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Safe asleep? Human–machine relations in medical practice

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Abstract

In the process of anaesthesia the patient must surrender vital functions to the care of clinicians and machines who will act for, and advocate for the patient during the surgical procedure. In this paper, we discuss the practices and knowledge sources that underpin safety in a risky field in which many boundaries are crossed and dissolved. Anaesthetic practice is at the frontier not only of conscious/unconsciousness but is also at the human/machine frontier, where a range of technologies acts as both delegates and intermediaries between patient and practitioner. We are concerned with how practitioners accommodate and manage these shifting boundaries and what kinds of knowledge sources the 'expert' must employ to make decisions. Such sources include clinical, social and electronic which in their various forms demonstrate the hybrid and collective nature of anaesthetised patients. In managing this collective, the expert is one who is able to judge where the boundary lies between what is routine and what is critical in practice, while the junior must judge the personal limits of expertise in practice. In exploring the working of anaesthetic hybrids, we argue that recognising the changing distribution of agency between humans and machines itself illustrates important features of human authorship and expertise.

Keywords: Anaesthetic practice; Human–machine boundary; Medical decision-making; UK

Introduction—researching expertise in anaesthesia

It is the goal of anaesthesia to maintain 'safety in sleep'.[1] Patients regularly, and counterintuitively, submit themselves to being 'sent to sleep' as it is euphemistically termed, and therefore it is in all our interests to understand how safety is maintained. Or to put it another way, to explore how expertise is acquired in a field of practice that is about much more than enabling surgery. The work that underpins anaesthesia is inherently dynamic: our observations show that it is in accommodating the unexpected and unexplained that expertise in practice is gradually acquired and maintained. Findings from our work contribute to the growing understanding that there is more to safe practice than strict adherence to clinical guidelines; more to the achievement of positive outcomes than rigid application of protocols derived from systematic reviews of evidence (Berg, 1997; Mol, 2002). Safe practice is about guidelines *and* situated knowledge; it is about evidence *and* experience.

Undertaking ethnography in anaesthesia is challenging! Some studies have compared the work of anaesthetists with those of airline pilots and air traffic control staff (Chappelow, 1994; Helmreich, 2000). Both groups of professionals operate in highly technologically mediated environments and need to maintain concentration at times when there *appears* to be little

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[1] In somno securitas (safety in sleep) is the adopted motto of the Association of Anaesthetists.

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happening. The aviation metaphor is useful to describe the phases of anaesthetic work, the patient's journey; 'takeoff' relates to the process of inducing the patient into unconsciousness using a variety of techniques, drugs and devices, where the patient surrenders fundamental forms of agency such as the ability to breathe. 'Landing' is about reversing this state, achieving 'emergence' or waking the patient up safely, assisting her to recover agency and control of functions, whilst maintaining pain-free status. Since these are the two dominant and critical phases of anaesthesia, what happens 'in flight' receives less attention in research and training programmes. Induction and emergence are the most *visible* phases of anaesthetic work and therefore the most studied. However, these are achieved, we argue, as much by maintaining routines, by mundane practice and management of the action in the normally uneventful 'middle' phase of the journey, as by key interventions at take-off and landing.

In this paper we ask 'what makes an expert?' and 'what sources of knowledge does an expert use in practice?' in the increasingly technologically mediated environment of anaesthesia. Our project finds common ground with sociologists and anthropologists of science and technology and with theories of knowledge production and feminist science studies. Such studies include early worker and feminist accounts of technology and accountability (Cockburn, 1985; Cooley, 1980; Haraway, 1991; Rose, 1983) and links with recent debates around the nature of agency, in which perspectives about the machine have developed from 'instrument' or device, to 'acting and interacting other' (Suchman, forthcoming). We are concerned with deepening our understanding of human–machine relations, because these are increasingly central to medical practice and therefore integral to the enhancement of patient safety and avoidance of adverse incidents. Below we examine different phases or types of work undertaken by anaesthetic teams. Then, acknowledging the actor network approach, we argue for a symmetrical perspective from which to view anaesthetic practice, since it is clear that the clinician does not (and cannot) entirely control the action, yet must arbitrate, interpret and critically, make judgements between human and non-human actants, agents and often conflicting sources of knowledge. We then turn from symmetry to asymmetry, in particular the problem of the differential distribution of agency and accountability in practice, and argue against a model of medical training that promotes the 'lone expert', and for a model that acknowledges the 'artful integrator'.

Our study draws on more than 140 h of annotated real-time observation of anaesthetic teams in practice in two English district general hospitals. In addition we carried out 21 semi-structured interviews with a purposive sample of practitioners including 4 debriefings (joint transcript readings) with practitioners following theatre sessions. The study focused mainly on the operating theatre environment, and included observation of and interviews with anaesthetists, surgeons, operating department practitioners, theatre and recovery nurses. Regular meetings were held to inform all staff of progress of the study and to secure their continued co-operation. None declined to be observed although two people declined to be interviewed. Patients on the operating lists were informed verbally and in writing of the study and written consent obtained.

Operating sessions were purposively sampled to cover a range of different types of surgery and anaesthetic practice and levels of anaesthetic expertise. Detailed contemporaneous notes were taken and transcribed immediately following the observation session. Three broad approaches were used for the observation. First, we followed the anaesthetist through from pre-operative patient visits to the operation itself. Some anaesthetists were able to take part in a debriefing interview immediately after the list, allowing the researcher to ask more directed questions about what she had seen. Second, we followed individual patients through from ward to theatre to recovery room and back to the ward. Third, we followed the 'tribes'—clinical functions where boundaries between different staff groups and areas of expertise appeared most fluid—in theatre, recovery rooms and intensive care units. In addition, departmental audit meetings and teaching sessions were observed.

Negotiating boundaries of work

Many boundaries are crossed, re-crossed, shifted and re-established in anaesthetic work: between team members; conscious/unconsciousness; human and machine; inside and outside the anaesthetic room–theatre, to name a few. Hindmarsh and Pilnick (2002) examined the intersection of two of these boundaries, teamwork and induction (sending the patient to sleep). Drawing on Goffman, they analysed induction practice as an example of where practitioners move from 'front stage' to 'back stage' (and reverse) working, in terms of the interactions between the human actors present. Teamwork is critical to safe anaesthetic practice, since this relies on the smooth and swift manipulation of devices, talk, bodies and drugs, where the team consists of a number of 'tribes' and hierarchies, such as the consultant anaesthetist, trainee anaesthetist, operating department practitioner (ODP); anaesthetic nurse; patient, and a number of others, e.g. surgeons, orderlies or ward staff. Some anaesthetic techniques require a strictly ordered performance by two or more practitioners, for example, in patients who are especially at risk of vomiting on induction a 'rapid sequence

induction' is required. In this the anaesthetist's assistant must apply pressure to a particular area of the patient's neck from the moment they lose consciousness until the anaesthetist has secured the patient's airway by intubation. Hindmarsh and Pilnick's video-based study demonstrates how these practices are aided by practitioners' talk, in that both anaesthetist and assistant will take their cue from, and act on the basis of, talk that is ostensibly directed at the patient.

Boundaries between human actors and between humans and machines get dissolved at key moments in the process, e.g. of induction, when administering the anaesthetic drugs and maintaining the patient's breathing function. This boundary crossing is critical, at such times a 'hush' descends on the anaesthetic room. Below is an example from our own study where just after induction, the ordered disconnection phase where the patient must be quickly transferred to theatre is threatened by a nurse 'randomly' entering the anaesthetic room in search of another anaesthetist. The anaesthetist momentarily loses track of what he was doing:

> …ODP then puts a white paper blanket over the upper half of the patient, removes the backing strip and sticks it down to just below the patient's ribs.
>
> ODP *Right,* signifying he is ready to go through to theatre.
>
> A1 unplugs the hot line. ODP disconnects the monitoring and takes the brakes off the bed. A staff nurse enters and asks for Dr Miles (anaesthetist), A1 says he hasn't arrived yet. This seems to distract A1 and he says, *what was I doing, oh yes*. A1 disconnects the breathing circuit.
>
> 08.48
>
> Patient is wheeled into theatre and transferred onto the table by 6 people. ODP picks up a sandbag from a stand close to the anaesthetic trolley. He positions the sandbag between the patient's calves, then bends the right leg and rests the foot into the sandbag. A1 connects up the monitoring and sets up the ventilator…

Induction and emergence in anaesthesia then allow for different kinds of interaction and behaviours amongst team members. The anaesthetic room is the place where the patient surrenders vital functions and goes to sleep—it is the anaesthetist's domain, a place where others, e.g. surgeons may be tolerated but do not 'belong'. During landing, this domain is less delineated—often taking place in theatre after the patient has been transferred from the operating table to bed. Waking up is a time when the attention of the anaesthetic team is intensely concentrated on the patient's face and clinical signs. Other activities may be happening all around, but again a tension is created around the 'space' in which emergence is performed.

Hindmarsh and Pilnick's important study shows how much work is achieved by anaesthetic teams through human *talk and action*. In our study we wished to take a step further, asking what IS a patient or what IS a machine in anaesthesia? Hirschauer (1991) in his graphic study of surgery speaks of the patients as 'dumb' and 'powerless', illustrating 'the vanishing patient', 'the body reduced to the area of operation', but also of them as 'virtual participants', neither present nor absent. Our aim was to recover, something of the agency of the silent actors—the patients and machines upon which action appears to be performed. A substantial part of the team's work lies in observing and interpreting the changing human–machine interface. During certain procedures it is not possible to disentangle patient and machine, to tell where (indeed if) human ends and machine begins. The anaesthetist's relationship with the machines is caught up with balancing different ways of knowing the patient in a setting in which progression (in the patient's journey) is almost always the goal. Because the patient cannot self-organise and perform closure of the procedure, the anaesthetist and the machines act as proxies to achieve this:

> A1 *Can we have her feet to the door and her head to the anaesthetic machine, that way I can reach the anaesthetic machine*? The patient's trolley is wheeled so it is at a right angle to the operating table.
>
> Recovery nurse covers the patient with the sheets. A1 opens another suction tube, turns the suction on. A1 *She's not quite on her side is she*? (to N2) N2 and A1 reposition the patient's shoulders. N3 to N2: *Chris… do the next…* N2 moves away from the patient. Anaesthetic machine beeps. A1:… *might have to wait for the CO_2 to rise before…* A1 ventilates, she takes the tape off the ET tube. Machine beeps (a single beep signifying it has just recorded the BP). The patient moves, CO_2 trace now going up and down.
>
> A1: *Claire, deep breaths*. Rec Nurse prepares the oxygen mask. A1**:** *Claire! (*then to Med Student)… *take the tube out when I'm happy that she is breathing regularly… not quite yet…* Patient is still again, the CO_2 trace now flat. A1: *Claire*! Patient gagging on tube, begins to chew it then stops, rubs her eye. CO_2 trace goes up and down again. A1: *Deep breath in!* she squeezes the reservoir bag and pulls the tube out. Rec Nurse puts the oxygen mask on the patient. A1 gets a litre of Hartmans out of the trolley drawer.
>
> A1: *So we know she is breathing because the mask is steaming up and you can feel her abdomen…* Rec nurse and A1 disconnect the monitoring. 15.12 RN and A1 wheel the patient to Recovery, then connect the monitoring.

Collective work

Each procedure affords a particular configuration of human and non-human relations. In studying this we end up exploring the relationship between three entities: patient, monitoring machines and the anaesthetists; we can call this the PMA collective. During the journey through induction into anaesthesia, duration of the surgery and emergence (in general anaesthesia), the PMA relationship is continuous, fluid, circular, and at its most hybrid moments symmetrical. We illuminate this functioning relationship in Fig. 1, (which is descriptive, rather than analytical).[2]

At induction vital functions such as breathing; signs of function such as blood pressure or oxygen saturation; and consciousness itself, are delegated to machines and to a human advocate, the anaesthetist, and those working in the anaesthetic team. Active participation, resistance, self-protection on the part of the patient appears impossible. The stewardship of the patient's interests involves employing a number of streams/sources of knowledge about the anaesthetised patient, not least what is being told about her through machines. These sources of knowledge are co-present but may attain varying levels of importance and visibility, see Fig. 2.

During induction, the patient almost literally flows into the machine(s). These machines vary in character from ventilator with its mechanical action and its directly delegated agency, to monitoring equipment—information and communication technologies that narrate and record the patient's behaviour electronically.[3] Here the relations between the three entities are fluid—the patient is literally part human, part machine; the anaesthetist (and sometimes members of the team) is mediator between patient and machine; the machine is mediating between patient and anaesthetist. All are hybrids in action and each is unable to act independently. It could be argued that what happens in highly developed Western anaesthetic practice actually weakens the modernist concept of human–machine divide. The PMA collective embodies the bridging of this divide in very particular ways. It follows then that the acknowledged working of hybrids in action has implications for the concepts of both 'human error' and 'machine failure'.

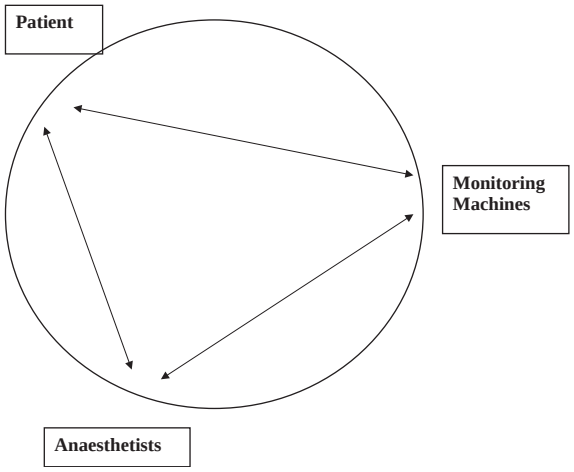

Fig. 1. PMA collective.

Mode	Manifestation
Clinical	Touch
Social	Pre-operative assessment
Electronic	Signals on monitors
Historical	Clinical notes
Experiential	Tacit skills, technique

Fig. 2. Examples of knowledge sources in anaesthesia.

Routine work: managing density

Perhaps one way of approaching the centrality of the human–machine relationship in anaesthesia is to examine routine work in the middle phase or 'flight'. Below is a field note sample from a 'routine' surgical list, on a 'routine' morning, during the procedure. It shows that routine practice is gravid with possibilities, histories, futures, distractions, the planned and the arbitrary. Drawing out this action density and heterogeneity and making this visible in meetings with practitioners was helpful in understanding expertise because this is often missing from explicit training (Smith, Goodwin, Mort, & Pope, 2002). It shows the role of 'mutual monitoring' of humans and machines and repeated checking work in maintaining safety.

In the story below we see how negotiations about future patients morning's, the severity of their medical condition and their likely post-operative location, overlay practices oriented to the present patient. Further, we see that unexplained CO_2 readings are intersected with the complexities of the patient's medical history, the specificities of the anaesthetic machines, with what the monitoring readings might be telling, and how such tellings or translations might introduce ambiguities.

[2]This may appear to be a 'black box' teamwork and the anaesthetic community of practice. We discuss this further in paper to appear in a forthcoming special issue of the journal Sociology of Health and Illness.

[3]When a ventilator is used its actions drive the patient's breathing, but the airway pressures it generates are picked up and displayed electronically, as are the oxygen saturation readings that are sensed and displayed separately on the anaesthetic machine.

Routine practices and common improvisations (such as here retaining infusion fluids to recommence after administering the antibiotic), are queried in the light of the patient's medical history. Juxtaposed are conversations about past patients and their trajectories; indeed one 're-appears' in discussion about a forthcoming inquest. In this way, temporally, spatially and materially disparate threads are woven into the routine practice of anaesthesia.

In examining this example of routine practice, we see the nature of errors that commonly arise with 'hybrids in action':

08.30. In the anaesthetic room. As the ODP is connecting up the monitoring I ask him how he finds the new machines. He tells me about a difficulty he had with the machine in theatre that morning. When changing the soda lime (a large canister of pink granules that absorbs carbon dioxide) the old machines just used to clip back in but with these machines you have to get it exactly right or you don't get a seal and end up with quite a big leak in the circuit.

During the procedure the anaesthetist encounters a CO_2 reading that was not falling to baseline.

ODP *This guy has dialysis 3 times a week, does that have any impact on the anaesthetic?*

Anaesthetist 1 *Not enormously, it means he won't clear the anaesthetic so we'll try and make it…*

A1 *changes the ear probe back to the pulse oximeter. The volume on the pulse oximeter is quieter. At first there is no trace on the monitor for the pulse oximeter, after a few moments the trace begins.*

09.16. A1 looks at the anaesthetic machine and mentions the CO_2.

ODP *What are you thinking? MH?*

A1 *I'm not really thinking MH, he's had too many anaesthetics, but he shouldn't have a CO_2 of that either.*

(MH—Malignant Hyperthermia, a rare inherited disorder triggered by anaesthetic agents, characterised by climbing temperature and a high CO_2)

Anaesthetist and ODP keep checking the machine connections, and the soda lime container for a possible leak, but they cannot locate the source of the problem—is it human or machine?

A1 and ODP talk about the anaesthetic machine.

A1 … *CO_2 trace…*

ODP… *leak… soda lime…*

A1 takes his gloves off, kneels down, looking and feeling round the canister of soda lime.

The anaesthetist decides the reading is erroneous but the problem remains unsolved, unexplained.

09.48. A1 writing on anaesthetic chart. A1 runs the back of his hand over the patient's forehead. A1 stands looking at the monitoring.

[Data omitted here, routine work]

10.04. A1 *This guy's getting steadily cooler … 36.3.*

ODP *Gamgee hat*

ODP brings in some Gamgee (cotton wool covered in gauze) and drapes it over the patient's head.

A1 We will do your lady but I wouldn't be surprised if she needs ICU post op. (to Surgeon 1)

CO_2 5.7, p 68, ox sat 99%, bp 99/59.

As the procedure finishes I ask A1: *Were you worried about the CO_2 earlier*?

A1 *Yes because the trace didn't drop to the baseline which means that he will have inspiratory CO_2 which you shouldn't have at all. It should wipe it out. So that means either a leak in the circuit or MH, it's unlikely to be MH as he has had too many previous operations. It seems to have resolved now and it didn't clinically cause any problems, also the falling temperature is comforting. In the anaesthetic room his CO_2 was 11 on 8litres and if I ran at my normal low flows of 1litre I was worried his CO_2 would have just climbed. I was also worried that the iso reading was not correct, but again that did not cause a problem clinically.*

10.12. ODP: *Drip for the next*?

A1 *Yes*

This functioning relationship is a collective of materials, techniques, bodies and plans. It is collectively producing knowledge and action. Following Callon and Rabeharisoa (2004) and Moreira (2004) we can also see how each entity is also a collective—the patient is the embodied achievement of all the work previously done to enable the moment of surgery/anaesthesia; it follows that the anaesthetist is a collective, incorporating and performing many different forms of knowledge, not least partly produced by the skills of ODPs and nurses; again, the machine is a collective, embodying the action of both patient and professional whilst translating between them. Each member of the collective is producing knowledge about the progress and safety of the procedure in hand. To balance, disentangle and judge between these knowledges, whilst remaining 'agnostic' as to their hierarchy, underpins safe practice, underpins expertise. Being able to recognise the possible explanations, the heterogeneity of knowledges involved, protects against mistakes and near misses, and actually *strengthens* practice.[4]

[4]A parallel can be drawn with Singleton (1998), where laboratory scientists reading large quantities of slides for the cervical screening programme. An awareness of the complexities, ambiguities, and sometimes arbitrariness, of the samples actually underpinned the expertise of those making judgements about them.

Balancing work: Multiple ways of knowing

So anaesthetic work involves simultaneous balancing of different knowledge sources or streams relating to the anaesthetised patient (and some others relating to non-patient issues). Fig. 2 is by no means exhaustive, but offers examples of these knowledge sources: clinical knowledge obtained by e.g. frequently touching patient; social knowledge gathered via pre-operative assessment; 'historical' knowledge gleaned from clinical notes and other inscriptions; electronic knowledge from the continuous readings given by monitoring equipment, and experiential knowledge—emanating from previous practice, acquired technique or management of incidents and how these compare with the present action.

Trainees must learn how to make judgements between knowledge streams. In this sample a junior anaesthetist talks over the problem of making sense of flows of knowledge that did not seem to accord with the expected patient trajectory. In attempting to balance these flows he is not able to integrate them into a situated diagnosis:

> A1: *I eventually got to see him about seven o'clock I think, and he didn't look particularly well but just as I was getting onto the ward I was bleeped by, erm a theatre nurse to say that they could send for the next one so I didn't really assess him as much perhaps as I should of. ….*
>
> *…then did a rapid sequence induction and I think his BP pre induction was about 110, 120 dropped to about 80 post induction, and he was still quite tachycardic, 150. Operation took about an hour, an hour an a half, erm, I poured in quite a lot of fluids and I was thinking 'oh he's obviously not very dry and not that well', but I didn't quite put everything together, the fact that he was clammy before and had spiked a temperature and I poured a lot of fluids in and stuff, erm, he was obviously septic but I didn't quite put it together. I thought of doing blood gases but I didn't do, but I wrote on the, erm… with the fluids his heart rate had come down, it was 150, but it came down to about 90, and his BP went up to about 90 as well. So basically started waking him up, put him on left lateral and what have you, saturations had been fine he was taking a long time to wake up and by this time the next patient was….*
>
> *…eventually (he) started showing signs of er waking up, just moved his arm a bit and er so I pulled the tube out and er put the mask back on and then he started with what I thought was a laryngospasm…*
>
> *…it was obvious he was going blue so tried to get a good seal and do a bit of CPAP thinking it was laryngospasm, to try and break it as it obviously wasn't working er, em at this point I think I asked, I asked for some help, ….*
>
> *Got him head down and er basically popped the tube back in, gave him the sux, well gave him the propofol first then gave him sux, then popped tube back in, eventually erm I got it relatively easily to get the tube back in erm and then popped the tube back in then frantic ventilation and the sats came up a little but only to about 80 by which time we started ventilating when A2 arrived and at which point I sat down and thought shit, and basically A2 took over.*
>
> *… I think we took the gases straight after and they were pretty shitty erh I think, I can't quite remember, CO_2 was about 60 odd, looked at it, PO_2 was 50, 60, his base excess was minus 10, which means he has actually been septic for you know for quite a while, well a fair few hours. To get base excess of that you have to, you know, it's not going to, a straight away thing, so obviously he'd been a lot more ill than we'd thought you know. So basically then he went to ITU. We cancelled the next patient…. Woke up in the morning and thought right, that's it, giving up anaesthetics.*
>
> *It was only speaking to A2 afterwards …from the sepsis point of view, I didn't put it together until speaking to A2 afterwards, but it was all there, I was on the right lines but I didn't put it together.*
>
> (Debriefing with trainee following critical incident)

Touch

A key knowledge source is 'touch' but touch is inextricable from 'technique'. Below a trainee anaesthetist speaks about one of the first few occasions in which he worked independently (without the direct supervision of a consultant). On being asked how skills develop, he explains the need to limit variations in technique to which one is exposed. He refers to a form of apprenticeship where the 'expert' embodies personal techniques; each different 'expert' he works with demonstrates different techniques. Here he refers to part of the induction process:

> … said he finds it difficult actually practising a technique as when he works with others (experts) all the time he is always shown different methods. He gave the example of femoral blocks, so far he has been shown 4 different methods and he says that he just needs to practise one, and 'learn how it feels'…
>
> (Observation notes, senior house officer, 6 months experience)

To acquire personal technique he must 'learn how it feels'; acquire a sense of what feels 'normal'. The one-dimensional explicit instruction in formal and textbook teaching about 'blocks' or regional anaesthesia[5] is

[5]'Block' is a shorthand term for regional anaesthesia, i.e. where a section of the body such as a lower quadrant is literally blocked by inserting a nerve paralysing drug, or as in epidurals on obstetrics where both lower quadrants are blocked.)

gradually underpinned in practice with knowledge that is also personal, cognitive and tactile; however there are many embodiments of this. In describing the need to 'learn how it feels', the trainee is talking about knowledge acquired by contact (literally resistance) from the patient's body; such haptic knowledge is conveyed in touch from patient to trainee who must learn how to 'feel' with the needle. Respondents often struggled to find ways to articulate this 'learn how it feels'. As Polanyi put it: 'We know more than we can tell'; in this case the trainee must 'dwell within' the technique to become skilled (Polanyi, 1967).

Machines

Monitoring machines offer a narrative about the patient, which the anaesthetist may believe, question or ignore. 'Narrative' is perhaps a strange term to use for what are mathematically based readings: e.g. blood pressure, oxygen saturation. Anaesthetists call this 'watching the numbers'. The machine narrative has a particular character: different from the other knowledge streams in that it is contemporaneous, unlike medical records; precise in numerical terms, unlike the patient's pallor or feel/volume of pulse; ahistorical in that it has no patient knowledge prior to the machine connections, e.g. medication that might affect 'normal' parameters.

Faced with the electronic narrative, the anaesthetist must keep making choices by balancing the electronic with the other knowledges. She must ask: how does the monitoring narrative cohere with the other sources of knowledge available? There are many examples from our study of the human actors' ambivalence about monitoring equipment, including not believing, discounting or over-riding 'the numbers'. If the monitors tell an unexpected story, the anaesthetist may:

1. Check the patient–machine interface:

> ODP1 and A2 talk about the ECG
> *can't be double counting…*,
> monitor still reading >250. A2 reaches under the drapes. ODP1 takes new stickers out and reaching under the drapes applies them to the patient.
> A2 sits down and writes on the anaesthetic chart.
> ODP1: *not a very good trace but the numbers are better*
> (the trace looks small on the screen, reading 83).
> A2 *yes, thank you*
> [Observation in theatre, consultant anaesthetist (A2) and assistant (ODP1)]

2. Wait for events to become clearer:

> A1 stood by the pump looking at the monitoring screen. He presses buttons on the pump, walks over to me (researcher).
> A1 *… totally isolated low BP (44/?) in the presence of a good radial pulse… artefact…*
> R *…I was going ask whether you believed it…*
> A1 *No*
> A1 back to the anaesthetic machine.
> A1 *See* (to me) he points to a blood pressure of 103/?
> [Observation, consultant anaesthetist (A1). R is observer]

3. Cross-check with other monitors:

> 'Apnea' flashing on the anaesthetic machine, it is also beeping.
> A1 has an empty syringe in his hand. He ventilates twice, waits.
> He ventilates twice again and waits.
> 11.15
> 2 beeps from the anaesthetic machine. Apnea still flashing.
> A1 closes the valve and ventilates, he looks at the patient's pupils, ventilates again.
> A1 goes into the anaesthetic room and returns with a nerve stimulator, places it against the patient's temples; patient's temples twitch.
> A1 *Thomas!*
> Patient is moving now, his hand towards his mouth.
> [Observation, anaesthetist in theatre]

4. Override the readings:

> The anaesthetic machine beeps – heart rate 40, A1 presses something on the anaesthetic machine then resumes his conversation with A3.
> 38 flashing on the anaesthetic machine with 'BRADY'[6] in a red box flashing at the top of the screen.
> A1 looks at the anaesthetic machine whilst talking to A3.
> BP 100/49.
> A1 looks over the curtain. The anaesthetic machine beeps again and is silenced.
> (Observation in theatre)

The anaesthetic machine has default limits that are set to correspond with the 'normal' patient; alarms will go off if these limits are exceeded. Most anaesthetists understand that their patient may not 'fit' this

[6]Bradycardia, the term given to slow heart rate.

construction of normality so they might want to recalibrate the machine to align it with the particular patient's physiological profile, where patient, anaesthetist and machines collaboratively construct the acceptable limits of normality. Often however this is not done because it carries the risk that the practitioners might fail to re-set the limits for the next patient.

An image offered by Suchman (1987) in her description of users of a new design of Xerox copying machines, seems useful here; it is as if the anaesthetic monitors are watching the patient through a 'small keyhole' and mapping their findings onto a trajectory of action which *ought* to work. The readings displayed on the monitors map onto a template that interprets them as 'bradycardia'. The patient *ought* to have bradycardia ('Brady' or slow heart-rate). Indeed, the patient *does* have bradycardia but the machine does not have access to other knowledge that might mitigate this, e.g. it cannot know whether the patient is taking beta blockers.

The monitors tell a particular kind of story about the patient, but what is puzzling here is that the machines in some way *are* the patient, because they are physically attached to the patient, patient and machine are (temporarily) one. In fact, as explained above, the monitors usually represent *all* patients, their limits reflect *aggregated* patents, although in some procedures they may be individually calibrated. This is where the task of understanding the relations within the PMA becomes especially tricky, prompting the question what IS a patient?

The different performances of the anaesthetists given above in relation to electronic readings are well known among practitioners. But we did not encounter a priori assumptions that machine knowledge was in some way inferior. The PMA collective works unhierarchically when it works best, i.e. when all forms of knowledge, e.g. algorithmic (monitors), empirical (touch, observation), social/historical (pre-operative discussion with patient) are balanced in action. It is known that changes may take place mid-flight: each patient's anaesthetic experience is context specific; practitioners may favour particular techniques, but each will say that the design, ('choreography' as one put it) coheres with the particular physiology of the individual patient. While the anaesthetic plan is patient specific, it may also alter during the journey, as it is well recognised by practitioners that reactions and behaviours cannot always be predicted.[7]

> *You never have all the information, or you never know that you have all the information, there may be some other information unknown to you, and in a situation like the one I was in, [anaphylaxis to an intravenous antibiotic] it was an evolving clinical pattern, and at each stage you make a diagnosis, you work on it, and if it doesn't fit, if the treatment isn't working or the situation is getting worse, beyond the expectations that you have for it, then you have to change and reassess. It's like watching a film, you don't just watch one shot of a film, it's an evolving process that you continue to interpret.*
>
> (interview with specialist registrar, 6 years' experience)

Constructing coherence

How does this multiplicity, this hybridity and symmetry in practice then progress and conclude? Emergence from anaesthesia involves the reversing the flow of functions, of agency back from the machines to the patient. This requires various disconnections and a smooth progression. Things may get tense at this time: *Come on Mrs M, time to wake up!* indicates to all practitioners in earshot that emergence is, or should be underway. Following this, the process of the 'handover' involves achieving a coherence of what has gone before, such that the patient is stabilised and future action by others is enabled. Handover involves crossing a physical boundary (i.e. from theatre to recovery room) and literally handing over the patient to a new practitioner by means of employing a body of talk that (mantra-like) *packages* what has gone before.

Achieving the handover means that the patient is no longer considered to be attached to the domain of surgery or anaesthesia, but becomes the legitimate inhabitant of a new domain, the recovery room, where different regimes of observation and monitoring apply. Coherence in handover is achieved by simplification of the previous events such that it is accepted by the recovery staff. The sample below is from a bronchoscopy procedure where the anaesthetist is demonstrating to the trainee how he ventilates the patient while he has many other things to do with his hands at that time. This is an efficient but idiosyncratic technique evolved in practice, (certainly not written up in textbooks!) which comes at the end of the procedure, during a period of high activity, where the patient is emerging from the anaesthetic:

> A1 places the black mask back over the pt's face and lifts the patient's head. A2 replaces the pillows. A2 picks the reservoir bag up off the floor, A1 drops it back down and ventilates, squeezing the bag with his foot.

[7]Here the anaesthetist recognises that he cannot ultimately control the flow of information on which he bases his decisions, an understanding analogous with one that evolved for the researchers during the course of the study—the ethnographer too cannot completely control the events and access to events that will be recorded as data (Goodwin, Pope, Mort, & Smith, 2003).

A1 *so easy, when you've got so many things going on, makes it easy, have a go*….
A2 squeezes the bag with her foot.

However, at the end of the procedure (which was complex and unusual), the anaesthetist hands a 'standard' case over to the recovery nurse:

A1…*Bronchoscopy under GA… standard… propofol, sux, midazolam, lignocaine to the cords… had a washy-brushy type thing so he will cough. He will breathe eventually*!
(Theatre/Recovery observation)

Here in a busy recovery room, the handover of 'Patient 6' is partially made—*'it all works…'* but there is a lingering doubt about his blood pressure, which has to be resolved when the anaesthetist reappears with a subsequent patient:

Patient 6 brought in. Nurse 1 has to move Patient 5 aside so that P6 can be got through the door. Brought by Anaesthetist 1 and nurse who carry on attending P6, other staff ignore this. A1 briefs a nurse who is going to recover.
[The child (P 4) starts to cry—this pierces the atmosphere….]
A1: *He is very crooked, but he likes to be like that—it all works* (relating to tubes). *OK*? He leaves.
Later….Nurse 1 sits down at phone and calls for P6 to be collected. She fills in desk diary, which seems to be a list of patients' names and numbers; checks through list and writes down names. N2 asks N1 to have a word with A1 as P6's blood pressure has gone up. N1 goes over to patient, consults notes and decides: *it's normal.*
A1 comes in anyway with P7**,** accompanied by ODP1 and one other.
A1: *are you ready for him?* (I think he must be being cynical) Briefs N1 re 79-year-old P7.
An orderly jokes with us that research looks like *skiving…*
N2 tries to get A1's attention about Patient 6's blood pressure. A1, N1 and ODP1 still smiling over P7. Phone rings, the orderly answers: *they're all busy at the moment.*
N1 talks to A1 who says: *it's fine, excellent.* P6 thanks him and squeezes his hand, A1: *you're very welcome*.
(Observation in Recovery room)

So a safe anaesthetic journey involves both a context specific design of human–machine configurations, and the flexibility to alter this design with evolving and dynamic conditions (routine and critical), which then become part of a post hoc rationalised design. Decisions are informed by the key knowledge producers: patient, machine and anaesthetist/team. None of these entities act unilaterally, e.g. the electronic 'norms' are constructed by patient and anaesthetist, and affected by the chosen anaesthetic technique and requirements of surgery; routines of work are constructed by devices, equipment and anaesthetists; the machine narrative emanates from both the patient and the machine. It can be seen that the range of actants, which potentially influence the course of the action is almost limitless. In this way the roles of designer, user, producer of anaesthesia are constantly being linked, and attempts at purifying the action by, e.g. the imposition of hierarchy, get resisted by heterogeneity of practice:

…you can be an expert in one theatre, and in the next-door theatre you may not be an expert. Because you are not used to working in that environment. (Refers to personal experience of a change in working environment) *OK, I had been a consultant for fifteen years; I felt like a fish out of water. And I felt unsafe because the equipment was unfamiliar to me. I mean it was all basically anaesthetic equipment that anyone can use but it was equipment that I was not at that time particularly familiar with. Working with staff that I didn't know and with surgeons that operated in a different way. And all these things, I mean you, you're actually degraded as an expert* (our emphasis). *And you are having to start to learn again, even though you have been a consultant for fifteen years. And that applies every time you move outside of that field which you've built up your expertise in over the years.*
(interview with consultant anaesthetist)

Agency, action and asymmetry

Our concept of agency here is that it is not necessarily the domain of humans. Agency, like power, can be accessed (but not possessed) by humans and or machines, and is a product of their interaction. When it is accessed it displays different, varied characteristics: the ventilator breathes for the patient and so the nature of its agency is delegated, it is a mechanical device that takes on a direct function of the patient. In contrast, the electronic monitors tell a continuous story about how the patient is responding to a complex situation involving invasive surgery, drugs and pain. The monitors are (algorithmically) interpreting this complexity and simplifying it, but this interpretation is subject to deconstruction/interpretation, as shown in the extracts above. So here are two rather different forms of machine agency (and it is easy to see, as Suchman points out, why 'intelligence' is attributed to one but not the other), but neither are exclusive to machines—the anaesthetist might decide to ventilate the patient manually for example, at times during induction when the drugs take effect but breathing has not either been restored or delegated to the ventilator. Or the anaesthetist might

keep her hand continuously over the patient's pulse if unable to read the monitoring, substituting touch for electronic reading, using touch 'mathematically'. In this context, agency ebbs and flows between humans and machines as does the character and context of knowledge production.

So the roles identified here of delegate or narrator (there are many others) can be undertaken by either machines or humans; depending on the context the machine or the human can be subject or object, active or passive. So far our account accords with the symmetry and circularity in the analysis of human–machine relations characterised by the actor network approach within science studies. However, in recognising that action and agency are distributed at times differentially, we come next, along with others (Oudshoorn, Brouns, & van Oost, in press) to the struggle to understand the problem of asymmetry in agency within the collective and between actants. Faced with often confusing or conflicting knowledge streams arising from distributed action, the anaesthetist must make judgements about them; this might involve overriding the machine or overruling a colleague. To observe that action is distributed, that knowledge is collectively produced, appears to ignore the form of professional accountability within which such teams work, in particular its medico-legal positioning. On a personal level it does not do justice to the enormous tension experienced by the junior anaesthetist working out of hours, as s/he encounters the frontiers of her expertise and must judge when to call for expert help. In medico-legal terms, it is not the machines who might be sued (although manufacturers might conceivably be); and when it comes to making a decision in the middle of the night about, e.g. how to treat a patient with a perforated bowel it is the anaesthetist, rather than the ODP/nurse, or the patient, or the machine, who must take it. So yes, agency is a product of action which is itself distributed, but the 'authorship of the tough decision', the criticality of the accountable human actor, provides a challenge for symmetrical accounts of collectives; authorship is intertwined with accountability (Suchman, 2002).

We have observed that the anaesthetist is the co-constructor of knowledge about the patient and the mediator of that knowledge. S/he is responsible, not as lone producer/guardian/actor, but as a collective one, responsible for maintaining the PMA. The collective labour of the PMA and its outcomes are the responsibility (but cannot be controlled by) of the anaesthetist, not the machine and not the patient. We found that the most common form of anaesthetic labour was that of ordering: the task of ordering patients on the list; ordering knowledge in production; ordering boundaries. Part of this ordering work actually involves re-imposing the human–machine divide—stepping in and judging when the machine may NOT be the patient, is NOT speaking for the patient, and therefore when it may be necessary to override the machine. So here the human–machine boundary is seen as temporary, situated, not inevitable or pre-existing. Here we find Suchman's elaboration of 'located accountability' helpful and her drawing on the development by others of a 'feminist objectivity'. Such an objectivity she says, values the 'artful integration' of practice (in our context the artful integration of knowledge sources). By showing and working on the PMA, the hybridity of its members, we avoid the dangerous 'purification', to echo Latour, which would pertain in say, heroic accounts of the lone expert.

Conclusions

So it is in recognising that knowledge is co-produced that safe practice is enhanced, in this context by making the balancing work outlined above more visible. The work of anaesthesia will become even more technologically sophisticated; developers are currently working on a machine which is said to measure and monitor the depth of anaesthesia, judgements about which are presently undertaken by the anaesthetist, informed by the available knowledges and tests. As Mackenzie (1996) points out in his essay on computer related accidental death:

> …as computerisation becomes more intensive, highly automated systems become increasingly primary. Ultimate human control—such as a human decision to activate the firing mode of an automated weapon system—is currently retained in most such systems. But the human beings responsible for such systems may have lost the intangible cognitive benefits from their having constantly to integrate and make sense of the data flowing in.

Making sense of different ways of the knowing the patient is at the core of anaesthetic practice and it is this activity which we argue needs to be retained in the context of elaborating machine functions. Many episodes in anaesthetic work cannot be fully explained, because practice is complex and tacit skills have been used to make sense of them. As Law and Mol (2002) put it: 'In a complex world there are no simple binaries. Things add up *and* they don't'. Clinical practitioners 'make decisions and perform actions, thus finding their way, generally fully aware that complete control of a treatment's unfolding is a fiction,' (Mesman, in preparation).

As for our own accountability for the research and its outcomes, we have sought to present our data and analysis to groups of practitioners wherever possible. The audiences have almost never heard of ethnography or structured observational methods, yet they engage very closely with the data and the complexity of practice

that it can reveal. Following the formal presentation of our report into what makes an expert anaesthetist and how practitioners acquire expertise; we were invited to work with the Royal College of Anaesthetists to integrate observational methods into the formal training of juniors.

More broadly, much sociology of technology has been aimed at deconstructing rhetorics of inevitability, autonomy and determinism that accompany innovations, just as the sociology of scientific knowledge problematised the 'natural' as applied to the sciences. Workers and sociologists of technology have sought to assert the accountability of humans and societies for the outcomes of technologies of destruction (Cooley, 1980; Mackenzie, 1990; Mort, 2002; Spinardi, 1994;Wainwright & Elliot, 1982). Ethnographies of technology, of human/technical collectives, continue to reveal the accountabilities that accompany design, production and practice. Accepting that artful integration may make the difference, in our case literally between life and death; that shifting boundaries may result in shifted outcomes, is we argue, what it means to be an expert in technologically mediated practice.

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