reassurance to patients, as a last PDSA, we updated the information leaflets about the process and staffing; as reassurance to us, we also instigated a patient satisfaction questionnaire. This has shown us that patients are happy with a clinical scientist as TOE operator (rather than a consultant cardiologist). I am also able to better coordinate follow-on TOE investigations arising from our other services, such as the heart valve monitoring clinics. Patients who had experienced the old service mentioned appreciating this continuity of care. All patients have reported a positive experience.

Staff have fed back that the changed service has led to other benefits, including increased utilisation of extended roles, staff motivation, career development and opportunities for more advanced services. This has helped us recruit more staff recently, including locum staff applying for a full-time position mentioning career-development opportunities.

**LESSONS AND LIMITATIONS**

This project has been very valuable for the cardiac investigations department. In addition to improved performance, directly benefiting patient treatment, inpatient flow and consultant cardiologist capacity, we have an exemplar project to help colleagues to learn about QI—which has already inspired other clinical scientists to become involved in QI and research projects.
Generally, there can be barriers in persuading colleagues and clinicians that clinical scientists are fully capable of extended roles and changing attitudes to our involvement. We were pleasantly surprised, therefore, to encounter no resistance to change nor negativity from any healthcare professional in our trust.

While our new process is ‘lean’ in making the most of staff skills,\textsuperscript{16} it is important to remember that the core of any healthcare professional in our trust. involvement. We were pleasantly surprised, therefore, to capable of extended roles and changing attitudes to our colleagues and clinicians that clinical scientists are fully desirable for each phase. There is a trade-off between waiting list and long waiting times (at NWAFT along for echocardiography remained high, and the large reduced demand or increased staffing levels. Demand for echocardiography remained high, and the large waiting list and long waiting times (at NWAFT along with many other hospital trusts\textsuperscript{5}) were noted at the start of this paper. Staffing for the service was not increased during the project—in fact a key benefit was the reduced demand on high-value clinical staff capacity.

CONCLUSION
This QI project used the MII to explore and refine change ideas to improve our TOE service by redesigning the clinical scientist role to increase capacity and so greatly reduce patient waits. This project has been successful, achieving its aim, and is proving to be safe and efficient with increased activity. Additional benefits include freeing considerable consultant cardiologist time for higher-value work and providing an enriched role for me as a clinical scientist (on the track to becoming a consultant clinical scientist through the HSST programme). We intend to continue developing our TOE service, including presenting TOE cases in multidisciplinary team meetings to assist with clinical decision-making about treatment pathways. The experience and results also encourage us to extend roles elsewhere in our department.

Twitter Grazia Antonacci @graziantonacci

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Contributors NK, MP and RS developed the service. NK collated the data and conducted the analyses with support from NP. NK led on the write-up with input from GA and NP. All authors contributed to writing, reviewing and editing the manuscript. NK is the guarantor.

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ORCID iDs Grazia Antonacci http://orcid.org/0000-0001-7742-8003 Nathan Proudlove http://orcid.org/0000-0002-1176-8088

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Appendix : Notes on training requirements for clinical cardiac scientists in TOE

Nikki Kaye, 2023

The clinical cardiac scientist will need a mentor to support them through the process of TOE training. Almost inevitably this will be a clinician, usually a cardiologist. The mentor should be accomplished in TOE, ideally with accreditation from the British Society of Echocardiography (BSE) or equivalent.

Training BSE accreditation

The BSE provides an accreditation process designed to set standards for, and test competence in, performing and reporting TOE studies. Their accreditation process is run as a service for practising echocardiographers. Though it is not compulsory or a regulatory requirement, it is recognised nationally and internationally as a mark of competence.

The BSE suggests that continuing education must be provided for TOE operators, and each operator must perform or directly supervise at least 50 studies per annum. It is the responsibility of the operator to monitor and keep evidence of continuing education.

BSE accreditation and training requirements

- A centre must have a designated Head of TOE who must have the BSE/ACTA or EAE TOE accreditation. They will be responsible for appropriate training for other operators.
- The Head of TOE should allow a reasonable length of time (for example 2-3 years) to achieve TOE accreditation, or will be given the opportunity to transfer the TOE lead role to a suitably experienced and TOE-accredited colleague.
- All primary operators must have, or be working towards, BSE/ACTA TOE accreditation.
- The accreditation process requires the candidate to submit a log-book and pass a written examination within a continuous 24-month period.
- Outpatient TOE studies must have an operator with appropriate training and with support of a nurse experienced in managing airways.
- For the full TOE accreditation process, see the BSE TOE accreditation pack: [www.bsecho.org/Public/Accreditation/Personal-accred/Personal-accreditation.aspx](http://www.bsecho.org/Public/Accreditation/Personal-accred/Personal-accreditation.aspx)

Maintaining BSE accreditation and appropriate skills

- An operator needs regular protected lists (at least 2-3 per month)
- Continuous membership of the BSE
- Re-accreditation is required every 5 years, examining evidence of continuing clinical activity, distance learning and attendance at courses and conferences.
Additional training and skills required

All clinical cardiac scientists should complete additional training outside the BSE TOE accreditation to ensure competency and to ensure that their job descriptions are reviewed to reflect their new responsibilities.

A suggested training plan for additional training for the clinical scientist is outlined below. This assumes a significant level of experience in regularly consultant led TOE and competency with additional. Required skills.

1. Observation - Regular observation in consultant led TOE is required to understand the process of the procedure and increase the knowledge of the additional anatomy seen on TOE. In addition, regular observation in reporting with consultant

2. Practical under direct supervision

3. Intubation skills

4. Informed consent

5. Cannulation training

Table 1: Summary of the requirements for scientist-led TOE service.

<table>
<thead>
<tr>
<th>Task</th>
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<tbody>
<tr>
<td>Clinical Scientist must obtain:</td>
</tr>
<tr>
<td>➢ HCPC registration</td>
</tr>
<tr>
<td>➢ BSE TOE accreditation</td>
</tr>
<tr>
<td>- Case studies (part of BSE accreditation)</td>
</tr>
<tr>
<td>- Exam (part of BSE accreditation)</td>
</tr>
<tr>
<td>Advanced training for clinical scientist includes:</td>
</tr>
<tr>
<td>➢ Regular observation in consultant-led TOE – understand the process and increase knowledge of the additional anatomy seen in TOE.</td>
</tr>
<tr>
<td>➢ Supervised practical skills (minimum 12-18 months)</td>
</tr>
<tr>
<td>➢ Intubation training and manipulation (12-18 months)</td>
</tr>
<tr>
<td>➢ Informed consent</td>
</tr>
<tr>
<td>➢ Cannulation training</td>
</tr>
<tr>
<td>➢ Have a patient specific directive (PSD) in place for conscious sedation if the scientist is responsible for sedation.</td>
</tr>
<tr>
<td>➢ Continuous development and training</td>
</tr>
<tr>
<td>Cardiac Nurse to lead sedation:</td>
</tr>
<tr>
<td>➢ Regular observation in consultant led TOE</td>
</tr>
<tr>
<td>➢ Supervised practical skills of safe sedation</td>
</tr>
<tr>
<td>➢ Good communication with the clinical scientist</td>
</tr>
<tr>
<td>➢ Be ALS trained (or ISL if the clinical scientist is ALS trained)</td>
</tr>
<tr>
<td>Organisation</td>
</tr>
<tr>
<td>➢ Approval from governance</td>
</tr>
<tr>
<td>➢ Sign off Patient Group Directive (PGD) if the cardiac nurse is responsible for safe sedation.</td>
</tr>
<tr>
<td>➢ Standard Operating Procedure (SOP)</td>
</tr>
</tbody>
</table>
Quality assurance and audit

Formal audit process must be in place. In centres with several TOE operators interval re-reporting of studies and/or comparison against surgical results is adequate.

A formal quality assurance system should be in place including: weekly review meetings, regular process audits consisting of blind over reading of selected studies to ensure compliance with departmental minimum standards, regular audit projects to check consistency of interpretation such as requiring all team members to report a set of images, outcome audit against other modalities or surgical results. Regular meetings, ideally weekly, must be held to review unusual, challenging or otherwise difficult cases. There must be established processes issuing appropriately revised reports as a result of multi-disciplinary team discussions.
Appendix B – Statistical Analysis

The QI project involved changing from a ‘Pre’ regime, under which the Consultant Cardiologist decided the volume of sedative and operated the TOE probe, to the ‘Post’ regime, under which the Clinical Scientist took over both tasks, so there are two independent variables Sedation and Operator. The outcome is an intubation Success or Failure.

Figure 2 in the main paper shows both the volume of sedative and the outcome (intubation success of failure) across the project.

In this appendix we apply some further statistical tools, but with great caution since i) we have a limited amount of data and ii) it is observation data (from a natural rather than designed experiment).

Contingency Table

<table>
<thead>
<tr>
<th>Sedation (mg)</th>
<th>Pre</th>
<th></th>
<th>Post</th>
<th></th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Success</td>
<td>Failure</td>
<td>Total</td>
<td>Success</td>
<td>Failure</td>
</tr>
<tr>
<td>0.5</td>
<td>0</td>
<td>0</td>
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<td>1</td>
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<tr>
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<td>3</td>
<td>0</td>
<td>3</td>
<td>9</td>
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<td>5</td>
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<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>3.0</td>
<td>12</td>
<td>0</td>
<td>12</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>3.5</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4.0</td>
<td>6</td>
<td>1</td>
<td>7</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4.5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5.0</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>33</td>
<td>4</td>
<td>37</td>
<td>32</td>
<td>0</td>
</tr>
</tbody>
</table>

Table B1 : Outcome by Sedation volume and Regime (Pre = Consultant, Post = Clinical Scientist)

The data are too sparse to look at both Operator and Sedation. We can though consider the association of the Sedation with the outcome, assuming no effect of Operator and no systematic difference between the patients under the two regimes.

Impact of Sedation

Note: Sedation was administered in units of 0.5mg. The X-Y graph below uses jittering (adding a small amount of random noise to the data display) to avoid overprinting; the histogram uses ‘dodging’ (showing the split data offset) also to avoid overprinting.

Analysis of Volume of Sedation

We can see that

- the Sedation does tend to be different by regime (Pre vs Post)
in Table B1 and the histogram in B2 (and the Mann-Whitney test give \( p < .005 \)) – under the Post regime less Sedation tended to be administered (by the Clinical Scientist) than in the Pre regime (by the Consultant). The medians are 1.5mg vs 3.0mg.

Analysis of Outcome by Volume of Sedation

![Probability of Successful Insertion vs Sedation](image)

**Figure B1 upper:** scatterplot with probit and logit fitted curves; lower: histogram (note: data are jittered or dodged around the actual values which are multiples of 0.5mg)

Attempting binary regression to model the outcome (Success / Fail) from the Sedation, by fitting the logit model (logistic regression):

\[
P(\text{Success}) = \frac{1}{1 + e^{-(b_0 + b_1 \text{Sedation})}}
\]

And the probit model:

\[
P(\text{Success}) = \Phi(b_0 + b_1 \text{Sedation})
\]

where \( \Phi \) is the cumulative distribution function of the standard normal distribution.

Give almost identical results, as shown in Figure B1 (upper), with

- Sedation being statistically significant (\( p=.015 \)) in both.
Using cross-validation[1] (with k=2 folds, because the dataset is fairly small, and 20 repeats), using the caret package,[2] gives Cohen's \( \kappa \) (kappa) of around .72 with standard deviations of around .17 (Monte Carlo techniques are used, so results differ slightly each time the procedure is run).

\( \kappa \) is a measure of correlation between raters (e.g. models vs observed) robust to imbalanced groups. Cohen suggested values of .61 to .80 indicate substantial agreement; a more recent suggestion is that .60 to .79 be regarded as moderate agreement.[3]

- We can therefore regard the logit or probit models as moderately robust (even with this small amount of data)

We might typically locate Sedation ≤ 4.5mg (i.e. as a threshold (P(Success) remains above 50%) but, given the impact on the patient and waste of resources from a failure (abandonment of the procedure), we might want to suggest a threshold with a much higher probability of success.

Experimenting with a conditional inference classification and regression tree,[4] suggests a threshold of Sedation ≤ 3.5mg, splitting our 58 datapoints with that level of Sedation and 100% success, versus the 11 above where success was 7/11 = 64%.

These analyses suggest this small study

- does support the hypothesis that Sedation volume is indeed associated with intubation success,
- and Sedation > 3.5mg should be regarded with caution.

References


Appendix C Consideration of SPC Analyses

Considering first OM1in – the inpatient waiting time from Referral to Receiving the TOE procedure (in days):

- We have 17 pre-change (baseline) datapoints, fewer than 20-25 (Mohammed et al, 2008) or 20-30 datapoints (Provost and Murray, 2022) recommended for XmR charts. This is unfortunate, but we cannot access more data retrospectively. It is a limitation and a learning point.

- If there are fewer than 12 datapoints a run chart should be used instead (Provost and Murray, 2022), but we have more than this.

- With fewer than 20 datapoints for a baseline we should regard the SPC centre line and process limits as 'soft' or 'provisional' (Mohammed et al, 2008) or ‘trial limits’ (Provost and Murray, 2022); this is more important for the XmR (as we are using) than for other SPC formats (Provost and Murray, 2022, pp.141-143, 165). It is recommended that a more robust centre line and process limits are recalculated once 20 points are available (op. cit.).

- Provost and Murray (2022, p.142) give an example of progressing from a run chart (with n=11 points), to an individuals (XmR) SPC chart with trial limits that can be frozen and extended (when k=12 is reached), and then repeating for robust limits (when k=20 is reached).

- Applying this to our data, we have trial limits calculated from the pre-change data (k=17) and extended (purple) (left) and this repeated taking in 3 post-change points to reach k=20 (right).

\[ UL = 17.3 \quad CL = 7.6 \]
\[ UL = 17.0 \quad CL = 6.8 \]
\[ UL = 11.9 \quad CL = 3.6 \]
\[ UL = 12.6 \quad CL = 3.8 \]
• We observe, firstly, that the 3 extra points make very little difference to the centre line (mean) and limits (3 sigma).

• Secondly, it is important to note that whilst trial limits “may not be useful” especially for XmR (op. cit., p.143), “for any number of subgroups [i.e., for any number of datapoints] a special cause signal will be a valid indication of a process with important special causes”; “So, if we have used fewer that [sic] the advised number of subgroups to create limits and we still detect special cause we do not have to worry about “false” special cause signals.” (Provost and Murray, 2022, p.276).

• The left graph highlights Rule 1 beyond the limits special case on the mR chart, which should be looked at first (Provost and Murray, 2022, p.281). The right graph highlights only Rule 2 shift special cause on the X chart – though note that the NHS template tool will only trigger on 6+ or 7+ points one side of the CL rather than the 8+ usually recommended (op. cit, p.135), there are 7 on the right graph but 9 on the left.

• On possible conclusion (particularly if the baseline or intervention were unclear) would be to focus on the right-hand graph (and discount the <8 points of shift) and conclude that there had been no change.

• Instead, we would argue for lefthand graph
  • That the similarity between the limits of the two charts mean that the short baseline (k=17), left, is useful (the quote above was “may not be useful”; our emphasis added), so focus on the left graph.

• This lefthand graph triggers Circumstance 3 of the guidance on when limits should be recalculated: “When changes tested have resulted in desirable special cause (improvement) on a Shewhart chart... In this case the centreline and limits should then be calculated for the new process.” (Provost and Murray, 2022, p.145).

• This is also discussed (op. cit, pp.288-289) as the alternative causal strategy, to evaluate the impact of a known intervention [without automatically recalculating the limits at known changes], and guided by subject matter [domain] experts (op. cit, pp.273, 275).

• We then have to decide on when the change occurred. “Use special cause signals relative to the extended limits to decide if changes made after the baseline data have an important effect on the measure. If the pattern of data points suggests a change in performance, recalculate new limits to reflect the new process.”

• As the baseline data has < 20 datapoints, we might have fallen back on run chart analysis (Provost and Murray, 2022, pp.90+).
  • A baseline median can be built from any number of datapoints, but to use the probability-based rules for detecting change 10+ is recommended. We have that here (k=17).
  • Doing this we observe a strong signal of shift (the point on the median is ignored) - all counted datapoints post baseline are below the median: 13, far in excess of the 6 required in the guidance.
• Considering the left-hand SPC and the run chart, we argue that the best interpretation of the data is that a shift occurred – accounting for
  • the mR SC at the start of PDSA1
  • The pronounced shift on the run chart from the start of PDSA1
  • The SPC shift signal triggered by the last 9 of the PDSA1 and 2 datapoints

• “Use special cause signals relative to the extended limits to decide if changes made after the baseline data have an important effect on the measure. If the pattern of data points suggests a change in performance, recalculate new limits to reflect the new process.” (Provost and Murray, 2022, p.289).

• We thus recalculate at the start of PDSA1, which shows stable behaviour before and after, and the mR SC is filtered out as it is at the point of behaviour change.
• After the recalculation we have 14 datapoints, satisfying than the 12+ recommended for robust new process performance measures (Provost and Murray, 2022, p.276).

![Run Chart](chart.png)

CL = 3.0

• We have no evidence from the SPC of material change in behaviour in PDSA2, though note that the behaviour shows early visual signs of improvement (shorter times and less variation).

• This is the chart we use in Figure 2 for OM1in.
Repeating this for OM1out – the outpatient waiting time from Referral to Receiving the TOE procedure (in days):

- We have 19 pre-change (baseline) datapoints, only one fewer than the recommended minimum of 20, again unfortunate, but we cannot access more data retrospectively.
- The centre line and limits are little different if we use the first 20 datapoints to construct our centre line and limits rather than 20.
- In addition, the SPC diagnosis is identical: a very definitive shift around the time of the changes introduced in PDSA1.
• There is strong evidence to recalculate at PDSA1.
• We have 12 datapoints from PDSA1, so sufficient to recalculate, freeze and extend again.

• We now see 8 points (the last 8) below the new centre line.
• Remembering that, if we see a special cause, it is always a valid signal, we argue we are justified to recalculate again at PDSA2.

• Now (right) we see no special cause.
• This gives us new trial or soft centre line and limits to estimate the performance of the process.
• This is the chart we use in Figure 2 for OM1out.

• This gives us a mean waiting time of 8.29 days, or 8 if we use the median for that last segment of data (PDSA2) – a temporary run chart on the SPC until we have 12 datapoints (Provost and Murray, 2022, p.276).

• We could then argue that it would be useful to go back to OM1in and recalculate at PDSA2 also to reflect this new phase consistently across the ‘family’ of this pair of metrics (op.cit., p.277), but we have decided to be conservative and leave the recalculation only at PDSA1.
Figure S1: Fishbone Diagram

- **Policies and procedures**
  - No BSE accreditation
  - No adherence to national guidelines
  - No audit or governance
  - No discussions of referrals

- **Communication**
  - Reduced communication of patient pathway
  - No MDT meetings

- **Equipment**
  - Limited access to TOE
  - Staff not available
  - Not up to date with new guidelines

- **People**
  - Interruptions by colleagues
  - Incomplete training

- **Staff pressure and workload**
  - Incorrect referrals
  - Patients jumping the queue

- **Arrangement of responsibility to download images**
  - Training on the echo machines

- **Training on the acquisition of 3D images and measurements**

- **Causes for concern in the current TOE service resulting in reduced quality and effectiveness**
**Figure S2 : 4N Chart** demonstrating that staff were frustrated with the wasted time during a TOE and the increased patient waiting times (yellow = areas of focus for this QI project, IP = inpatient)

<table>
<thead>
<tr>
<th>Present</th>
<th>Future</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Nuggets</strong></td>
<td><strong>Nice ifs</strong></td>
</tr>
</tbody>
</table>
| - I feel supported in my role  
- I feel we can progress our roles and developments  
- We have a nice working relationship across the TOE team  
- I feel supported by the clinicians | - I would like to see advanced services for clinical scientists in other clinics  
- If all TOE referrals were triaged to avoid unnecessary referrals  
- It would be nice to start the TOE list on time and finish on time  
- I would like to be able to have availability for IP tests to have TOE  
- I would like to be able to get on with the clinic without long delays |

<table>
<thead>
<tr>
<th>Niggles</th>
<th>No Nos</th>
</tr>
</thead>
</table>
| - I feel we waste a lot of time during the TOE procedures and could spend our time doing other important work.  
- I get annoyed when there are no TOE results on the system  
- I get annoyed when I don’t know the reason for the TOE and previous history  
- I feel like an idiot trying to explain to the patient why we are waiting | - I don’t want to feel responsible for delays in appointments and/or impact the department.  
- I don’t like feeling guilty if we cannot find availability for a TOE especially if they are urgent.  
- I don’t want to feel nervous and anxious as I don’t know what the cardiologist wants me to do as no communication.  
- I don’t want to feel pressure that I cannot speak out as they are clinicians |
Figure S3: Driver Diagram
also locating the metrics (OM = outcome metric, PM = process metric, BSE = British Society of Echocardiography)

Interventions

Change Idea A
Clinical scientist as the main operator in TOE instead of consultant cardiologist

Change Idea B
Clinical scientist review TOE referrals to reduce wasted slots due to booking inappropriate patients

Change Idea C
Remove the 2nd cardiac clinical scientist whose role is to acquire images

Change Idea D
Change the patient information leaflets to inform that clinical scientist would be main TOE operator

Outcomes

- Cardiac Investigations Department performance
- Patient Satisfaction

Primary drivers

- Reporting vs BSE TOE guidelines
- Number of operators
- Number of available slots
- Efficient use of improve TOE capacity
- Appropriate Sedation
- Patients Informed and Reassured

Secondary drivers

- Training and education
- Leadership and monitoring
- Number of slots per week
- Flexibility of the system
- (Reduce) waste in the system
- (Reduce) staff workload
- (Reduce) Consultant input to TOE
- Volume of sedative
- Governance and audit
- Intubation training

GOAL 1
Waiting times:
Referral to TOE procedure

GOAL 2
Intubation success / fail rate

GOAL 3
Use of Consultant Cardiologist time

GOAL 4
OM1in
OM1out

OM2

OM1in
OM1out

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Table S1 : Niggle-o-gram for staff satisfaction: niggles experienced by staff members involved with the prior TOE service (yellow = agreed priorities)

<table>
<thead>
<tr>
<th>Niggle</th>
<th>Incidence (0-9)</th>
<th>Impact (0-9)</th>
<th>Influence (0-9)</th>
<th>Code (0-9)</th>
<th>Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>Takes too long to perform a TOE with all the delays</td>
<td>8</td>
<td>9</td>
<td>9</td>
<td>8-9-9</td>
<td>3</td>
</tr>
<tr>
<td>Wasted time waiting for the cardiologist during the TOE</td>
<td>8</td>
<td>9</td>
<td>5</td>
<td>8-9-5</td>
<td>7</td>
</tr>
<tr>
<td>No communication between operator (cardiologist) and the clinical scientist and cardiac nurse.</td>
<td>7</td>
<td>7</td>
<td>4</td>
<td>7-7-4</td>
<td>8</td>
</tr>
<tr>
<td>No report on the system so when the patient comes back for a TTE, there is no results for guidance.</td>
<td>9</td>
<td>9</td>
<td>0</td>
<td>9-9-0</td>
<td>6</td>
</tr>
<tr>
<td>Trying to find slots and no flexibility on appointments</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8-8-8</td>
<td>2</td>
</tr>
<tr>
<td>Long waiting times for a TOE which delays patients management</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8-8-8</td>
<td>1</td>
</tr>
<tr>
<td>Limited progression in cardiac science</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8-8-8</td>
<td>4</td>
</tr>
<tr>
<td>Limited training for progression</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8-8-8</td>
<td>5</td>
</tr>
</tbody>
</table>

---

Becomes irrelevant with change to be scientist-led (PDSA A)

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<table>
<thead>
<tr>
<th>Potential barriers</th>
<th>Details</th>
<th>Proposed actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of support</td>
<td>- No support from the trust</td>
<td>- Propose the benefits to the trust and governance</td>
</tr>
<tr>
<td></td>
<td>No governance approval</td>
<td>Prepare a letter for governance</td>
</tr>
<tr>
<td></td>
<td>No mentor for training</td>
<td>Provide evidence of other organizations which have the process in place</td>
</tr>
<tr>
<td>Lack of understanding</td>
<td>- Other healthcare professionals</td>
<td>- Explain the needs of improving the services of advanced imaging to support the pressures and workload.</td>
</tr>
<tr>
<td></td>
<td>Not a clinician performing the test</td>
<td>More patients are undergoing valvular intervention who require advanced imaging prior to surgery.</td>
</tr>
<tr>
<td>Lack of staff engagement</td>
<td>- Lack of knowledge and understanding of the vision</td>
<td>- Share the vision from the onset</td>
</tr>
<tr>
<td></td>
<td>No involved in the process</td>
<td>Embedding QI within the department</td>
</tr>
<tr>
<td></td>
<td>Don’t want to be involved</td>
<td>Show how this will benefit the team</td>
</tr>
<tr>
<td></td>
<td>Don’t want to progress</td>
<td></td>
</tr>
<tr>
<td>Staff shortages and workload</td>
<td>- Consultants’ ability to provide support and training</td>
<td>- Long term gain would be to reduce unnecessary referrals.</td>
</tr>
<tr>
<td></td>
<td>Clinical scientist shortage in main TTE to release them for advanced training</td>
<td>Reduce number of TTE and go straight to TOE</td>
</tr>
<tr>
<td></td>
<td>Time for training and teaching</td>
<td></td>
</tr>
<tr>
<td>Lack of training and education</td>
<td>- Lack of confidence in competence in ability</td>
<td>- Could be released to other trusts for the training</td>
</tr>
<tr>
<td></td>
<td>Ensure enough numbers for competence</td>
<td>Be involved with every consultant TOE list to improve confidence</td>
</tr>
<tr>
<td>Lack of supervision and leadership</td>
<td>- Clinicians maybe reluctant to relinquish advanced procedural skills, perhaps concerned about the consequences on their own individual practice.</td>
<td>- Propose the expansion of services which require multiple operators to reduce pressures Expanding roles will help deliver increased imaging demand</td>
</tr>
<tr>
<td>Lack of evidence</td>
<td>- Lack of evidence such as policy and procedure</td>
<td>- Demonstrate to the organization the need for the service and its success at other trusts. The cardiology workforce, GIRFT report and NHS Long term plan explain the need for advanced training in healthcare scientists.</td>
</tr>
<tr>
<td>Reduced opportunities for cardiology trainees</td>
<td>- Training clinical scientists may reduce training opportunities for cardiology doctors Although with time, clinical scientist will be involved in the training of medical juniors as well as other clinical scientists.</td>
<td>- Clinical scientist train cardiology trainees in TTE therefore could eventually train in TOE Consultant cardiologist lists could be training for cardiology trainees especially for the intubation.</td>
</tr>
</tbody>
</table>
Figure S4: SPC G-Chart of Cases between **Complication** or **Failure** Cases

This format is designed for relatively rare events. Pre-change these were not very rare, but appear to have become so post-change.

The first 5 (grey) points are our complication or failure events shown on Fig 2. The metric is the number of cases between these events, so the first of our events in Fig 2 has censoring before it (the previous complication or failure event off to the left of Fig 2’s PM2 graph so is not included here).

The last (blue) datapoint is the end of our data – with no complication or failure so far.

The horizontal line, the Centre Line (CL), is the ‘theoretical median’. If \( G_{bar} \) is the mean of the number of cases between events, then:

\[
\text{theoretical median} = \ln(2) \times G_{bar}
\]

The template shows the SPC-style Upper Limit (UL), which works out to be 39.46 cases, suggesting special cause (improvement) has been achieved.

However, we have very few data points so cannot establish a strong baseline. Nevertheless, any special cause is “a valid indication of a process with important special causes”) (Provost and Murray, 2022, p.276).

Alternatively, we might ignore this process limit and treat it like an early stage run-chart analysis. Then, as with special cause on SPC, this last ‘so far’ data point might be considered ‘astronomical’ (Rule 4) even with these limited data “because it is a visual analysis not dependent on a median [and so] can be applied at any time based on the user’s degree of belief” (op. cit. p.100).

The A and B are the first and second of the two lists per month (prior to the change to the scientist led service).