TADAA: Enabling Continuous Improvement for Anaesthetists

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Abstract

In fulfilling their primary aim of patient safety, anaesthetists have traditionally focused on monitoring patients' vital signs during anaesthesia. In recent years, analysis of adverse events in medicine and other safety-critical domains has seen increased interest in 'system' and 'human' factors. Task analysis is one approach that has been used to gain a deeper understanding of anaesthetists' activities and interaction with other theatre staff. In the past such studies have been intermittent, complicated by the expense and potential intrusiveness of observers. This has motivated our current research project, Towards Automated Detection of Anaesthetic Activity (TADAA). In this paper we identify three key abilities for anaesthetists – record keeping, technical knowledge and skills, and communication – and consider how ongoing, automated, real-time task analysis might enable anaesthetists to practice continuous improvement.

1. Introduction

A special report on Health 2.0 in a recent issue of *The Economist* quoted Andy Grove, formerly chairman and CEO of Intel and more recently undergoing treatment for cancer and Parkinson's disease, on his first-hand observations of the health care sector's ability to translate discoveries into delivery of care: "health care often lacks real-time information systems and data feedback loops are sluggish. Learning comes in batches, like slow and infrequent trains, not like continuous Federal Express deliveries" [1, pg S6].

Even anaesthesia, one of the medical disciplines that leads the way in process evaluation and improvement, was recently described as: "something then [when 'modern' anaesthesia was first practiced in the 1840s] nameless and profound *that even today we understand but partly*" [2, pg 23, emphasis added].

The importance of understanding and improving the practice of anaesthesia cannot be underestimated. As Aitkenhead notes: "In anaesthesia, every complication has the potential to cause lasting harm to the patient" [3, pg 367]. This is clearly reflected in the most recent systematic review of adverse events (AEs) – injury caused to patients as a result of errors or accidents during medical treatment - in New Zealand (NZ) hospitals [4]. Approximately 58% of AEs occurred during surgery/anaesthesia, 12% of which resulted in permanent disability or death, and 30% of which were 'highly' preventable.

One approach to better understanding anaesthesia is task analysis. This typically involves independent observers in the operating theatre, watching anaesthetists and recording their activity under a number of *a priori* categories. While anaesthetic task analysis studies over many years have provided valuable insights, they have been conducted intermittently at best. Theatre poses several challenges for observers in recording accurate and consistent data. So when the third author of this paper planned a major study employing task analysis, he approached the first two authors to investigate the possibility of using Radio Frequency Identification (RFID) technology to supplement the data recorded by observers. This was the genesis of our current research project, Towards Automated Detection of Anaesthetic Activity (TADAA).

Details of TADAA-related system design and development to date have been published elsewhere [5, 6]. In this paper we look ahead to the completion of the system and consider: How would an ongoing, automated, real-time task analysis system enable anaesthetists to understand, and ultimately to improve, their practice? In the next section we give a short overview of anaesthesia, and review literature on the key abilities for anaesthetic practice, and existing systems for anaesthetic monitoring. A brief description of our planned final system for TADAA follows. We then discuss how that system might enable anaesthetists to practice continuous improvement in key abilities.

2. Background

In this section we give a short overview of anaesthesia, and review the literature on key abilities for anaesthetic practice, and existing systems for anaesthetic monitoring.

2.1. Anaesthesia - What, Why, How, and Who ?

Anaesthesia serves two essential purposes: it immobilises patients during surgery, making it easier for surgeons to operate; and it renders the surgery painless to the patient, making it less traumatic for them [2]. Textbooks generally identify five phases within an individual anaesthetic procedure[3]:

1. Pre-operative evaluation. Prior to entering theatre, patients are interviewed and their medical records checked. An anaesthetic plan is prepared, identifying potential risks.
2. Induction. Once in theatre, patients are positioned on the operating table, anaesthesia is induced, and the airway is secured, typically by intubation. Induction is normally the busiest phase for the anaesthetist.
3. Maintenance. During surgery, anaesthetists monitor, and respond to changes in, patients' physiological data relating to temperature, fluid balance, heart rate, blood pressure, pulse oximetry, tidal volume, respiratory rate, peak respiratory pressure, inspired oxygen, mix of respired gases, and so on. Maintenance is normally the least busy phase for the anaesthetist.
4. Emergence. At the completion of surgery, anaesthetists allow patients to awaken and remove any device used to secure their airway.
5. Post-operative handover. Anaesthetist escort patients from theatre to a recovery area, such as the Post Anaesthetic Care Unit (PACU), and give instructions to the staff for ongoing care.

In NZ hospitals, at least one qualified anaesthetist is present in theatre for the full duration any anaesthetic procedure. It is not uncommon for multiple anaesthetists to be present. Consultants may supervise registrars, or teach students while performing anaesthesia. Particularly complex anaesthetic procedures may warrant multiple consultants and/or registrars. During a lengthy procedure anaesthetists commonly work in shifts, involving a handover. In addition, an anaesthetic technician will normally be present in theatre, to assist the anaesthetist, ensure that sufficient drugs and supplies are on hand, and resolve problems with anaesthetic equipment.

2.2. Key Abilities for Anaesthetic Practice

This brief overview illustrates that anaesthetists exercise a range of abilities in interacting with various people. Smith suggests that excellence in anaesthesia demands a combination of technical knowledge (eg – of pharmacology) and skills (eg – intubation), and non-technical "behavior and attitudes" [7, pg 4]. This somewhat nebulous term is explored in greater depth by Glavin [8]. From interviews with anaesthetists about their work, industrial psychologists identified 15 non-technical abilities grouped into four categories, shown in table 1.

While the abilities identified by Smith and Glavin are all undoubtedly of value to anaesthetists, which are the most important? Smith starts his editorial with the line: "We [anaesthetists] owe it to our patients, our colleagues, and ourselves to strive for excellence" [7, pg 4]. Taking his lead, we consider the question of which are the key abilities for anaesthetic practice from three perspectives: patients, colleagues, and anaesthetists themselves.

2.2.1. Patients

Patient safety is anaesthetists' primary goal, in line with the first principle of medicine: First, Do No Harm. It seems a reasonable assumption that their own safety is also the major concern for patients. The most common measure of patient safety is the frequency of AEs. In the most recent systematic review of AEs in NZ hospitals, Davis et al [4] report that around 12% of patients undergoing surgery experienced an AE, 30% of which were 'highly' preventable. The three greatest contributing factors are shown in table 2.

Table 1 - Anaesthetists' non-technical abilities, from [8]

Situation awareness	Gathering information Recognizing and understanding Anticipating	**Decision making**	Identifying options Balancing risks and selecting options Re-evaluating
Task management	Planning and preparing Prioritizing Providing and maintaining standards Identifying and utilizing resources	**Teamwork**	Co-ordinating activity with team members Exchanging information Using authority and assertiveness Assessing capabilities Supporting others

Almost half of AEs resulted in full or in part from system factors. We believe that many of these factors can be traced back, via the data-information-knowledge continuum, to record keeping. Poor record keeping leads to poor access to information, which in turn leads to poor knowledge, such as policies and protocols. Poor communication exacerbates the problem. Staff may be unaware that a particular policy or protocol exists, or that circumstances currently exist that mandate its use.

Anaesthetists are well aware of the importance of record keeping. It has long been standard practice to complete an anaesthetic record for each procedure. Some anaesthetists were using IBM 'information recorders' and punch cards to record such data as early as 1968 [9]. But many regard it as a tedious aspect of their work [10], and treating the patient always takes precedence: "While the anaesthetic record is usually completed as the anaesthetic proceeds, there are times, such as during induction or a crisis, when it is not possible to complete the chart contemporaneously. This delay can lead to inaccuracies. In addition, studies have shown that anaesthetists tend to record 'normalized' data" [3, pg 366]. Thus the accuracy and completeness of the record cannot be guaranteed.

In many hospitals, anaesthetists are also encouraged to record incidents that led to AEs, or that may have. The objective of such systems is to identify the root causes of incidents, so that policies and protocols can be introduced or amended to minimise the risk of future incidents. But it is widely acknowledged that incidents are under-reported [11]. Some go unnoticed, or their contribution to an AE isn't realized. Individual anaesthetists have their own thresholds for how serious an incident must be to warrant reporting. In some cases very obvious and potentially very dangerous incidents have gone unreported, such as an anaesthetist being asleep during a procedure [12], to avoid creating trouble for themselves or colleagues.

Communication and consultation failures have been identified as significant contributors to AEs in many studies before and since Davis et al. The largest recent observational study of communication in theatre [13] found that the two most common communication failures were poor timing (46%) and too little, or too much, information (36%). For anaesthetists, communicating all relevant, and only relevant, information can be challenging due to the volume of data they receive. When a critically ill patient is in theatre, for example, anaesthetists typically have more than 250 streams of monitor data to choose from [14]. While monitors may be programmed to raise an alarm when certain situations arise, studies have found that as much as 92% of such alarms are either false or 'clinically insignificant' [14]. Thus anaesthetists are constantly filtering out the information that is relevant, both for their own work and for the surgeons and other theatre staff.

Table 2 - Major factors contributing to preventable surgical / anaesthetic AEs, from [4]

Factor	Details	% of AEs
System	Access to information, Policies / protocols, Communication, Organisational culture, Record keeping	49
Consultation	With peers, With specialists	36
Education	Professional knowledge and skills	27

Table 3 - Most important attributes for anaesthetists according to surgeons, from [16]

Quality Attribute	Ranking	Quality Attribute	Ranking
Ability to calmly manage a crisis	1	Quick emergence	2
Familiarity with requirements for procedure	3=	Quick induction	3=
Correct intubation	3=	Timely starts	3=
Correct placement of invasive monitors	3=	Short turnaround times	3=
Communication with theatre staff	3=	Good relationship with patient	10

The timing of communication is important in two respects. To remain relevant, information must be communicated before it is out-of-date. And the information should be communicated at a time when the recipient is able to act on it. As Coiera notes [15], much of the communication in clinical scenarios is interruptive, requiring the recipient to suspend their current activity. Once they have handled the interruption, the recipient may forget to resume the activity, or may forget at what stage the activity was suspended, and consequently repeat or omit parts of the activity. Anaesthetists therefore must be wary of interrupting surgeons and other theatre staff.

2.2.2. Colleagues

In addition to minimising interruptions, what do surgeons expect of anaesthetists? A seminal study considering this question was conducted by Vitez and Macario [16]. They interviewed surgeons, identifying and ranking 25 'quality attributes' for anaesthetists. The top ten rankng attributes are shown in table 3.

The results suggest that surgeons place a high value on anaesthetists' knowledge ('Familiar with procedure') and skills, both technical ('Correct intubation', 'Correct placement of monitors') and non-technical ('Calm in a crisis'). 'Quick emergence' and 'Quick induction' also relate partly to anaesthetists' skills, but are probably desired by surgeons more as a means of minimising their down-time between procedures (also evident in 'Timely starts' and 'Short turnaround'). The importance of communication with theatre staff, and patients to a lesser extent, is also highlighted.

Record keeping was not one of the 25 attributes identified in the interviews. This probably reflects the relatively minor role of record keeping in surgical work. It is likely that had Vitez and Macario interviewed staff from the other groups they identified as anaesthetists' colleagues – nurses and hospital administrators – record keeping would have featured. Indeed Macario subsequently published papers aimed at clinical staff taking on administrative responsibility [17]. He highlights the importance of controlling the variable costs of surgery, requiring accurate records of the quantity of drugs and supplies used, and of time lost to missing or malfunctioning equipment, or 'non-standard' treatment

One group of colleagues overlooked by Vitez and Macario are the other members of the anaesthetic team: anaesthetic technicians, and possibly junior anaesthetists or students. We could find no published research into technicians' and students' expectations of anaesthetists. However we believe that, in comparison with surgeons, both groups would place more value on communication and less on quick procedures and turnarounds. Technicians' ability to assist anaesthetists depends largely on receiving clear and timely instructions. Students in theatre will benefit most from hearing not just what anaesthetists are doing, but why. Students may prefer longer induction, emergence and turnaround times if it allows anaesthetists more time to discuss procedures. Technicians may also prefer longer turnaround times if they have greater opportunity to restock drugs and supplies, or resolve equipment problems.

2.2.3. Anaesthetists

Different groups of anaesthetists' colleagues clearly have varying opinions on which abilities are most important for anaesthetic practice. Is the same true of anaesthetists themselves? From surveying anaesthetists about what they considered the core of anaesthetic work, Larsson et al [18] have identified four types. Figure 1 shows the types and the proportion of respondents in each one.

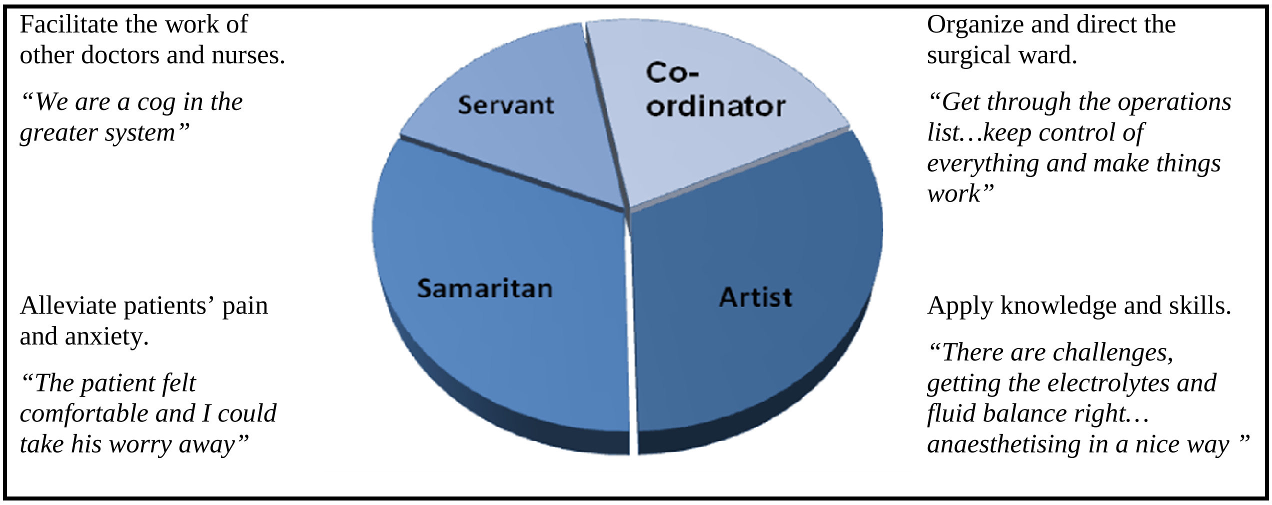

Figure 1 - What anaesthetists consider the core of their professional work, from [18]

The results suggest that anaesthetists are almost equally split between Artists, Samaritans, and Servants and Co-ordinators. They can be distinguished by, for example, how they regard patients and which abilities they consider most important:

- Artists see patients as physiologic objects, with vital signs that must be kept within certain limits. They will consider the technical knowledge and skills more important than any non-technical abilities.
- Samaritans see patients as individuals, each with a history, with fears and concerns, possibly in pain. They might be expected to emphasize the 'Gathering information' and 'Decision making' abilities indentified by Glavin [8], particularly in relation to the patient.
- Servants see patients as group projects. They will likely regard the 'Teamwork' abilities as most important, particularly within the theatre team.
- Co-ordinators see patients as one of the components necessary for surgery. They focus mostly on 'Task management' abilities, as applied across all theatre teams within the ward.

Larsson sees the primary value of these four types as an educational tool: helping to identify a trainee anaesthetist's strengths and weaknesses; and providing four perspectives from which they can reflect on their experiences in anaesthetic practice.

2.3. Monitoring Anaesthetic Activity

Notwithstanding these differences in approach, patient safety is the primary concern in anaesthetic practice. As Aitkenhead notes, monitoring anaesthesia is crucial to patient safety: "In anaesthesia, every complication has the potential to cause lasting harm to the patient. Therefore deviations from the norm must be recognized and managed promptly and appropriately"[3, pg 367]. Traditionally anaesthetists have expressed 'the norm' in terms of patients' physiological data (or vital signs), and recognised 'deviations' by monitoring these. Advances in technology have greatly increased both the range of signs that can be monitored and the accuracy of monitoring. Computerized systems to measure and display patients' vital signs, and to automatically create electronic anaesthetic records, are now widespread in theatre. Many systems are able to detect critical changes in patients' signs, and raise alarms [19]. A handful of systems have evolved into so-called 'closed loops' or 'anaesthetic robots', able to automatically act on their own alarms by administering drugs via infusion pumps [20]. However, even the most advanced anaesthetic robots still rely on human anaesthetists to perform many tasks during induction of, and emergence from, anaesthesia, and to handle emergencies.

Recent years have seen an increased research interest in the effect of anaesthetists' activity on patient safety. Smith concludes his editorial on excellence in anaesthesia with: "We [anaesthetists] should consider methods of recording the behavioural traits and practical unwritten knowledge exhibited by excellent anesthesiologists, and we should explore the means of making these more widely visible" [7, pg 5]. Weinger believes that "a scientific description of the anesthesiologist's task patterns and workload would aid in our understanding of the nature of the anesthesiologist's job and provide a more rational basis for improvements" [21, pg 78].

The shift in research interest is partly the result of AE analyses, such as Davis et al [4], consistently indentifying 'system' or 'human' factors as significant contributors. It has also been inspired by demonstrated benefits of similar research in other safety critical domains, most notably aviation [22]. Several aviation safety practices have been adopted in anaesthesia, such as checklists [23], incident reports [11], simulation-based training [24], and task analysis [21].

Task analysis typically involves independent observers, either in theatre or using video recordings, watching anaesthetists and classifying their activity into *a priori* categories. Observers provide more complete, accurate, and consistent data than is available in the anaesthetic record or in incident reports. However, observers are not without disadvantages. They may make errors when fatigued, distracted, or activities happen out of their field of view. Maintaining intra- and inter-observer consistency in classifying activities can be difficult [25]. Observers may distract anaesthetists and other OR staff, potentially causing changes in behaviour that confound the research or even pose a safety hazard. Observing video recordings can mitigate some of these issues, but the field of view is more limited and recording frequently raises privacy concerns for staff and patients [26]. In addition, the cognitive limitations of humans necessarily limit the level of detail that an observer can reliably record. The most activity categories used in published studies we reviewed is 41 [27]. In comparison, a hierarchical task analysis (HTA) of anaesthesia [28] has so far identified 196 tasks at the lowest level of detail, including 114 during the induction phase alone. Observers, even using video, are unlikely to be capable of quickly, accurately, and consistently distinguish that many tasks.

An automated anaesthetic activity monitoring system, using sensors and activity recognition software, offers the potential to do so. Sensors offer immediate and precise recording of data, less intrusion in theatre (particularly if wireless), less risk of distraction or fatigue, and a lower ongoing cost. Sensor data is less immediately accessible than video, going some way to alleviate privacy concerns. In addition, detailed sensor data lends itself to a wider range of data analysis than *a priori* activity classification. Examples of such systems include:

- anaesthetists narrating their actions into a microphone, with voice recognition used to identify activities [29]
- anaesthetists' activity is recorded on video, with image analysis used to identify activities [26]
- anaesthetists using RFID-tagged equipment to assess their intubation skills [30], [31]
- anaesthetists using RFID-tagged syringes, allowing detection of drug administration [32]

However, these systems are rare, and have not progressed beyond very limited use. As already noted, speech-based systems may distract surgeons and other theatre staff, and video-based systems raise privacy concerns. Systems that place RFID tags or barcodes on single-use items, such as intubation equipment and syringes, carry a significant overhead in terms of cost and preparation time.

3. TADAA - Towards Automated Detection of Anaesthetic Activity

These are the considerations that have motivated our current research project, Towards Automated Detection of Anaesthetic Activity (TADAA). We are developing a system using RFID technology to detect the activity of anaesthetists in theatre. Employing RFID mitigates risks related to distraction and privacy that are inherent in other sensor technologies, such as video. We place RFID tags only on anaesthetists and a handful of 'landmark' locations in theatre, greatly reducing the cost and setup time involved. Although our system is at a very early stage, we envisage a future system with three components:

1. Recorder module. Combining anaesthetists' location and orientation data with existing task analysis data, the anaesthesia HTA [28], and patient monitoring data, we expect to be able to detect anaesthetic activity and create an activity record for each procedure.
2. Library module. The activity records will be stored in a central repository. They will be searchable by, for example, date and time, patient, anaesthetist, surgery type, anaesthetic type, and outcome.
3. Viewer module. The activity records will be viewable as text or in various graphical forms, such as heat maps, and animation.

The system will store activity data at three levels of detail:

1. At the lowest level will be raw location and orientation data. This level of detail would be used primarily to produce different graphs, such heat maps, in the viewer module.
2. At the next level will be individual tasks, such as those identified in the HTA of anaesthesia [28]. This level of detail would provide support for Weinger's 'scientific' analysis of anaesthetic activity. It would also serve as the 'script' for creating animations in the viewer module.

3. At the highest level will be activities, consisting of a sequence of tasks. This level would support comparison with activity records created by observers. It would also be the default text view in the viewer module.

4. Discussion

How might an ongoing, automated, real-time activity detection system as described above enable anaesthetists to improve their practice? We consider this question in relation to three key abilities for anaesthetists identified in section 2 above: record keeping, technical knowledge and skills, and communication.

4.1. Record Keeping

The system will interface with existing automated anaesthetic recording systems to update those parts of the anaesthetic record that relate to activities, such as intubation and extubation, and the administration of drugs. This will remove more of the ‘tedious’ manual recording required of anaesthetists, leaving them free to focus on their core work.

The system may automatically produce incident reports. Automated incident reporting will remove some of the onus on anaesthetists to report errors made by colleagues, and the potential souring of relationships that can result. The report will be able to include an accurate record of activity leading up to the incident, which will:

- support Weinger’s ‘more rational basis’ [21] for identifying problems and improvements .
- serve as evidence of professional conduct (or misconduct) in the event of medico-legal proceedings.

The system will also record activity which is not currently included in the anaesthetic record, but is of interest. For example, drugs that are drawn up but not given to patients do not appear in the anaesthetic record. However, they are useful to administrators, as one of the variable costs of surgery.

4.2. Technical Knowledge and Skills

The system will enable anaesthetists to become familiar with the activity required for particular anaesthetic procedures. As one doctor quoted in *The Economist* put it: “When you get [Health IT] right, a doctor is no longer limited by lessons of personal experience” [1, pg S8]. The library module will allow retrieval of exemplar procedures based on a range of search parameters. The viewer module will enable anaesthetists to study the activities as a checklist, an animation, or in other ways that suit their learning style.

By analysing many activity records for the same anaesthetic procedure, the system may enable anaesthetists to synthesise Aitkenhead’s ‘norm’ [3] for the procedure in terms of anaesthetic activity. Just as patient monitors can raise alarms in real-time when patient vital signs reach dangerous levels, so the recorder module might be programmed to raise alarms when anaesthetist activity deviates from the activity norm.

Activity records might serve as test scripts for evaluating new equipment, theatre layouts, or processes. The viewer module might allow anaesthetists to create models of physical environments. Viewing animations of previous anaesthetic procedures in the proposed new environments could then show up potential problems. Similarly, the recorder module might allow anaesthetists to manually enter activity records to reflect new processes. Viewing those could show up potential conflicts with existing environments.

4.3. Communication

The viewer module, if used in real-time, will provide a new communication channel for staff outside theatre. For example:

- surgeons waiting between procedures will see the progress of emergence, turnaround, and induction, and judge when they need to return to theatre.
- co-ordinators will see anaesthetic progress in each theatre, and judge whether surgical lists need to be re-organised, or anaesthetists need to be relieved.

The system will also promote non-interruptive communication within theatre. It will provide an objective measure of anaesthetists’ current workload to other staff in theatre. If the system is extended to monitor the activity of other theatre staff, then anaesthetists will have an objective measure of other people’s current workload. Staff can balance this against the importance of any information, and alter their communication accordingly.

5. Conclusion

Anaesthetists' primary concern is patient safety. It is no surprise, then, that anaesthetists have traditionally sought to understand anaesthesia through the state of patients. They have expressed 'the norm' for anaesthesia in terms of patients' vital signs, and recognised 'deviations' by monitoring those signs. Advances in technology have permitted an ever-widening range of signs to be monitored with increasing accuracy, greatly reducing the incidence of anaesthesia-related injury and death.

Recent years have seen increased research interest in the impact of 'human factors' on patient safety, reflecting findings from analyses of adverse events, and the benefits from similar research in other safety-critical domains. Task analysis is a research approach adopted from the aviation industry. Several studies of anaesthetic task analysis have provided valuable insights into the nature of anaesthetists' work. But employing observers to collect activity data for analysis is expensive, and creates potential privacy concerns and safety risks that make it impractical for ongoing use.

We believe that an automated, real-time data collection system offers a viable alternative. Our current research project, Towards Automated Detection of Anaesthetic Activity (TADAA), aims to develop such a system. In addition to capturing data, we envisage our final system including a library, for storage and retrieval of activity records, and a viewer, for visualising activity records in various forms. We expect this system to support anaesthetists in improving three of their key abilities: record keeping, technical knowledge and skills, and communication. We also believe that the system could be expanded into other medical disciplines, offering great potential to enable all clinicians to practice continuous improvement in key abilities for their practice.

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