Prevention of accidental awareness under general anaesthesia - a regional service evaluation

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Abstract:	The United Kingdom's Fifth National Audit Project investigated the incidence and causes of accidental awareness during general anaesthesia. Subsequently, guidelines produced by the Association of anaesthetists of Great Britain and Ireland provide key recommendations to minimise awareness. These include using processed electroencephalogram for patients receiving total intravenous anaesthesia with neuromuscular blockade and using audible low end-tidal anaesthetic concentration alarms for volatile anaesthesia. The South-coast perioperative audit and research collaboration undertook a five day regional service evaluation, assessing the measures in place to minimise awareness and conducting a practitioner survey. Eight hospitals participated with 382 theatre attendances analysed. Processed electroencephalograph monitoring for patients receiving total intravenous anaesthesia with neuromuscular blockade has been widely adopted into regional practice, from 23% of cases in national audit project 5, to 85% in this snapshot. During volatile anaesthesia, age adjusted low end tidal anaesthetic concentration alarms were used in 34% cases. The range was 0-97% at different hospitals, suggesting heterogeneity in practice. 76% anaesthetists rarely alter the default anaesthetic machine alarm settings. Therefore instigating default low end tidal anaesthetic concentration alarms could improve compliance with guidelines and reduce the risk of awareness for patients.

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Abstract

The United Kingdom's Fifth National Audit Project investigated the incidence and causes of accidental awareness during general anaesthesia. Subsequently, guidelines produced by the Association of anaesthetists of Great Britain and Ireland provide key recommendations to minimise awareness. These include using processed electroencephalogram for patients receiving total intravenous anaesthesia whilst paralysed and using audible low end-tidal anaesthetic concentration alarms.

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Eight hospitals participated with 382 theatre attendances analysed. Processed electroencephalograph monitoring for patients receiving total intravenous anaesthesia with neuromuscular blockade has been widely adopted into regional practice, from 23% of cases in national audit project 5, to 85% in this snapshot. During volatile anaesthesia, age adjusted low end tidal anaesthetic concentration alarms were used in 34% cases. The range was 0-97% at different hospitals, suggesting heterogeneity in practice. 76% anaesthetists rarely alter the default anaesthetic machine alarm settings. Therefore instigating default low end tidal anaesthetic concentration alarms could improve compliance with guidelines and reduce the risk of awareness for patients.

Keywords: Awareness; pEEG; BIS; prevention; volatile, alarm

Key phrases

- Processed EEG monitoring for patients receiving TIVA and paralysis has been adopted into regional practice
- There is a wide variation in the use of low end tidal anaesthetic alarms
- Anaesthetists rarely change default anaesthetic machine alarms
- A lack of pEEG monitors and education on how to interpret them remain barriers to full guideline compliance
- pEEG is increasingly being used to reduce the quantity of volatile anaesthesia used

Introduction

Accidental awareness during general anaesthesia (AAGA) is a rare but potentially devastating event. The fifth national audit project (NAP 5) by Pandit et al (2014) demonstrated an incidence of 1:19,000 general anaesthetics, rising to 1:8,000 if patients received neuromuscular blocking drugs (NMB). The harm caused by AAGA varies between patients but severe harm, including long term sequalae and post-traumatic stress disorder have been reported (Mashour 2010, Cook et al 2014). Perhaps because of this, despite its rarity, awareness attracts mainstream media attention (Cole-Adams 2018).

AAGA is clearly an important outcome, to both patients and clinicians, resulting in a number of large, high quality, randomised trials including B-aware (Myles et al 2004), B-Unaware (Avidan et al 2008), BAG-RECALL (Avidan et al 2011), and the Michigan awareness control study (Mashour et al 2012). A Lewis et al (2019) Cochrane review combined these with numerous smaller trials. This compared the effectiveness of two key pieces of monitoring – processed electroencephalogram (pEEG) and end tidal anaesthetic concentration (ETAC) to reduce awareness. The percentage of volatile anaesthetic a patient exhales correlates to their depth of anaesthesia. The minimum alveolar concentration (MAC) is the percentage of exhaled anaesthetic at which 50% of people don't move to a standard surgical stimulus (Mapleson 1996). ETAC monitoring is routinely used during volatile anaesthesia, however, the use of audible alarms warning of low concentration is not universal. It is not possible to measure the real time concentration of intravenous anaesthetics and therefore alternative methods to measure depth of anaesthesia have been developed. Processed EEG monitors use forehead electrodes to detect and analyse the raw electroencephalogram. They estimate the depth of anaesthesia, producing a scale from 0-100, where 0 is an isoelectric EEG and 100 is maximal alertness. The Cochrane review found that while processed electroencephalogram (pEEG) guided anaesthesia may reduce awareness compared to using clinical signs, there was no

difference when comparing pEEG monitoring to end-tidal anaesthetic concentration (ETAC) monitoring, with audible low agent alarms (Lewis et al 2019).

Association of Anaesthetists guidance has previously discussed the role of ETAC monitoring in their 2015 Recommendations for standards of monitoring during anaesthesia and recovery (Checketts et al 2016, p. 93), suggesting '*during inhalational anaesthesia, end-tidal anaesthetic vapour monitoring with pre-set low agent alarms appears a suitable and effective means of estimating depth of anaesthesia'*. These guidelines were updated by Klein et al (2021, p. 1218) and now explicitly suggest for volatile anaesthesia '*During the maintenance phase of anaesthesia, an audible alarm should be enabled to indicate a low ETAC (e.g. < 0.7 age-adjusted minimum alveolar concentration) in order to reduce the risk of AAGA'*. This newly strengthened guidance sits alongside several recent publications providing recommendations on minimising AAGA. These include Nimmo et al (2019) 2018 Association of Anaesthetists of Great Britain and Ireland (AAGBI) safe practice of total intravenous anaesthesia guidelines (TIVA) and Pandit et al (2019) NAP 5 handbook. These publications advocate the use of pEEG monitoring in patients where ETAC monitoring is not possible, but awareness remains a risk, such as TIVA with neuromuscular blockade, while noting that ETAC monitoring offers the simplest means of AAGA risk reduction in volatile anaesthesia.

Additional suggestions include that pEEG monitoring should start prior to induction and continue until full NMB reversal (Klein et al 2021). While for TIVA the use of target controlled infusions (TCI), visible cannulas, anti-syphon valves and standardised remifentanil dilutions are all advised (Nimmo et al 2019). The guidance also highlights the value of monitors with an age-adjusted low minimum alveolar concentration (MAC) alarm over a simple low ETAC alarm, as this avoids the requirement for the anaesthetist to calculate and programme alarms for the age adjusted MAC for each patient (Klein et al 2021). The minimum monitoring standards provide an example age adjusted low MAC alarm of <0.7 but do not explicitly recommend using this threshold. From previous literature, there is

not a clear consensus on the optimum alarm to reduce awareness, but the largest awareness studies have previously used age adjusted low MAC alarms of <0.5, 0.7 and 0.8 respectively (Avidan et al 2008, 2011, Mashour et al 2012, Jain et al 2016, Sudhakaran et al 2018). It is unknown which alarm thresholds are currently being used in practice.

Finally pEEG can be considered as an adjunct in high risk patients (Klein et al 2021). This is due to increasing evidence that pEEG guided anaesthesia may facilitate a reduction in anaesthetic delivered, leading to reduced post-operative delirium. (Punjasawadwong et al 2018, Radtke et al 2013)

Despite the increasingly clear guidance on the subject, anecdotal observations and local audit by members of the South-Coast Perioperative and Audit Collaboration (https://wessex-sparc.com/) suggested that the use of audible low ETAC alarms was not universal. The group decided to quantifiably test this assertion by conducting a regional service evaluation to provide a snapshot of measures used to minimize AAGA and **assess** if current practice follows recent guidelines and recommendations.

Methods

A regional multi-centre service evaluation of the measures used to avoid AAGA was undertaken within all eight hospitals (appendix 1) in the Health Education England Wessex deanery for 5 days starting on Monday 28th June 2021. As a service evaluation ethical approval was not required but site-specific processes for service evaluation approval were followed at each hospital. Our evaluation had two parts – a theatre assessment to provide a snapshot of practice and an anaesthetist survey. Each theatre in every hospital was assessed a maximum of once daily, with information gathered about the type of anaesthetic and any measures in place to reduce accidental awareness. This

included the use of ETAC alarms and pEEG monitoring. In all cases the type of pEEG used was bispectral index (BIS) monitoring, although in several cases raw EEG, somatosensory evoked potentials and motor evoked potentials were also employed. We undertook the survey of anaesthetists to understand their knowledge and usual practice regarding awareness. This was completed by the responsible anaesthetists at the time of the theatre visit and each clinician only completed the survey once, but may have had their theatre practice assessed more than once. All data was collected by anaesthetic trainees locally (appendix 1) and submitted electronically to a central database with subsequent analysis and visualisation undertaken using R statistical software (v4.2; R Core Team 2023).

Results

Eight hospitals participated with a total of 382 theatre attendances analysed, with every anaesthetist approached consenting to data collection. 259 individual anaesthetists answered the survey, 11 anaesthetists declined to take part. Figure 1 shows their seniority, **with 162 consultants, 54 staff grade or SAS doctors and 42 trainee anaesthetists. The trainee anaesthetist respondents were 14 core trainees and 28 registrars. The seniority of one respondent was unknown.**

Processed EEG use

Table 1 below gives an overview of the types of anaesthetic used and frequency of pEEG and neuromuscular blockade (NMB) use.

Table 1 Type of anaesthetic used alongside use of pEEG. Values are count (percentage).

When pEEG was used (118 cases), it was applied before induction of anaesthesia in 61 cases (52%) and after induction in 57 cases (48%). pEEG was used in 85% cases during TIVA with NMB (81 out of

95 cases). In the 14 cases where pEEG was not used, five patients were paralysed throughout surgery, nine patients only received NMB at induction of anaesthesia. The specialities involved when TIVA and NMB were used without pEEG were, five neurosurgery, four cardiac, two orthopaedics, two vascular and one unspecified speciality.

Figure 2 shows anaesthetists' normal practice around pEEG and TIVA, **with 64% following Association of Anaesthetists guidance to always use pEEG when using TIVA and paralysis. However** 15% of anaesthetists surveyed rarely or never use pEEG in this situation. Interestingly 22 (10%) out of 219 volatile cases used **pEEG** and when surveyed nine people commented that they use pEEG during volatile anaesthesia to reduce anaesthetic amounts.

Considering possible barriers to using pEEG, figure 3 shows practitioner's confidence when using **pEEG**. **This showed that only 53% of practitioners were 'very' or 'completely' confident in using pEEG monitors.** In addition, in the free text section of our survey, seven anaesthetists said they would value further education around pEEG monitoring and four practitioners cited a lack of availability of **pEEG** in their departments. Data were not collected about the number of pEEG monitors available for clinicians to use in their departments.

TIVA safety

Figure 4 shows how often practice follows the Association of Anaesthetists TIVA guidance (Nimmo et al 2019) for having anti-syphon valves (90%), a visible cannula (72%), pump alarms (98%) and separate syringes for drugs (87%).

Volatiles

During volatile anaesthesia low ETAC alarms were used in 103/219 (47%) cases, age adjusted alarms were used for 75 patients (34%). Table 2 shows provides a breakdown of the types of alarms used and the low MAC thresholds set by clinicians. Considering ETAC by hospital sites there was a range from 0 to 97% suggesting heterogeneity in practice which is demonstrated in figure 5.

Table 2 Age adjusted MAC alarm settings used when patients received volatile anaesthesia

From our survey of anaesthetists, a minority (15%) of anaesthetists 'always or usually' check the volatile alarms on a machine as seen in figure 6. Most anaesthetists therefore use the default setting, although 79% feel at least 'fairly confident' to change alarms if required. In the free text section of the survey six anaesthetists wanted anaesthetic machines to default to age-adjusted MAC alarms and a further three felt end-tidal control on all machines would be beneficial in reducing awareness. One anaesthetist was concerned about the risk of alarm fatigue if low MAC alarms were the default.

Discussion

This service evaluation has identified examples of good practice as well as areas where further improvement is still required. The use of pEEG monitoring when paralysing patients with TIVA was a key recommendation in the wake of NAP5 and has been reiterated in numerous guidelines since (Pandit et al 2014, 2019, Klein et al 2021). Following this widespread endorsement, our evaluation suggests this has been adopted into practice: from 23% of cases in NAP5, to 85% in this snapshot. The more recent **2021** recommendation to apply pEEG monitoring prior to induction of anaesthesia is also being adopted, albeit less widely with 52% of patients receiving this care. Of the 14 TIVA cases with neuromuscular blockade that did not use pEEG monitoring, a significant proportion were in populations with limited validation of pEEG or which had factors making its use more difficult. Five patients underwent neurosurgery, where the surgical site or use of image guided surgery (IGS) may

affect pEEG use. Four patients also underwent cardiac surgery where it has been shown that the hypothermia associated with cardiopulmonary bypass produces a significant fall in **pEEG** values (Schmidlin et al 2001). However, it is unclear if the reduction in **pEEG**, also reduces the anaesthesia required or correlates with the risk of awareness.

Meanwhile ETAC alarms are less widely used. Significant variation between hospital sites as seen in figure 5 indicates that high compliance rates are possible. The survey results go on to suggest that most anaesthetists do not check or modify ETAC alarms. These two findings combined, point to default alarm settings as a potentially key variable for changing practice. To exemplify this; it is noteworthy that one site (Hospital B, Figure 5) was used as an unpublished pilot for this project. In this pilot the site showed poor complicate with ETAC monitoring and subsequently enacted new default alarms. Following this, in our regional evaluation it had high compliance with ETAC monitoring and improved overall regional compliance significantly. This suggests that poor concordance with ETAC monitoring can be addressed. Therefore, wide dissemination and action on these results could easily improve ETAC alarm uptake with a subsequent reduction in the risk of AAGA for patients.

A number of challenges around ETAC alarms remain. Age has a significant effect on the ETAC required to achieve the MAC, meaning age-adjusted alarms are recommended (Mapleson 1996, Cooter et al 2020). A definitive answer on the optimal cut-off to reduce the risk of awareness while minimising alarm fatigue remains elusive (Shanks et al 2015). Using an age adjusted MAC alarm of <0.5 has a high positive likelihood ratio, reducing the frequency of alarm triggering but possibly missing cases of awareness (Mashour, Esaki et al 2009, Mashour, Wang, et al 2009). Alternatively a MAC alarm set at 0.7 has a low positive likelihood ratio, but could be associated with alarm fatigue (Schneider 2015). Our evaluation shows that an age adjusted low MAC alarm of 0.7 is the most commonly adopted threshold in the Wessex region.

This study has several advantages. It was performed across an entire region, with hospitals ranging from rural district general hospitals to a large tertiary centre. The authors believe these findings are likely to be of relevance to many anaesthetic practitioners in the UK and internationally. The study was conceived, designed, and delivered entirely by anaesthetic trainees without external funding; representing excellent value to the health service and offering opportunities for trainees of various grades to engage in meaningful service evaluation and quality improvement.

A limitation of our study was only visiting theatres once a day and only monitoring theatres in hours. Out of hours anaesthesia is more heavily trainee delivered with reduced consultant supervision and we did not investigate if practice differs at this time. Not every theatre was surveyed daily in this snapshot, it is unknown if this was because the theatre was not utilised that day, or due to trainee selectiveness that could induce bias. However all anaesthetists approached facilitated data collection and there was a high response rate of 96% for the survey.

Overall our evaluation provides a valuable snapshot of measures taken to avoid accidental awareness under general anaesthesia. It shows that pEEG monitoring has been widely adopted for TIVA cases with NMB. However, it also highlights significant divergence from Association of Anaesthetists recommendations around ETAC monitoring and alarms. The authors hypothesise this could be largely corrected by simple changes to default alarm settings and would encourage anaesthetists to evaluate practice at their own institutions.

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Table 1 Type of anaesthetic used alongside use of pEEG and neuromuscular blockade. Values are count (percentage).

	Total (%)	pEEG used (% of total)
All cases	**382 (100)**	**118 (31)**
When used, EEG applied		
Before induction		61 (52)
After induction		57 (48)
Volatile	**219 (57)**	**22 (10)**
Neuromuscular blockade used	120 (55)	18 (15)
TIVA	**117 (31)**	**96 (82)**
Neuromuscular blockage used	95 (81)	81 (85)
Regional	33 (9)	0
Sedation	9 (2)	0
Local	4 (1)	0

Table 2 Age adjusted minimum alveolar concentration (MAC) alarm settings used when patients received volatile anaesthesia

	Total	%
No alarm set	116	53
Low MAC alarm set	103	47
Non-age adjusted alarm	*28*	*13*
MAC ≤ 0.5	*5*	*2*
MAC < 0.7	*70*	*32*

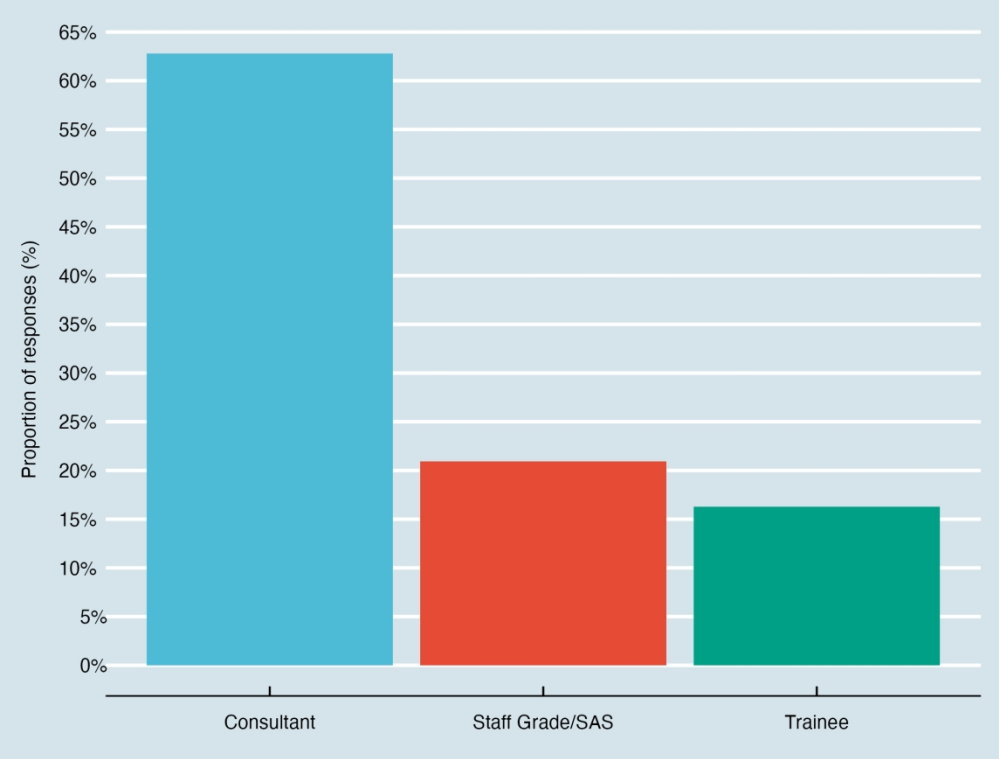

Figure 1 - Respondent grade of doctor completing survey

183x139mm (300 x 300 DPI)

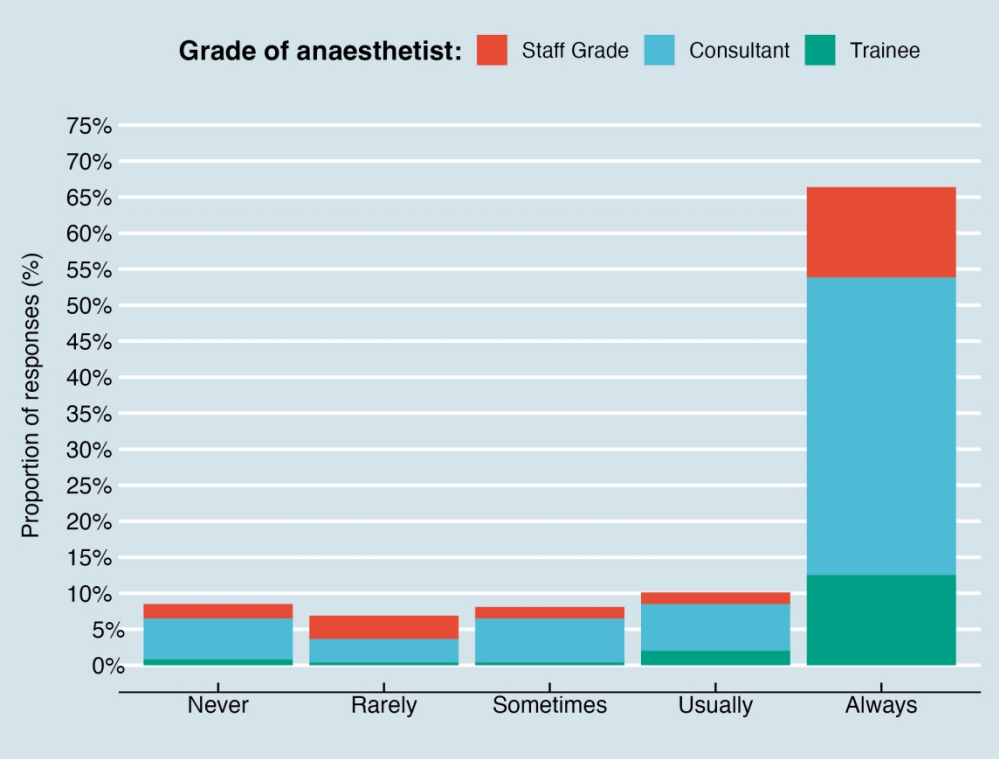

Figure 2 - Anaesthetists reported use of pEEG monitoring for patients receiving TIVA and neuromuscular blockade

183x139mm (300 x 300 DPI)

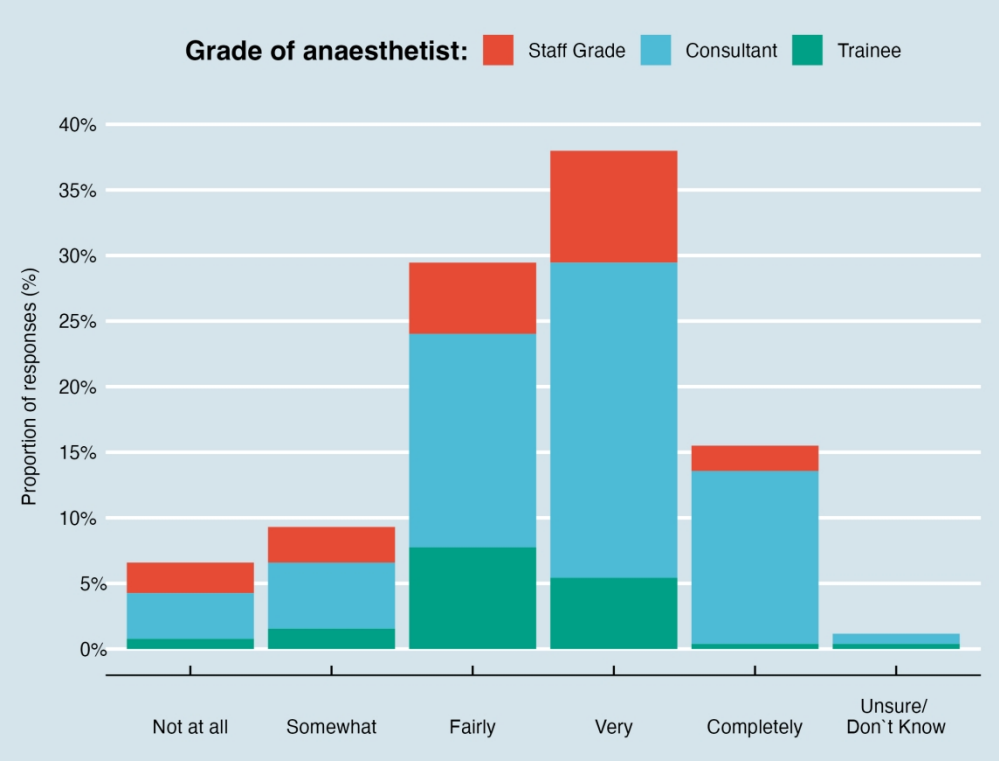

Figure 3 - Anaesthetist confidence in using pEEG monitoring

183x139mm (300 x 300 DPI)

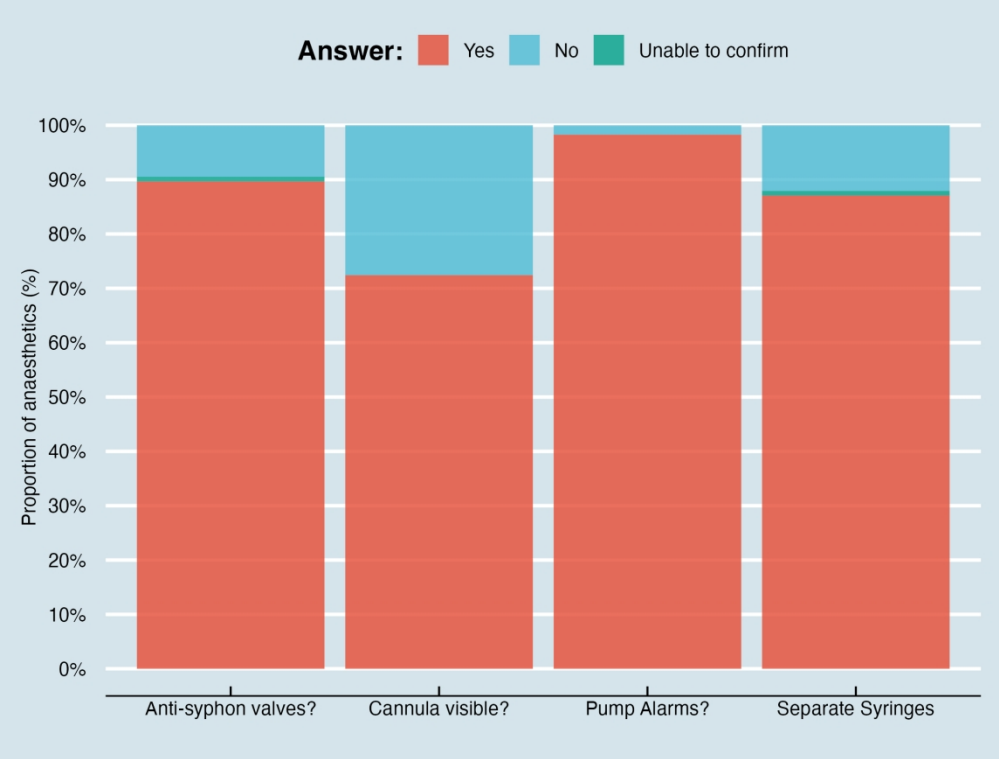

Figure 4 - Percentage of time key TIVA safety measures used

183x139mm (300 x 300 DPI)

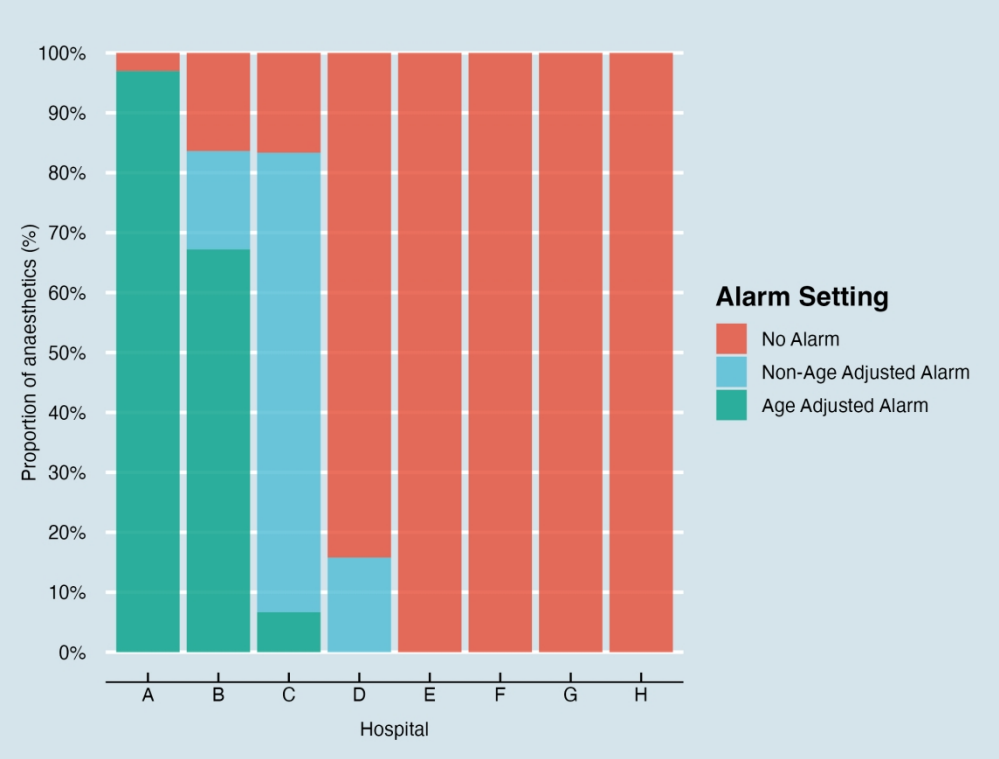

Figure 5 - Use of low end-tidal anaesthetic concentration (ETAC) alarms in different Wessex trusts

183x139mm (300 x 300 DPI)

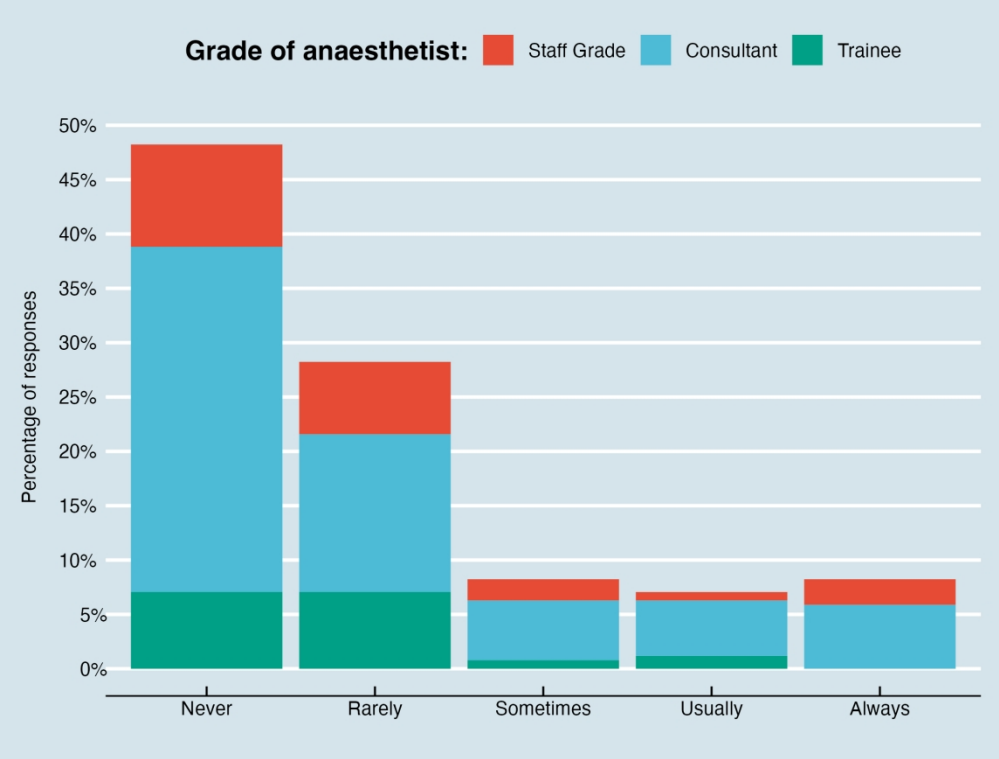

Figure 6 - Frequency with which anaesthetists check or modify end tidal anaesthetic alarms

183x139mm (300 x 300 DPI)

Appendix 1

SPARC awareness investigators and participating trusts

University Hospital Southampton
Local lead - Katie Preston.
Elizabeth Auer, Rory Sharvill, Robert Taylor, Joseph Kinsella

Queen Alexandra Hospital
Local lead - James Collis
Alexander Jackson, Daniel Growcott

Basingstoke and North Hampshire Hospital
Local lead - Christine Garner
Megan Joyce, Alexandrina Roman, Richard Partridge

Royal Hampshire County Hospital
Local leads - Frances Ng, Hermione Tolliday
Tom Peck

Salisbury District Hospital
Local lead - Adam Bhujwalla
William Denehan, Charlotte Towell, Toby Pitts-Tucker, Laura Dinsmore, Kerensa Houghton, Xantha Holmwood

Dorset County Hospital
Local leads - Harris Wain, Lucy Charig
Charles Archer, Zhi Jiun Yap, Claire Joannides

University Hospitals Dorset (Poole Hospital and Royal Bournemouth Hospital)
Local lead - William Smith
Siobhan Orr, Amy Cash, Michael Girgis