Can Clinicians Communicate With Designers? Design Themes From Prototyping With Anesthesiologists

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Abstract

This study investigates the role of the anesthesiologist as designers to create new avenues of communication, co-operation and education between clinicians and design related expertise. In this study a comparison is made of how nine anesthesiologists envisage the anesthesia machine as a prototype composition relevant to their specialization, experience, and environment. Currently clinicians are trained to modify their behavior to meet equipment requirements (Dalley et al. 2004); this research seeks to balance established approaches to take into account established behavior, previous experiences, habits and the capability of simulation validation. In recognizing the anesthesia machine must cater to all specializations and levels of expertise, the question for this study is: can clinician prototyping and simulated use provide design themes consistent with current equipment and workplace layout, published studies or new innovation?

INTRODUCTION

An awkward design evolution

Anesthesia's history of clinician inspired design is similar to the development of many biomedical devices that originated from clinical needs and clinician invention. Today's anesthesia machine stems from early hand held devices and now largely conforms to a table and chassis format derived in the 1930s. However in the last 40 years the design of anesthesia equipment has become constrained by the complexities of technology, regulation and standardization for safe use. Technological advances have "widened the gap between the load of information and the quality of its delivery" leading to emerging technologies negatively affecting healthcare safety through inadequate design (Kohn et al., 2003; Kiefer & Hoeft, 2010). Contradicting the digital revolution, the ergonomic layout is awkward as a result of its design evolution where technological devices for anesthesia delivery and patient monitoring have been applied with little regard to ergonomics encountered in procedural diversity and vigilance (Westhorpe, 1992; Calkins,1992). The current design approach delivers complex equipment in a legacy format as a standardization in recognizable form, components and perceived safe use that diminishes the importance of ergonomic work methods (Weinger, 1999). In the last decade, evidence of continued investigation is limited, suggesting that ergonomic problems are either risky to resolve, dependant on technology advances, or ignored.

This paper first questions design issues surrounding this awkward precedent and second, develops a relationship centered methodology, engaging and connecting the professions of design and anesthesiology with the technologies and practices of simulation and prototyping. We hypothesize that a new partnership methodology with anesthesiologists should improve the clinicians' ability to efficiently and effectively communicate potential future directions.

Relevance and motivation

The physical and procedural needs of the clinicians' workplace have received variable input in the design of equipment with emphasis being placed on engineering and screen based digital interaction (Kiefer & Hoeft, 2010). This brings about situations where the anesthesiologists must both physically and cognitively adapt to the equipment as the user adapts to a variety of clinical situations (Weinger 1999). The anesthetic machine is a physical composition that presents operational controls and sensory feedback. There has been no fundamental change in its structural form (a 4 wheeled trolley with table, storage draws and mechanisms for the delivery and monitoring of anesthesia) over the last 80 years. However new anesthetic machines have replaced many physical interactions with monitor based activities that increase the training and operational requirement for users as new features are layered upon existing features. Consequently this can mask the anesthesiologists understanding of safe operation in both normal and critical situations (Dalley et al., 2004). This raises the need for design methods and discussion at the level of innovation rather than at the later stage of developmental evaluation, a situation identified by Martin et al. (2008) as under-recognized due to medical device development being technology driven.

Design issues

Studies over the last 40 years have identified deficiencies in the ergonomic relationship between anesthesiologists and the anesthesia machine (Duri et al., 1973; Boquet et al., 1980; McIntyre 1982; McDonald et al.,1990; Cooper et al., 2002; Decker & Bauer, 2003; Seagull et al., 2004). Although these studies constitute valid workplace analyses of use methods, (component arrangement, chassis design and the application of new technologies), they only identify problems related to the equipment available at the time of study. This results in establishing a design bias; it focuses on the current design problem (i.e. patient monitoring and usability) rather than identifying future design directions. Therefore new design ideas are constrained by the evolutionary composition of the anesthesia machine, an established convention of use and the methods of investigation.

Human factors methods to study the man-machine relationship and inform design have resulted in iterative and useful advancement, however predicting the "reverberations of technological change" is more difficult (Woods & Dekker, 2000). A new prospective approach where equipment is designed for purpose, use, environment and technology may facilitate this. Anticipating how technology changes systems is demanding in healthcare. Woods & Dekker (2000) identified the need for designers to see design concepts as "representations of hypotheses or beliefs" and to explore their vulnerabilities. Primarily designer's use observation to understand a context. Roth et al. (2004) suggests this should lead to a consolidation of the hypothesis and a refinement in experimental methods. While contextual investigation is important, the complexities of healthcare work, described as the "messy details" by Nemeth et al. (2004), are complex to untangle, requiring alternative methods for authentic partnerships and discovery.

Individual disciplines have perspectives and methods to investigate design issues that are varied. Anesthesia's demand for safety has led to investigation through a retrospective paradigm of established equipment and environment. Seagull et al. (2004) discuss the role of human factors to impact the design process by using cartesian graphs from contextual video as a tool to communicate with designers, whereas Nazir & Beatty, (2000) suggest communication can come from surveying anesthesiologist's attitudes and the results are consistent with "known principals of safe, ergonomic design." Conversely an engineer or designer seeking to solve a problem is influenced by their professional perception in identifying and interpreting problems, and also in applying their professional knowledge. Wilcox (2005) explains this potential bias as "engineering egocentrism" and Lui (2003), in discussing the under-recognition of aesthetics in human factors, terms it "design intuition". Kossack et al. (2007) suggests industrial design and human factors are capable partners and should lead the "hands-on conceptual prototyping and testing". A further combination is provided by Schwartz (2005) a cognitive psychologist who postulates to users (otolaryngology surgeons) that their ideas, revealed in design assisted prototyping, can be accomplished by engineering through a post design technological build. Well established in human factors is the premise for direct contact with clinicians at the early stage of design, however focus groups, observation and information gathering limits the capability of clinicians to communicate and test their ideas. Martin et al. (2008) addresses the limited publication and guidance on ergonomic issues as indicative of commercial confidentiality and the cost benefit of maximizing the design focus towards evidential factors i.e. improving usability to reduce medical error.

Prototypes in anesthesia are comparatively rare with few published examples. Novel ergonomic concepts are limited to Boquet's 1980 study, others evaluate technology and more commonly interfaces and displays (Cooper et al., 1978; Jungk et al., 1999; Drews & Westenskow, 2006; Lui et al. 2010). Westhorpe (1992) describes (what can now be seen as) the short 'revolution' in equipment design during the 1980s -90s when a variety of novel workstation layouts (Gambro Engstrom 2000, Engstrom Elsa/EAS, Physio BV Physioflex, Dräger Cicero) were produced by manufactures. Calkins (1994) update of the 1992 Society for Technology in Anesthesia (STA) workshop that served to stimulate discussion and speculate on the future design of the anesthesia workstation suggested ergonomics and human factors investment in anesthesia was limited. While the outcomes of this workshop are diverse and conceptual, transferable or testable methodologies for idea generation and innovation evaluation are absent. This period of criticism and design diversity is concluded by the innovative 'Siemens Kion' (Hughes 2001). While ergonomic problems have been recognized, and innovative technologies have been integrated, these novel designs inspired to address the anesthesiologist's workplace have not been universally accepted and innovation has become moderated to an established and accepted convention.

The anesthesiologist's hypotheses

The aim of this study is for the anesthesiologist to prototype, iterate and evaluate their own hypothesis, therefore articulate ideas still in the discovery phase. This investigation centers on developing a new paradigm to understand how anesthesiologists respond to their activity, rather than to an evolutionary artifact. By anesthesiologist's prototyping their perspectives of specialization, habits and use methods, new themes may become apparent and compared to those promoted by other researchers. Viewing the activity from the point of view of the anesthesiologist provides a differing starting point from which to discuss equipment design. In this study a comparison is made of how nine anesthesiologists envisage the anesthesia machine as a prototype composition relevant to their specialization, experience, and environment. Currently clinicians are trained to modify their behavior to meet equipment requirements (Dalley et al. 2004); this research seeks to balance established approaches to take into account established behavior, previous experiences, habits and the capability of simulation validation. In recognizing the anesthesia machine must cater to all specializations and levels of expertise, the question for this study is: can clinician prototyping and simulated use provide design themes consistent with current equipment and workplace layout, published studies or new innovation?

METHOD

Prior to the experiment a managerial review of the proposed study was undertaken and the designer assigned to a specialist anesthesiologist under the title 'departmental visitor'. The designer spent several months observing in the operating room to establish a contextual background and relationship with clinical staff. Nine volunteer participant anesthesiologists (four female, five male, all specialists with many years of experience, and with individual procedural sub-specialty e.g cardiac surgery, vascular surgery or plastic surgery) were recruited by the specialist anesthesiologist from two hospitals and briefed on the project objectives by the designer two weeks prior to the experiment. The brief explained the aim of the experiment sessions including the methods of prototyping and evaluation. Participants' were asked to individually and independently reflect on their specializations, to adopt a needs and wants focused concept without constraint on the feasibility of technical workings.

To engage the clinician's viewpoint three methods are integrated:

• Prototyping - a method to iteratively define and validate an innovation or change and to test the hypothesis. It is also a method of researching, creating different sets of conditions to learn more about a system.

• Participation design - where users participate in the design process facilitated by designers.

• Simulation - an established technique in anesthesia that provides an assessment dependant on the fidelity of both the scenario and the concept. Simulation can provide equivalence in environment, methods of observation and recording not feasible in some operating rooms (Merry et al. 2008).

Each participant engaged in an individual experiment and the resulting concepts were not revealed to others. The research team completed an exploratory test of the method first to standardize the procedure, materials and scenario. To communicate the anesthesiologist's ideas of machine structure and component placement a team of designer, specialist anesthesiologist and simulation expert utilized a simulation centre and simple prototyping materials. Each participant received a set of polystyrene blocks comprising of sizes relevant to anesthesia machine components, i.e. ventilator, carbon dioxide absorber, vaporizer, rotameters. The blocks could be adapted, cut, drawn upon and mounted on rods at required heights and position. The room where the participants constructed and tested their prototype was similar to the space in an operating room, and this included drapes, trolleys, other theatre equipment and video recording devices. A manikin took the place of a patient. A design assistant (not a member of the research team so as to avoid any bias) with no knowledge of anesthesia was employed to work with each anesthesiologist to assist in the prototyping stage. The method provided for evaluation, revision and documentation. On completion of the prototype a validation scenario was enacted (consisting of an anesthetic induction, maintenance, and reversal for a non-complicated surgical procedure e.g. appendix removal). This confirmation, directed by the simulation expert required participants to reproduce a set procedure and interact with the prototype. Being physical, contact could be made as gesture, i.e. a 'block' screen could be touched on the 'drawn in' controls. After the scenario was successfully accomplished the prototype was measured in a cartesian coordinate system of x-y-z using the operating table as a reference point. Drawn in Solidworks® it provided a 3D computer model that could be viewed from any position.

RESULTS

Each participant commenced by communicating their hypotheses to the design assistant. A white board sketch concept was developed and prototypes constructed (Figure 1). During the experiment participants evaluated reach distances, eye-lines, visibility and task relationships between patient, machine, and other personnel (Figure 1). The composition of each design idea was quickly established leading to iterative adjustments acknowledging their specialization and procedural requirements.

Figure 1

Left, participant's initial whiteboard drawing and right, participant evaluating design concept during the prototyping stage

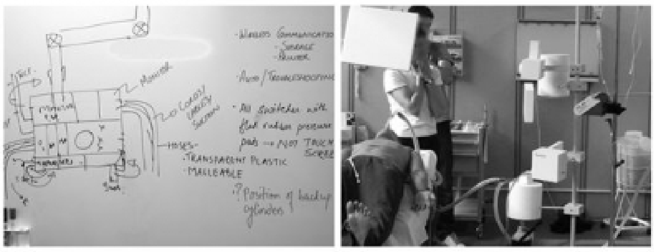
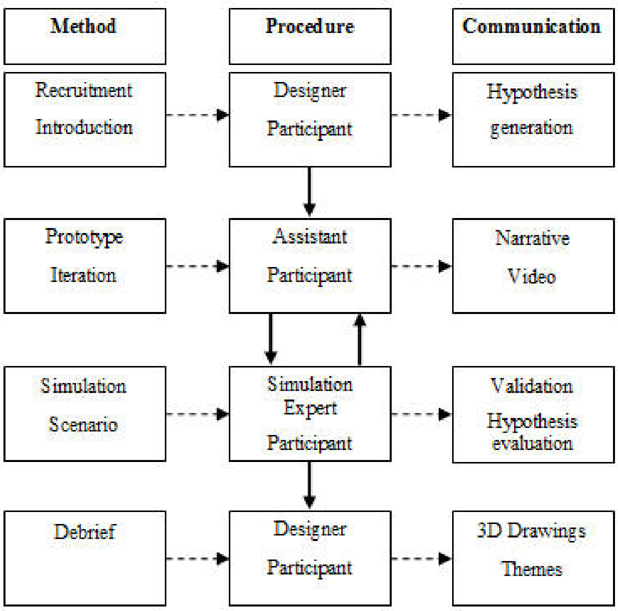


Table 1

The prototyping procedure as identified in the experiment



All participants' completed the experiment. Each participant demonstrated the capability to complete the experiment within a 2-4 hour period however the simulation scenario forced all participants to solve issues, necessitating a return to the prototyping stage. This is identified in the design procedure (Table 1). Simulation ensured the concept was usable and prototyping provided an effective communication method. All participants produced dissimilar concepts and three primary categories were identified as design themes (Table 2).

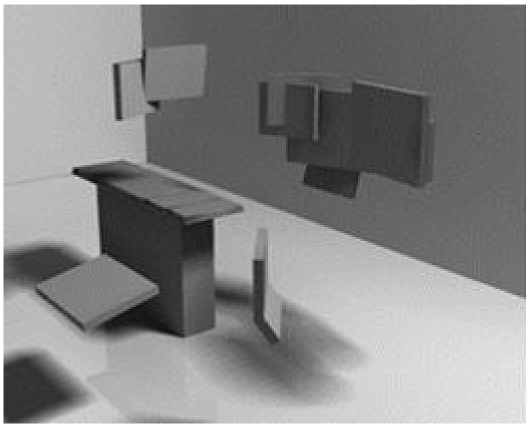
Table 2

Primary categories and occurrence

Category	Occurrence	Design outcome
Traditional table based layout	2	Conventional size and placement
Divided layout	5	Separate machine and table
Monitoring machine and display	2	Unconventional, new monitoring technologies

Figure 2

Overlay of all nine participants screen placement including two withdrawal stations (wall screens are not shown)



Each prototype was then categorized into secondary descriptive design themes:

• All participants designed prototypes conforming to a visual and reach arc centering on the anesthesiologist's position at the head of the patient during the induction phase of anesthesia. This is illustrated in figure 2 with an overlay of the location of all participants' screens.

• Seven concepts are designed without table or storage capability with intention for easy manipulation and close proximity of interface activities in relation to the patient.

• Three of these concepts were designed for left handed use, the remaining (including the two traditional table based layouts) were right handed.

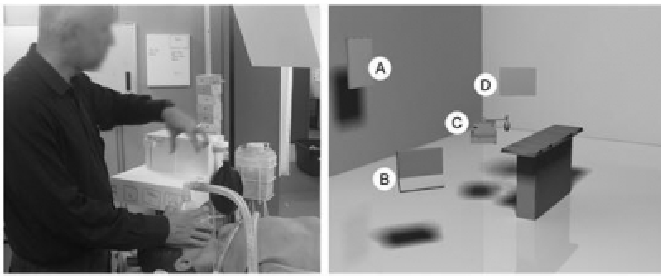
• Two concepts made provision for a secondary 'monitoring' position that included screens and controls. These were designed as withdrawal stations by participants who specialized in longer surgical cases (cardiac surgery or faciomaxillary surgery), an example of this design is illustrated in figure 3.

• Two participants designed wall screens that shared gas pipeline supply information to the operating team and 2 concepts applied emerging technologies for head mounted display and responsive tactile interfaces.

Evidence from comparing the prototypes provided design themes, and the qualitative commentary validated the method. This illustrated issues concerning both the anesthesiologist's workplace activity and the experiment method.

Figure 3

Left, interacting with the prototype during simulation scenario, a concept by a participant who specialized in longer surgical cardiac surgery cases. Right, the same concept in 3D computer model, A wall screen (communicating gas pipeline supply information to the operating team), B withdrawal station, C machine and D monitoring screen



DISCUSSION

Communicating the hypotheses

The clinicians' accepted the method and were able to communicate, prototype and validate their concepts. Providing time between the introductory talk and experiment allowed each participant to reflect on their experience and generate a hypothesis. Commencing the experiment by sketching up ideas demonstrated a common and capable method of communication. The limitation of two dimensional illustrations is that many problems are not apparent, nor are the participants' intentions fully understood. Limited use can be made of the sketches by external designers outside of the experiment.

Low resolution prototyping materials and methods were successful in providing for a variety of skill levels and reinforced the methodology for clinicians to articulate and communicate their design hypothesis. Participants were not just explaining why, but also validating, problem solving and demonstrating. The opportunities in this method to iterate were more evident than expected with participants independently acting out the idea to resolve technical and ergonomic issues. Conversations between the participant and the design assistant often diverged into personal reasons behind decisions; for example, a mistrust of digital technologies, the impact of various procedures on the environment, and the need to accommodate and interact with the operating team. The 3 dimensional computer models afforded a greater transparency than participant sketches or photographs suggesting the use of contemporary design language in communication with designers.

Simulation evaluation

Employing simulation (a method that anesthesiologists are familiar with) took this study beyond the test of currently available options to a test demonstrating efficacy of their new hypothesis. Underpinning this was a prescription that by utilizing a simulation facility, equipment and expertise, an emphasis was placed on participants that the workshop was about physically testing new ideas. This method controlled the experiments fidelity, limiting bias from the research team. Additionally the scenario provided an opportunity for participants' to clarify concept ideas.

Design themes

Categories between compositions could be ascertained in two ways from the computer models; first in relationship to the patient and the environment and second, in comparison with other participant's prototypes. Participants revealed a range of ideas, from traditional analogue to high tech tactile interfaces, from small 'transformer' like machines to more complex systems that were ambidextrous, from unique innovations for dealing with cabling to withdrawal stations with seating-based control panels and worktablets. The established form of the anesthesia machine dating from the 1930s was contradicted by the experiment outcomes. This is a criticism of the established and a three-dimensional critique of environment use and component arrangement. Overall the consensus was to disassemble the current workstation format into a separate machine and table. This disassembly was divided again into machines with traditional analogue inputs and screen based monitoring and those focusing on innovative monitoring. The categories define the range of clinician hypothesis, the interpretation of focus and resulting design themes (Table 3).

Table 3

Design themes

Category	Design focus	Design theme
Traditional table based layout (traditional technology)	Small iterations to resolve problems i.e. inadequate clean and dirty storage, wheels and brakes, cabling	**Equipment layout** Conventional approach BV Physioflex (see Vallikari 2009)
Divided layout (traditional technology)	Workspace layout and machine position in relation to patient and requirements for procedural preference arrangements	**Workplace layout** Task focused (Boquet 1980)
Divided layout (new technology)	Ventilation and gas delivery reduced in size, focus on novel interface and interaction methods including tactile feedback, new monitoring technologies	**Procedure/situation awareness** Monitoring and interface focused (Jungk 2000, Drews 2006, Lui 2010)

These outcomes ranged from incrementally innovative to radical concepts and can be aligned to published research (including many of the conceptual results from the 1992 STA workshop) inferring the anesthesiologists' perspective is very different from established convention and industry design (Calkins, 1994). The traditional layout serves to resolve problems, whereas the divided layout actively changes the composition of equipment. However the approach of the third theme to the experiment follows current research in prioritizing the display and interaction of critical information as a key focus. This lends support to the investigations by Drews (2006) and Lui (2010) of novel technologies and Nazir & Beatty's (2000) survey of anesthesiologists' "cautious approval to more radical approaches."

Design diversity can be attributed to practitioners' assessment of their workplace and specialization, clearly reflecting how the modern anesthesia machines must cater to all specializations and levels of expertise. This supports the difficulties encountered in overcoming a convention of use even though it could lead to improved ergonomics. The diversity of designs suggest that designers may not be capable of working via second or third hand information such as photos, focus groups or questionnaires. This suggests that participant's had brought new knowledge through a prospective method unattainable by traditional methods. Each participant showed a capability to communicate and manage ideas in producing a complete three dimensional prototype. Dialogue from the video recordings was initially seen as communication on how something should be or where in the prototyping process it should go, becoming an ergonomic description. These descriptions are much more telling than first thought in demonstrating anesthesiologists know what they want and have the capability to communicate with naive designers.

Utility

This study devised a method to engage and record anesthesiologists' ideas and criticisms of equipment and work methods; important in recognizing how new technology may be applied and accepted. We hypothesized that prototyping (an unfamiliar method) in partnership with simulation (a familiar method) can supplement and later be refined by a structured a human factors program. Rather than implementing design changes that force compromise upon the anesthesiologists to become usable, this method may help investigators and designers understand ergonomic behavior from the anesthesiologist's viewpoint.

As a design method, prototyping provided a measurable result in physical terms and a qualitative outcome in useful design narrative and effective design communication. Our assessment of simulation as a rudimentary yet capable design tool for hypothesis evaluation resulted in a successful test. Rather than speculation or identifying the problem of awkward ergonomics repetitively with ever more complex tools, the findings would recommend the identification of needs. The demise of new and radical anesthesia equipment such as the BV Physioflex and Siemens Kion (Vallikari 2009) may be due to engineers and designers instigating both new technology interaction and ergonomic change without understanding the fundamental and familiar needs of anesthesiologists. This suggests that efficient and active involvement of users in conceptual investigation may educate designers in the advancement and acceptance of both technology and ergonomics in anesthesia equipment. Many participants later commented on a refreshed outlook to their work environment, ergonomics, and future technologies, alongside this were comments on the limited training in equipment (ergonomic) setup and adjustment; concluding that the 'see one, do one, teach one' culture of healthcare leads to both good and bad habits being be passed on.

Limitations in the study

Although physical prototyping and user participation is common to industrial design, limitations exist in this method as analysis is often indicative of the design professions reliance on intuition. Anesthesia's use and acceptance of clinical simulation (Merry et al. 2008) may advance this combination. A structured program implemented in a variety of institutions would be required to validate findings, additionally, as a common design of equipment is sold worldwide, demographics, training and culture may provide diverse responses.

CONCLUSION

This research questioned the evolution of the anesthesia machine by applying anesthesiologists' career knowledge to understanding individual needs through a method of prototyping and validation. While an evolutionary design approach from industry does not meet the wants of users, it may be seen as sufficient to meet minimum needs. This study demonstrated anesthesiologists are aware their workplace is awkward and have demonstrated the ability to communicate solutions biased to their individual specializations. They have also show capability to use both design tools (prototyping) and evaluative measures (simulation) to communicate their perspective. We suggest clinicians have a part to play in design conception however selection of participants' should reflect a cross section of users rather than advocates of change. The argument for a retrospective paradigm of engineering, industrial design and human factors leading in conceptual design has not proven successful in resolving greater ergonomic issues and infers a convention of sustainable awkwardness can be mitigated by a revolution in digital technologies. Being now at the cross roads of this digital implementation, a prospective paradigm of design facilitated communication by clinicians could assist in making industry aware how new partnerships and possibilities can be implemented, including the use of simulation as a design method.

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