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Supporting Clinical Perception

A multi-method approach to how technology
may support clinical perception

Thesis for the degree of Philosophiae Doctor

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Norsk sammendrag

Fasilitert klinisk persepsjon: En multimetodisk utforskning av hvordan teknologi kan understøtte klinisk persepsjon.

Hovedformålet med denne avhandlingen var å utforske hvorvidt og hvordan klinisk persepsjon kan understøttes av teknologi, og i hvilken grad slik støtte kan komme til nytte i klinisk arbeid. Ved først å observere og intervjue perioperativt personell kartla vi hvordan koordinering av klinisk arbeid ble praktisert i og rundt en operasjonsavdeling. Funnene viste at det å fortløpende oppfatte informasjon fra pågående perioperative aktiviteter var viktig for koordineringen av klinisk arbeid. Funnene antydet også at det å dele oppdaterte forventninger om forløpet av fremtidige aktiviteter kunne bidra til bedre koordinering. For å utforske disse funnene i større detalj, utviklet vi en prototype for formidling av slik informasjon til sykepleiere ved en kirurgisk sengepost. Informasjonen ble presentert på en skjerm som var synlig for både sykepleiere og tilfeldige forbipasserende. Ved å simulere sengepostarbeid med sykepleiere som deltakere og intervjue deltakerne etterpå, fant vi at et slikt hjelpemiddel kunne være nyttig selv om informasjonen var både abstrahert og avidentifisert for å ivareta personvernet til pasientene som informasjonen vedrørte. Videre undersøkte vi hvorvidt det å kunne forutse fremtidige perioperative arbeidsoppgaver hadde noen betydning for koordineringen av arbeidet. Et sted hvor dette praktiseres rutinemessig er i traumemottak hvor alvorlig skadde pasienter mottas av et traumeteam som står klart når pasienten ankommer sykehuset. Vi fant at tidligere aktivering av teamet ga raskere håndtering av pasienten. Disse funnene var basert på data fra et helt år med traumepasientmottak. Tilslutt undersøkte vi hvorvidt måten klinisk informasjon ble presentert på hadde betydning for hvordan informasjonen ble vurdert. Her brukte vi blodprøveresultater fra ekte pasienter, men presenterte disse resultatene på forskjellige måter. Medisinstudenter måtte vurdere resultatene, mens vi registrerte deres vurderinger og tiden de brukte. Vi fant at presentasjonsmåten påvirket hvordan informasjonen blir vurdert, og at deltakerne foretrakk forskjellige presentasjonsmåter til forskjellige typer pasienter.

Avhandlingen viser at teknologi kan understøtte evnen til å oppfatte klinisk informasjon. Videre belyser avhandlingen noen områder hvor slik teknologi kan komme til nytte for sykehuspersonell.

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Ovennevnte avhandling er funnet verdig til å forsvares offentlig for graden PhD i Medisinsk teknologi. Disputas finner sted i Auditoriet 'MTA' fredag 9. mai kl 12:15.

Preface

During my internship at the Hospital of Hammerfest I observed and experienced various types of patient management. Whenever a patient from Hammerfest was admitted, the patient was usually already in the examination room with blood samples drawn when I (as the first hospital physician) was made aware of that patient: “A new patient is waiting for you to come see him!”. Sometimes I was busy with other patients and couldn’t come right away. In addition, I preferred to read up a bit on the patient’s current problem and any previous illnesses before entering the patient’s room. Hence, the patient’s stay at the emergency department could be lengthy.

However, with patients from more distant cities in the hospital region the workflow was quite different. Usually the referring physician phoned me to give me a review of the current problem. The referral letter was sent electronically giving me access to it before the patient arrived. Transporting the patient to the hospital could also take one or two hours, providing me with enough time to finish whatever I was doing, read the referral letter and any health record entries from previous admissions. Before the patient arrived, much of my own paperwork was already done, and I was well prepared for the patient encounter. Patients could stay as little as 20-30 minutes in the emergency department before they were moved to one of the specialist departments with a preliminary diagnosis and a treatment plan.

During internship I also experienced that one of my most important tools as a physician – the electronic health record (EHR) – mainly supported documentation, and to a little extent diagnosing and managing the patient. Sometimes it felt as if I was able to manage the patient *despite* of the EHR rather than because of it.

These personal experiences from practising hospital medicine were some of the most important reasons for me to apply for a PhD-scholarship within medical technology. I wanted to make a contribution on how we can support health care workers in delivering high-quality and high-efficiency health care services.

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Abstract

BACKGROUND

Patient care and management in hospitals is more difficult than ever before. Not only must clinicians perceive and interpret vast amounts of medical information related to single patient management, they are also expected to coordinate their own and their patients' activities to achieve most health benefit per value spent. The overall objective of this thesis was to explore, develop and evaluate technology that may support perception and interpretation of information related to individual patient management and care coordination.

METHODS

The research has been conducted within the context of perioperative care, including operating theatres, post-anaesthesia care units, trauma team management of emergency patients and assessment of individual patients' laboratory test results. Field work with focused interviews and in-depth interviews with perioperative staff were carried out to understand what information supports perioperative staff members in managing their own and their patients' activities, and how that information is perceived. Patient status overviews were iteratively developed and evaluated through simulated ward work scenarios to understand what information supports surgical ward nurses in managing perioperative care, and how that information can be presented on a digital whiteboard without compromising patient privacy. An observational retrospective cohort study was conducted to evaluate the importance of projected perception of a care activity on patient management. Finally, we did a balanced, crossover experiment with medical students as participants to explore the effects of four laboratory test result presentation formats on the quality and efficiency of perception and interpretation of such results.

RESULTS

Perioperative activities unfold unpredictably, and perioperative care management relies heavily on ad hoc communication. Although schedules are perceived as important collaborative artefacts, they provide limited support for timely execution of individual work.

A patient management status board including a continuously updated list of recent care events as well as a list of estimated onset of expected future events was welcomed by ward nurses. Such a status board was expected to facilitate perception and improve awareness on new care information as well as reduce the workload of coordinating care. Continuously updated estimated projections of expected future events were considered to be an effective means of interdepartmental communication.

There was a significant association between the efficiency of the initial intrahospital trauma patient management and the time from trauma team activation until patient arrival (i.e. the amount of temporal projection). The descriptive data suggested that 10-20 minutes pre-arrival *activation* of the team was optimal timing. Pre-activation trauma team *notification* was not associated with the efficiency of patient management.

The formats with which laboratory results were presented influenced both speed and quality of the assessment. Participants preferred different presentation formats for different kinds of patients. A table sufficed for sets of laboratory results consisting of few blood samples, but line graph visualisations seemed favourable for sets of laboratory results consisting of many samples. No single presentation format was superior in all respects.

CONCLUSION

Presenting proper information at the right place and right time is important, and for some information presentation format also may matter. Providing clinicians with timely updates on care activities and estimated onset of expected future events seems to be a fruitful technological solution to support coordination of hospital services. Furthermore, information visualisation has a potential of enhancing the perceptual and cognitive skills of clinicians – influencing the clinical assessment of patient data both qualitatively and quantitatively.

Acknowledgements

First of all I thank my supervisor and assistant supervisor – Arild Faxvaag and Andreas Seim – for having introduced me to health informatics research. It requires an open-mind to be able to establish a sustainable cooperation with a person who suffers semi-neurotic and open-sourced stubbornness. Thank you for having guided me through these years as a PhD-student!

I am specially thankful for the extended collaboration with Torbjørn Torsvik and Erlend Andreas Gjære. Together we have designed studies, designed interfaces, recruited participants, conducted experiments, analysed data and written papers. In addition I am very grateful that Gustav Mikkelsen, Oddvar Uleberg and Ole-Petter Vinjevoll have shared their time and expertise with me.

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Finally, and most importantly, I owe great gratitude to my beloved Mari! Thank you for reminding me to log out of “PhD” and log in to “Home”.

List of papers

PAPER 1

Lillebo, B., A. Faxvaag. 2013. Continuous Coordination in Perioperative Work. *(submitted for publication in 'Journal of Interprofessional Care', March 2013. Revised according to reviewer comments and resubmitted, October 2013).*

PAPER 2

Gjære, E. A., B. Lillebo. 2013. Designing Privacy-Friendly Digital Whiteboards for Mediating Clinical Progress. *(submitted to 'BMC Medical Informatics and Decision Making', September 2013).*

PAPER 3

Lillebo, B., A. Seim, O. P. Vinjevoll, and O. Uleberg. 2012. What is optimal timing for trauma team alerts? A retrospective observational study of alert timing effects on the initial management of trauma patients. *Journal of Multidisciplinary Healthcare* 5: 207–213.

PAPER 4

Torsvik, T., B. Lillebo, and G. Mikkelsen. 2012. Presentation of clinical laboratory results: an experimental comparison of four visualization techniques. *Journal of the American Medical Informatics Association : JAMIA* 0: 1–7.

Introduction

> *"In public health spending per capita, Norway ranks among the highest of all OECD nations – but we have not achieved a correspondingly high level of health in return. More people are falling ill, our population is ageing, more people need help for longer periods, more diseases are treatable with new technology, and the queues are lengthening for specialist health care services. These developments are simply not sustainable, and we must deal with them. If we are to succeed in changing this direction, we must act now!"*
>
> (*The Coordination Reform: Proper treatment - the right place and right time. Report No. 47 (2008-2009) to the Storting.*, 2009, p. 1).

Coordination of health care services is challenging (Strauss, Fagerhaugh, & Wiener, 1985). Although advances due to rise in specialisation have provided improved diagnostic and treatment possibilities, these improvements have not been followed by similar improvements in our ability to integrate the delivery of health care (Stange, 2009). More than ever, hospitals stand as complex institutions, within which the perioperative environment holds the most challenging coordination needs with its highly specialised staff, equipment and procedures:

> *"(...) today's complex perioperative processes, sometimes perceived as chaotic, unwieldy, and frustrating, have grown up without direction in response to developments in surgical practices and technology. Consequently, inefficient perioperative systems have dampened the benefits of new surgical techniques and high technology."*
>
> (Sandberg, Ganous, & Steiner, 2003)

Developments in computer technology have found their way into clinical work. Not only does computer technology support advanced diagnostic and treatment procedures (e.g. computed tomography), it also supports documenting and reviewing patient problems, obtaining and following test results and more

(Lærum, Ellingsen, & Faxvaag, 2001). In Norway, electronic health record systems are used on a daily basis in hospitals and by almost all general practitioners (Heimly, Grimsmo, Henningsen, & Faxvaag, 2010). Ostensibly, computer technology has achieved a certain influence on contemporary clinical work, and some institutions have demonstrated that quality and efficiency of health care delivery can be improved by implementing health information technology (Chaudhry et al., 2006). However, it is not likely that the full effects of information technology on delivery of health care services have been attained (Bates & Gawande, 2003).

'Medical informatics' is a young discipline compared to other medical disciplines, but the amount of research within this field has increased fast, and today "much is expected of medical informatics to help achieving health for people throughout the world, both in contributing to the quality and efficiency of health care and to innovative biomedical as well as computer, health, and information sciences research" (Haux, 2010, p. 3). The development of comprehensive electronic health records "combined with appropriate concepts for representing, accessing and visualizing health data" has been suggested as one of the promising future research directions of medical informatics (Haux, 2010, pp. 7–8). Accurate and timely clinical perception is and has been a valued skill in medical education and practice since long before the introduction of computer technology in healthcare (Boudreau, Cassell, & Fuks, 2008; Osler, 1901). However, information and communication technology may support clinicians in perceiving clinical information by distributing important information through pagers or mobile phones (Kuperman et al., 1999), or by presenting medical data differently from how they were entered (Palma, Brown, Lehmann, & Longhurst, 2012). Such technological possibilities raise an important question: If we try to support clinical perception by changing how information is accessed, distributed and presented, can we improve clinical reasoning and care management?

In my work on this thesis I have approached this question by applying a mix of evaluation methods derived from both the natural sciences and the social sciences (i.e. retrospective observational study, crossover experiment, design science research, field work, in-depth interviews and focused interviews). Hence, this thesis endeavours to improve quality and efficiency of health care delivery by providing health care workers with clinical perception support.

This work was partly motivated by the current prognosis of non-sustainable health care delivery as described in the Norwegian Coordination Reform of 2008: ‘Proper treatment – the right place and right time’. The way I see it, improvements in information technology is one of the measures that can contribute to the reestablishment of sustainable health care. To reflect this potential, I have made a similar vision for clinical perception support:

“Proper information – the right place, right time and right format…”

Lillebo, 2013

Background

Context and constructs

Some of the terms and constructs used in this thesis as well as the context in which the studies have been conducted, warrant a more thorough description. What I am referring to are perioperative care, clinical reasoning, perception, visualisation, overview, awareness and privacy; each of which has been the main topic in vast amounts of literature and research. My intention is not to systematically analyse and define all these terms based on all current knowledge, rather my intention is to characterise them sufficiently well so that the reader is able to understand how I have applied these terms throughout this thesis.

Perioperative care

What lies at the core of perioperative care are the surgical procedures carried out in the operating theatre. However, perioperative care also involves other care activities undertaken before, during and after surgery, most of which take place outside of the operating theatre, i.e. in the emergency department, at post-anaesthesia care units (recovery), intensive care units, wards, or outpatient clinics. Thus, the efficacy of contemporary perioperative care depends on a joint effort of a range of perioperative staff members. This complexity makes perioperative care vulnerable to delays and other contingencies (Sandberg et al., 2003). What seems to be certain about perioperative care processes are that they are uncertain. The perioperative care processes rarely unfold as planned, and estimates of duration of surgery are not precise (Bardram & Hansen, 2010; Macario & Dexter, 1999; I. H. H. Wright, Kooperberg, Bonar, & Bashein, 1996). The quality of perioperative care processes does not only depend on the dexterity of the surgeon, nor the reasoning skills of the anaesthesiologist. The quality also depends on continuous care management decisions made by ward nurses, nurse anaesthetists, operating theatre technicians, cleaners and more. Little is known about how such management decisions are carried out and how they can be supported; how to "weigh up the many factors, medical, social and psychological to arrive at a particular course of action" (Norman, 2005).

Clinical reasoning

Understanding clinical reasoning has been regarded an important step towards improving medical diagnostics, reducing medical errors and improving patient care. However, decades of research has not succeeded in identifying one best strategy for approaching and solving clinical problems (Norman, 2005). Nevertheless, two clinical reasoning strategies have had major influence on our understanding of and research on clinical reasoning: 'decision making' and 'problem solving' (Elstein & Schwartz, 2002).

'Decision making' involves "updating opinion with imperfect information" (Elstein & Schwartz, 2002, p. 730). Through application of Bayes' theorem or decision trees decision making strategies ensure that the clinical opinion is systematically integrated with knowledge of probabilities and utilities of all possible outcomes in order to arrive at the best decision (Elstein & Schwartz, 2002; Kassirer, 2010).

The 'Problem solving' strategy embraces two somewhat contradictory approaches to clinical reasoning: 'the hypothetico-deductive strategy' and 'pattern recognition' (Elstein & Schwartz, 2002). While the former includes explicit and meticulous testing of hypotheses, the latter comprises more of a direct recall or categorisation based on previous experience. Such pattern recognition can be an effective and efficient approach to straightforward and frequently encountered problems (Norman, 2005), yet clinicians might turn to the more formal hypothesis testing approach for more difficult problems (Elstein & Schwartz, 2002).

Prior to and essential for any clinical reasoning strategy is, however, the ability to accurately and timely perceive the clinical problem. Misperception can lead to wrong hypotheses, recognition of non-relevant patterns or application of wrong probabilities in the decision analysis. Many health care errors are related to misperception or failure to act soon enough on abnormal medical findings (Bordage, 1999; Kohn, Corrigan, & Donaldson, 1999). While there is a vast amount of literature on clinical decision support systems or decision tools (Liu, Wyatt, & Altman, 2006), clinical perception support has not received the same amount of attention.

Visualisations and Overviews

Visualisation has been defined as "The use of computer-supported, interactive, visual representations of data to amplify cognition" (Card, Mackinlay, &

Shneiderman, 1999). Within the field of information visualisation research the concept 'overview' has been central. 'Overview' has been used, described and defined in various ways, often including characteristics such as facilitating perception and awareness of a collection of objects or data (Hornbæk & Hertzum, 2011). A technical description of the term 'overview' implements that an overview is something visual, i.e. a visualisation. I will refer to this denotation of overview as 'graphical overview'. Adding to this, 'overview' is also often referred to as something that is achieved, obtained or gained through both passive and active mental processes. Thus, an overview may also be a user-centred non-visual concept, i.e. a mental representation of a collection of objects or data (Hornbæk & Hertzum, 2011). I will refer to this alternative denotation of overview as a 'mental overview'. Based on these and other less frequent uses of the term 'overview' in the literature, Hornbæk and Hertzum developed a taxonomic model of the notion of 'overview' in which they linked graphical and mental overviews: "Overview is an awareness of [an aspect] of an information space, acquired by [a process] [at a time], useful for [a task] with [an outcome], and provided by a [view-transformed] [visualization]." (Figure 1).

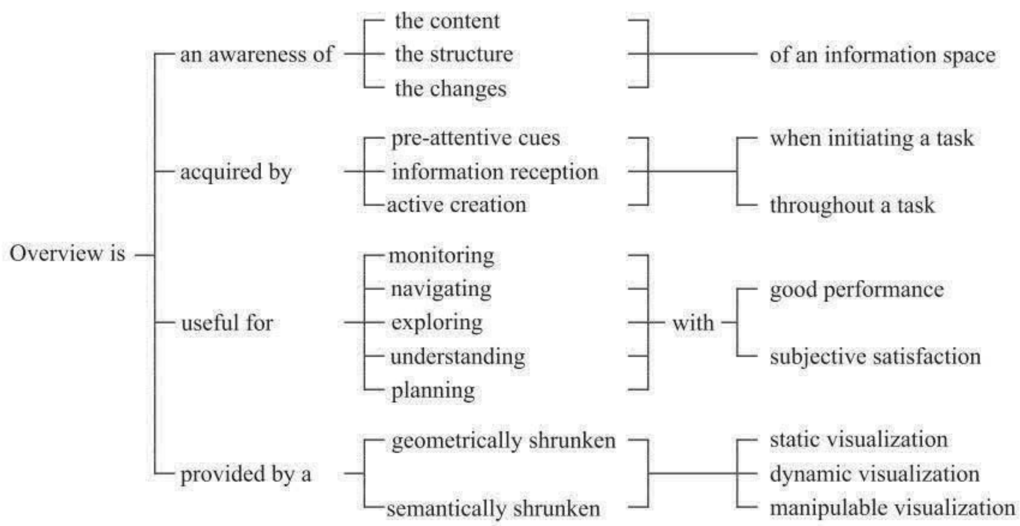

Figure 1: Taxonomic model of overview.
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Whenever I use the term 'overview' without further specification, I refer to the technical denotation: 'graphical overview'. The non-technical alternative denotation – 'mental overview' – is closely related to the concept 'awareness'.

According to the taxonomic model a [mental] overview is an awareness of the content/structure/changes of an information space. This description of the concept 'mental overview' bears close resemblance to a widely adopted definition of 'situational awareness'.

Awareness

Various definitions, descriptions and uses of the word 'awareness' exist, in which many restrict 'awareness' to one particular information space – awareness of something (Schmidt, 2002). For instance, in the context of collaborative writing "awareness is an understanding of the activities of others, which provides a context for your own activity" (i.e. 'group activity awareness') (Dourish & Bellotti, 1992, p. 107). Within the field of Computer Supported Cooperative Work (CSCW) 'awareness' is usually related to the activities and context of cooperating actors: "The term 'awareness' of course refers to actors' taking heed of the context of their joint effort." (Schmidt, 2002, p. 286). In the context of coordination of work in a hospital awareness has been divided in three types: social (awareness about another person), spatial (awareness about a place) and temporal (awareness about past, present and future activities) (Bardram, Hansen, & Soegaard, 2006). CSCW does not regard 'awareness' as an independent state of mind, rather as being or becoming aware of something (Schmidt, 2002). Correspondingly, the denotation of the word 'awareness' within CSCW is sentience, attention or undifferentiated consciousness – i.e. some sort of ability, openness and readiness to perceive (Schmidt, 1998).

However, 'awareness' may also be regarded as a product. Within the field of Human Factors such an understanding of 'awareness' has gained much attention as part of a popular definition of situational awareness: "Situation awareness is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" (Endsley, 1995, p. 36).

This definition is supplemented by a model of situation awareness that illustrates how situation awareness is related to other constructs such as decision making, performance, task, system factors and individual factors (Figure 2). In this model situation awareness is regarded as a product ('having knowledge of') of various cognitive processes such as attention, perception, analysis and synthesis. This product has three distinct levels: 1) Perception of elements, 2) Comprehension of their meaning, and 3) Projection of their status in the near future (Endsley, 1995, p. 36). Transferred to a medical context these three levels of situation awareness have been referred to as detection (level 1), diagnosis (level 2) and prediction (level 3) (Drews & Westenskow, 2006), and objective measurement of situation awareness has been suggested as a means of evaluating medical equipment, training and procedures (M. C. Wright, Taekman, & Endsley, 2004).

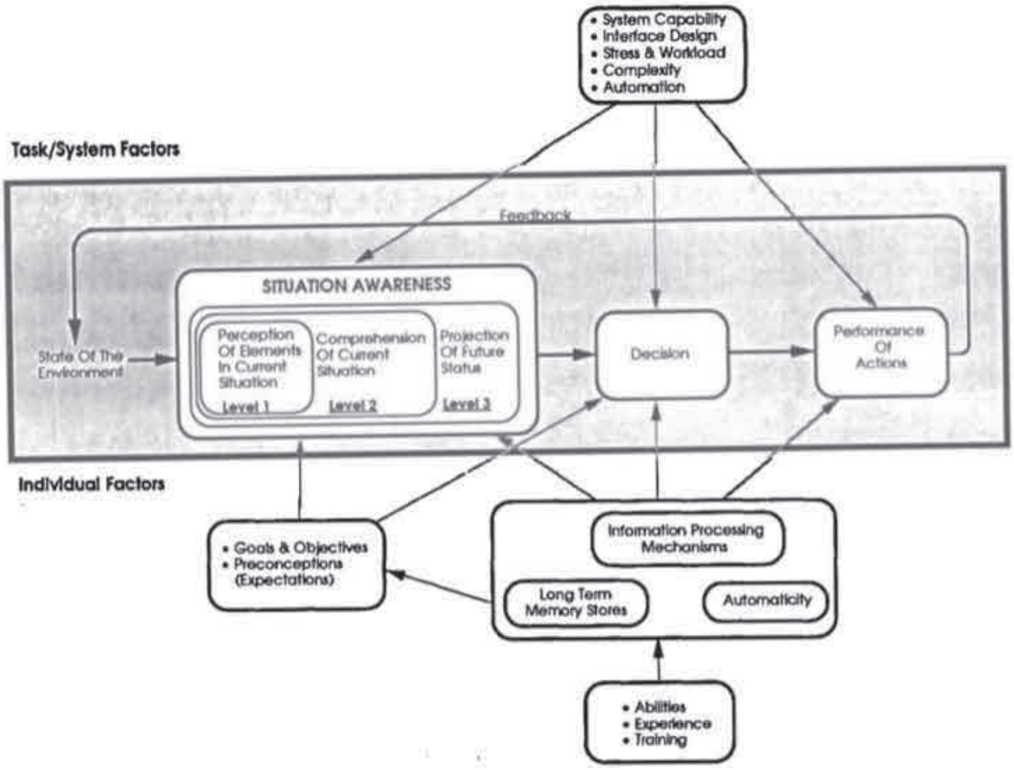

Figure 2: Model of situation awareness.
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Although Endsley's definition has caused some controversy, its popularity and the wide range of application areas serve as an acknowledgement of situation awareness as a "viable and important construct" (Wickens, 2008). Still, the discussion seems to continue as to whether 'awareness' should be regarded as a product, a process, or both (Salmon et al., 2008). Irrespective of how and if that discussion ever will end, I will use the term and construct awareness in this thesis as if it is a product (in accordance with Endsley's model).

Privacy

The idea of supporting clinicians' awareness by providing them with graphical overviews of perioperative care is somewhat opposed by patient privacy regulations. By law, clinicians in Norway are obliged to actively prevent others from having access to or knowledge of health related information or other personal information that they have come to know through their professional work as clinicians. Clinicians are also prohibited from acquiring such information themselves if not related to delivery of health care services (*Health Personnel Act*, 1999, para. 21). However, information may be shared if patient privacy concerns have been attended to by leaving out identifying characteristics (*Health Personnel Act*, 1999, para. 23). In addition, if the patient does not oppose, confidential information may be shared with collaborating personnel in order to provide safe health care (*Health Personnel Act*, 1999, para. 25).

To some extent, the concepts of privacy and confidentiality hamper or at least contrast the concepts of graphical overviews and situational awareness in a clinical environment. Privacy has been defined as "the right to be let alone" and it may be applied to both patients and patient information (Moskop, Marco, Larkin, Geiderman, & Derse, 2005). While *physical* privacy refers to a patient's right to not being bodily exposed to others, *informational* privacy refers to "prevention of disclosure of personal information" (Moskop et al., 2005, p. 54). The latter application of 'privacy' may also be referred to as 'confidentiality' indicating that "those who receive the information have a duty to protect it from disclosure to others who have no right to the information" (Moskop et al., 2005, p. 54). Clinical information technology may include digital representations of patients including combinations of text, photo, audio, video and even interactive 3D-renderings. Although a patient has accepted – step by step – that a clinician may enter his personal zone of physical privacy in order to diagnose the patient correctly, the patient may not have understood the extent of all the information that is aggregated over time. The combination of advanced diagnostic technology and record keeping of medical and social problems over time, may result in a digital representation of a patient's life that contains more information than the patient would like to disclose (e.g. the patient could be reproduced digitally in 3D and reexamined digitally from every possible angle). Accessing this collection of information can be compared to intruding a patient's physical privacy. This illustrates that being able to protect patient information from disclosure –

informational privacy – should play an important role in design and implementation of clinical information technology. Unless otherwise specified, whenever I use the term 'privacy' within this thesis, I define privacy as the right to be let alone – both physically and informationally.

A review of the literature

Approaching the scientific literature that relates to this thesis has been a great challenge. Relevant research findings have been published in a wide range of scientific journals embracing various scientific fields such as medical informatics, computer supported cooperative work, human factors, quality and safety, informatics, social sciences, information visualisation, management, and medicine – including several special areas therein. Relevant studies have been conducted in both non-clinical and clinical settings and with different names on similar concepts (e.g. data display, display format, presentation format, visualisation, graphical overview, graphical display). Thus, searching for relevant studies and deciding on when to stop searching for even more studies have been a daunting task. The majority of the literature has been found through searches on Google Scholar and Pubmed, by reading the list of references in relevant papers and by consulting knowledgeable colleagues for their advice.

In this review of the literature on supporting perception of perioperative care activities I have not included studies of mobile technologies. This does not imply that mobile technologies are incapable of supporting perception of perioperative care. In fact, mobile technologies may even be superior. The reason for not including mobile technologies in this review of the literature was to confine the theoretical background to what was most relevant with respect to my studies. On the other hand, I have extended the application area of clinical perception support beyond perception of care activities, by also including clinical perception of individual perioperative patients' medical data.

I do not proclaim that this review of literature is equal to a systematic review of previous scientific studies on clinical perception support. Rather, the intention with this review is to emphasise the relevance of the research objectives upon which this thesis is founded.

While standardisation of work and outputs can be effective mechanisms for coordinating assembly line manufacturing, these coordination mechanisms have not proven comparably effective within perioperative care. Unexpected problems frequently preclude clinicians from continuing as planned. Instead, clinicians must adapt to new situations and make new decisions based on their growing insight into their patients' health problems and the status of the ongoing care activities. It has been claimed that the health care system operates at its best when adult human beings are able to flexibly communicate with each other and work things out based on their needs and ideas (Glouberman & Mintzberg, 2001). However, the flexibility in information and communication practices and technology within healthcare may be questioned as clinicians spend considerable amounts of their time on documentation and care coordination compared to direct patient care (Hendrich, Chow, Skierczynski, & Lu, 2008).

The importance of communication within health care has been demonstrated in several studies embracing various study designs and clinical contexts including the perioperative (Coiera & Tombs, 1998; Moss & Xiao, 2004; Weigl et al., 2011; Westbrook et al., 2010). Smooth collaboration and communication is essential and may prevent and limit the economic and medical consequences of unexpected break downs in perioperative care. Although frequent communication episodes may be disruptive, the positive effects of communication should not be underestimated. The ability to maintain an awareness of what is going on beyond a person's immediate workspace has been found to be an important factor for ensuring timely execution of perioperative activities, and frustration and conflict may arise whenever unexpected changes in clinical activities are not communicated properly (Ren, Kiesler, & Fussell, 2008).

Information and communication technology (ICT) certainly plays a part in contemporary perioperative care considering the widespread adoption of e.g. mobile phones, pagers and hospital information systems. However, care overview technology that supports clinicians in timely execution of their work is rare. It has been claimed that execution is the fundamental difficulty of modern medical care, and that reliable, efficient and individualised care can only be provided with the increased use of ICT (Bates & Gawande, 2003). Especially important is assisting clinicians in detecting changes in clinical status and notifying them whenever changes need to be followed up. A systematic review from 2010 identified twelve studies on failure to follow up test results and the impact on patient outcomes. The authors concluded that it is a substantial problem that test results of hospitalised patients are not followed up (Callen, Georgiou, Li, & Westbrook, 2011). Furthermore, the authors claimed that the current knowledge of the negative impacts such failures have on the patients, together with contemporary advances in the functionality of clinical information systems, are convincing arguments for continuing the exploration of new technological solutions for improving patient care.

A qualitative study of nurse coordinators at a high-volume trauma hospital found that an information tool for supporting communication and care coordination should have the following design goals in order to fit into the nurses' tasks: "(1) making information compatible with the mobile nature of their work, (2) enabling rapid information access and note-taking under time pressure, and (3) supporting rapid information processing and attention management through the effective use of layout design, shorthand symbols, and color-coding." (Gurses, Xiao, & Hu, 2009, p. 667). While traditional, paper-based handover sheets might meet some of these design goals (Randell, Woodward, Wilson, & Galliers, 2008), the use of large shared displays (e.g. electronic whiteboards) has been suggested as a means of improving awareness and reducing the effort of clinicians to monitor and display clinical work (Randell, Wilson, Woodward, & Galliers, 2010).

Large care activity displays (e.g. whiteboards) are common in health care institutions such as hospitals. Although such artefacts have mostly been developed without supervisory or regulatory control, the design and use of such displays have been shown to be strikingly similar even in quite disparate hospital environments (Wears, Perry, Wilson, Galliers, & Fone, 2006). Such traditional artefacts have played and still play a significant role in perioperative communication, coordination and collaboration (Xiao, Schenkel, Faraj, Mackenzie, & Moss, 2007). The usefulness of this kind of status boards in health care coordination has been ascribed to certain properties: they are malleable (i.e. easily reconfigurable), ecological (only the needed features and contents 'survives'), locally owned (decisions on contents and design are made by the users, not their managers), widely available (can be used by anyone in the area), informal (minimally regulated), and accessible (requires few skills to be used)

(Wears et al., 2006). However, privacy breaches have been shown to be quite common in hospital environments, and publicly available status boards have been pointed out as a potential source for breaches (Mlinek & Pierce, 1997). Critiques claim that masking the identity of patients and sensitive medical information by symbols and difficult medical terms is not enough. Such 'security by obscurity' always runs the risk of being decoded by patients and passers-by, especially if a hospital employee becomes the patient. Hence, status boards should either be redesigned, removed or located in access controlled areas (Bardram et al., 2006; Mines, 1995; Scupelli, Xiao, Fussell, Kiesler, & Gross, 2010).

Computer-based, electronic or digital whiteboards (also called eWhiteboards and status boards) have some properties that dry-erase whiteboards do not have. For instance, they may store the information so that it can be used to make managerial decisions on a higher level. Furthermore, the information may easily follow the patient if he is transferred to other hospital departments (Randell et al., 2008; Wears et al., 2006). In addition, computerisation makes it feasible to apply different levels of privacy based on the location of the board and the specific access control policy at that location.

If one does not want to leave out sensitive information, the only way dry-erase whiteboards can be protected is by placing them in staff-only areas (Scupelli et al., 2010). Digital whiteboards, on the other hand, may be protected by screen savers, authentication measures and aggressive time-outs (Aronsky, Jones, Lanaghan, & Slovis, 2008). However, conventional authentication techniques can be tedious and hamper smooth clinical work-flow (Bardram, 2005). An alternative approach is superimposing 'privacy blinders' over parts of the information (Tarasewich & Campbell, 2005). A blinder may conceal sensitive information while keeping non-sensitive information visible, e.g. covering sensitive information behind an opaque area. To remove the opaque area and reveal the sensitive information the user has to interact with the display, and such interaction may require some sort of authentication.

From early implementations of computerised patient tracking systems, researchers found that computerised patient tracking tools improved interdepartmental communication, reduced the number of phone calls and facilitated monitoring care activity status (Horak, 2000), decreased patient waiting times and improved patient satisfaction (Boger, 2003), reduced discussion and walkthrough time, improved quality of data and communication processes related to bed management "resulting in a better patient care" (Masée, Dijk, Dassen, & Baljon, 2003, p. 358).

More recent implementations and evaluations of computerised whiteboards have found improvements in multidisciplinary communication and coordination of care that are probably related to increased situational awareness and quick access to care information (Bardram et al., 2006; France et al., 2005; H. J. Wong, Caesar, Bandali, Agnew, & Abrams, 2009). In addition to clinical benefits, computerised whiteboards have also been found to have financial benefits and to serve administrative, educational and research purposes (Aronsky et al., 2008).

Through surveys clinicians have reported positive experiences with computerised whiteboards, but this has been shown to depend on staff group, evolve over time and differ between departments (Hertzum, 2011). Besides, even with reductions in communication load, and self-reported high satisfaction with computerised whiteboards, observational data have indicated that the number of coordination breakdowns related to patient status may increase (Taneva, Law, Higgins, Easty, & Plattner, 2011). This has been attributed to lack of trust in colleagues responsible for manually updating information contents of the electronic whiteboards, and Taneva et al. suggests that "a greater degree of automation in status communication technologies will avoid trust-related breakdowns" (Taneva et al., 2011, p. 91).

Correspondingly, comparisons between dry-erase and computerised whiteboards have found that dry-erase whiteboards are more extensively used and have greater information accuracy compared to computerised whiteboards (Patterson, Rogers, Tomolo, Wears, & Tsevat, 2010). Understanding user work processes is important before replacing non-computerised with computerised technology (Pennathur et al., 2007).

Some weaknesses with many of these studies of shared care activity displays are that evaluations are often based on non-systematically collected experience from implementation and use, only considering self-reported data from users, or focusing on *if* it works or not. Little attention has been paid as to *what* information should be presented on care activity displays, and *how* that information should be presented to comply with both usability and privacy concerns. Few studies have included hard outcome measures on the quality and quantity of care. Hence, there is room for more studies on how we can support clinical perception of perioperative care activities and what we can achieve by supporting it.

Supporting clinical perception of perioperative patients

Perception of individual patients and their medical data has deep roots in medical practice as one of the core competencies medical students have to acquire (Boudreau et al., 2008; Osler, 1901). In addition to seeing, hearing, touching, smelling and sometimes even tasting the patient (Henschen, 1969), the diagnostic process often also includes perceiving and interpreting textual (e.g. free-text health record entries), numerical (e.g. laboratory test results) and pictorial (e.g. X-ray) data as presented in a patient's health record. Although health records of today to a large extent have been transferred from paper to computers, the presentation format of the health record contents has not changed much. Many electronic health records still bear a profound resemblance to paper records. Information is usually saved in free text with a tabular format (Figure 3) or mimicking paper on screen (Lium, Tjora, & Faxvaag, 2008; Wyatt & Wright, 1998).

	03.09.10 kl: 08:01	02.09.10 kl: 08:30	01.09.10 kl: 08:02	31.08.10 kl: 08:40	30.08.10 kl: 08:01	29.08.10 kl: 09:15	28.08.10 kl: 08:33	27 kl:
ALAT (P) (70-10)								
CRP (P) (5.1-0)	39 H	45 H	39 H	23 H	8 H	8 H	12 H	14
HB (B) (17-13.4)	8.7 L	8.2 L	8.2 L	8.5 L	8.6 L	8.9 L	9.4 L	9.1
Kalium (P) (4.4-3.5)	4.2	4.4	4.2	4.1	4.1	4.1	3.9	3.9
Kreatinin (P) (72-40)			36 L	36 L		36 L		35
Leukocytter (B) (10-3.7)	1.9 L	2.2 L	1.9 L	1.9 L	2.1 L	1.5 L	1.2 L	1.3
Natrium (P) (145-137)	137	139	139	139	140	139	139	13
Nøytrofile granulocytter (B) (7-1.8)	1.1 L	1.45 L	1.25 L	1.28 L	1.42 L	0.86 L	0.63 L	0.7
Trombocytter (B) (390-145)	70 L	68 L	54 L	36 L	37 L	40 L	48 L	39
Fosfat (P) (1.5-0.8)								
Ion Ca-norm (S) (1.32-1.18)	1.19	1.21					1.1 L	1.1
Magnesium (P) (0.94-0.71)								
Bilirubin total (P) (20-0)								
Karbamid (P) (8.1-3.2)								
Glukose (P) (6.3-4.2)	5.7	5.9				5.1	5	
Akt. bikarbonat (VB) (27-21)								25
GT (P) (80-10)								
pCO2 (VB) (6-4.5)								5.9
pH (VB) (7.45-7.35)								7.3
Basofile-% (B) (2-0)								

Figure 3: Example of tabular presentation of laboratory test results.
This table design was used in the Paper 4 study. Results beyond reference ranges are marked with red colour and an 'L' if the result is below and an 'H' if the result is above the reference range.

One attempt to improve the presentation format of health record contents was the LifeLines project (Plaisant et al., 1998). In the Lifelines project a summary of the contents of a health record was presented graphically as interval lines and punctual events on a zoomable timeline. Details could be accessed by interaction (clicking) and specific types of information were highlighted by colour, line thickness and labels. A comparison of the Lifelines presentation of health record contents with a tabular presentation of the same contents, found that participants using Lifelines had more rapid response times on intercategorical and interval comparisons, and higher recall of contents (Alonso, Rose, Plaisant, & Norman, 1998). Still – more than a decade later – timelines are barely implemented for displaying medical history and clinical observations, even though healthcare professionals are supportive and recognise many potential benefits of timelines (Gill, Chearman, Carey, Nijjer, & Cross, 2010). It seems fair to claim that the current state of applied information design in electronic health record systems does not differ significantly from what was claimed 15 years ago: "[well-known design factors that support perception and interpretation of data] seem to have had little influence on medical-record format” (P. Wright, Jansen, & Wyatt, 1998, p. 1542).

A particular subset of health record contents has to a larger extent adopted timeline visualisation techniques: laboratory results. Laboratory results can be visualised as line graphs plotted in a coordinate system with time running along a linear ‘x’ axis and the numerical values of the laboratory results represented by a position on a linear ‘y’ axis (Figure 4). However, alternatives exist such as the unit-independent technique which has a logarithmic time scale on the ‘x’ axis, and standard deviation units on the ‘y’ axis (Mayer, Chou, & Eytan, 2001). Diagrams and graphs have been criticised for taking up much space (Wyatt & Wright, 1998). However, space-saving small graphs have been developed to permit richly detailed patient status summaries in only one page (Powsner & Tufte, 1994), and prototypes have been made to demonstrate the feasibility of presenting various types of medical data separately or combined into graphical overviews on very small screens (Chittaro, 2006).

Figure 4: Line graph of the concentration of C-reactive protein (CRP) in plasma.
Y-axis represents concentration in mg/L, and X-axis represents date of blood sampling.

Meta-analyses of the efficiency of tables versus graphs have arrived at different conclusions. One meta-analysis found that the effectiveness of graphs is task dependent with moderate complexity favouring graphs, and with no differences between tables and graphs with small or high task complexity. The authors of the meta-analysis concluded that task complexity should be “controlled for to make a research findings meaningful” (Hwang & Wu, 1991, p. 19). Another meta-analysis concluded that there is no practical difference between tables and graphs with respect to *decision accuracy*, and that the variations in findings between original studies of ‘graphs versus tables’ can be explained by sampling errors (Schaubroeck & Muralidhar, 1991). However, the latter meta-analysis included only studies with between-subject design in their analysis, and the authors also call for more research on the topic: “If indeed the choice between tables and graphs does not affect decision quality, then, with the possible exception of user preferences, comprehensibility and speed are the remaining considerations in choosing an information display format” (Schaubroeck & Muralidhar, 1991, p. 141).

While more recent non-clinical studies have included more variables in trying to understand if and how tables are better than graphics and vice versa, results have differed from study to study in favour of tables, graphics or none (Coll, Coll, & Thakur, 1994; Coll, Thyagarajan, & Chopra, 1991; Lohse, 1993; Meyer, Shinar, & Leiser, 1997). Interestingly, Meyer et al. found that performance measures are influenced by the structure of the data and the participant’s knowledge of that structure; more structure and more knowledge benefited line graphs more than tables (Meyer, Shamo, & Gopher, 1999). The interaction of line graphs, structured data and knowledge of this structure improved participants’ ability to predict future trend. These findings might be transferable to a clinical context in which physicians try to predict the future trend of a patient’s laboratory test results. The laboratory test results of a patient are not likely to vary randomly over time, i.e. they have some structure that may be related to the disease, time of day, patient activity and more. Knowing how laboratory test results tend to vary with various diseases and other contextual factors constitutes an important part of what clinicians must learn.

Patients with chronic diseases have been pointed out as one particular group whose management might benefit from having time-oriented presentation formats of clinical data, although this has not been empirically tested (Samal, Wright, Wong, Linder, & Bates, 2011). One of few clinically oriented evaluation studies of graphs versus tables found that laboratory test results presented as line graphs were assessed faster than results presented in a conventional table (Bauer, Guerlain, & Brown, 2010). One third of the interpretations of the data differed based on presentation format.

Comparing and combining the results of studies of the effects of visualisation techniques on perception and interpretation of data is challenging considering the wide range of visual and contextual variations that may or may not be incorporated in the experiment (e.g. colour, size, orientation, shape, texture, participant, skills, data, task, complexity). It is reasonable to think that the benefit of having laboratory test results presented as graphs may differ between emergency management of a trauma patient and longitudinal management of a patient with multiple chronic diseases. There might even be differing benefits within each of these two groups of patients as well.

Research Objectives

The main objective of this research project was to explore whether, how and to what extent supporting clinical perception has or might have an impact on clinical work. In this research project I have approached two different clinical tasks – *Managing clinical activities* (Paper 1-3), and *Interpreting medical data* (Paper 4) – and I have included both qualitative and quantitative assessments of efficiency and efficacy of clinical perception support.

Managing clinical activities (perceiving care activities)

PAPER 1: CONTINUOUS COORDINATION IN PERIOPERATIVE WORK

The objective of this study was *to characterise how perioperative coordination was achieved at a modern hospital with emphasis on how and when each actor perceived/knew when to contribute to the collaborative care process.*

PAPER 2: DESIGNING PRIVACY-FRIENDLY DIGITAL WHITEBOARDS FOR MEDIATING CLINICAL PROGRESS

This study was conducted to understand more specifically the information needs related to perioperative patient management at a surgical ward, and explore how such information can be presented on a digital whiteboard. The objective of the study was *to understand what information supports surgical ward nurses in managing perioperative care, and how can that information be presented on a digital whiteboard without compromising the privacy of their patients?*

PAPER 3: WHAT IS OPTIMAL TIMING OF TRAUMA TEAM ALERTS? A RETROSPECTIVE OBSERVATIONAL STUDY OF ALERT TIMING EFFECTS ON INITIAL MANAGEMENT OF TRAUMA PATIENTS

The objective of this study was *to evaluate what is the effect of projected perception of a care activity on patient management?* The care activity was trauma patient management, and the evaluation included whether pre-arrival notification of trauma teams or variations in timing of trauma team activations had any effect on initial intra-hospital trauma patient management.

Interpreting medical data (perceiving the patient)

PAPER 4: PRESENTATION OF CLINICAL LABORATORY RESULTS: AN EXPERIMENTAL COMPARISON OF FOUR VISUALIZATION TECHNIQUES

Unlike paper 1, 2 and 3, which focused on multiple patient management from a care coordination perspective, this paper focused on perception and interpretation of individual patients' medical data. Medical data were represented by authentic clinical chemistry test results from four patients, each presented with four different visualisation techniques. The objective of the study was *to evaluate what is the effect of presentation format on perception of laboratory test results?*

Methods

> *We like to pretend that our experiments define the truth for us. But that's often not the case. Just because an idea is true doesn't mean it can be proved. And just because an idea can be proved doesn't mean it's true. When the experiments are done, we still have to choose what to believe.*
>
> Jonah Lehrer, The New Yorker, December 13, 2010

Research and development within the field of medical informatics draws on a multitude of methods from academic and professional disciplines such as natural sciences, social sciences and engineering. However, central in much medical informatics research is the design, development and evaluation of medical information artefacts (e.g. an electronic health record system) (Friedman & Wyatt, 2006). Such an artefact may be considered as an intervention in a clinical environment, and the researcher may want to analyse the efficacy, efficiency and impact on various levels such as the artefact in itself, the user, the patient and the organisation. Depending on what questions the researcher wants to address, various research approaches may be applied (Malterud, 1996). These approaches may be divided in 'objectivist' approaches with a logical-positivist philosophical orientation, and 'subjectivist' approaches with an intuitionist-pluralist philosophical orientation (Friedman & Wyatt, 2006).

The objectivist approaches value measurable observations and quantifiable analyses of performance and efficiency of a specified intervention that is usually related to a predefined and rationally derived gold standard (Friedman & Wyatt, 2006). One example might be a randomised controlled trial of the effect of electronic alerts to prevent venous thromboembolism among hospitalised patients (Kucher et al., 2005). Based on predefined and measured variables the researcher tries to explain any variation between individual observations (Sandelowski, 1996). The analysis of the observations is usually based on statistics and should be unbiased by the researcher's previous experience and beliefs.

The subjectivist approaches, on the other hand, depend more on the researcher, and the researcher's abilities to describe and interpret (Malterud, 1996). Each particular observation is unique and should be interpreted with respect to the context in which it was explored; “qualitative research is quintessentially about understanding an empirically real or constructed particular in the fullness of whatever contexts are relevant” (Sandelowski, 1996, p. 526). One example might be to describe how mobile information devices may affect doctor-patient communication (Alsos, Das, & Svanæs, 2012). The value of a medical information artefact can be understood by observing how the resource is used, asking what the users feel about it and by exploring in-depth any deviating observations (Sandelowski, 1996; Tjora, 2012).

An overview of the methods that were applied in each of the individual studies included in this thesis is presented in Table 1. Details regarding these methods are described more thoroughly in separate subsections.

Table 1: Overview of study design, selection of participants and data analyses.

Paper	Study Design	Selection	Analysis
Continuous Coordination in Perioperative Work (Paper 1).	In-depth interviews. Field work with observations and focused interviews.	Perioperative staff from multiple departments at a single hospital.	Systematic text condensation.
Designing Privacy-Friendly Digital Whiteboards for Mediating Clinical Progress (Paper 2).	Design science research process model. Simulated scenario. Focused interviews.	Ward nurses from a surgical department and an observation unit.	Systematic text condensation.
What is optimal timing of trauma team alerts? A retrospective observational study of alert timing effects on initial management of trauma patients (Paper 3).	Retrospective cohort study.	A whole year of trauma team activations at a single hospital (extracted from a quality registry).	Pearson’s Chi-square. Descriptive statistics.

Paper	Study Design	Selection	Analysis
Presentation of clinical laboratory results: An experimental comparison of four visualization techniques (Paper 4).	Balanced, crossover experiment.	Medical students responding to e-mail and poster advertisement at the campus.	Cohen's Kappa. McNemar's test. Mixed Model Analysis. Multinomial test. Friedman test. Wilcoxon Signed-Rank test.

Study design

In-depth interviews

An in-depth interview is a common data acquisition technique within qualitative research. Interviews are useful for describing a person's experiences and describing what the world looks like from that person's point of view (Tjora, 2012). Before commencing any interviews, the researcher determines what major themes should be covered, and prepares relevant open-ended questions. However, during the interview the informant is allowed to make digressions to other topics that the interviewer perhaps had not thought of before the interview. Thus, the task of the interviewer is not to keep the informant strictly to a predefined set of questions and topics, rather to create a comfortable dialogue in which the informant can share his or her experience and reflections (Tjora, 2012).

In-depth interviews should be quite long-lasting to give the informant enough time to feel comfortable and speak openly. Interviews can be audio-taped and transcribed and may generate much data from only a few informants.

Focused interviews

The focused interview, as a research method, was initially developed as a method to assist interpretation of statistically significant effects of mass communication, but intervention studies in general and studies of responses to concrete situations in everyday life may profit by the use of focused interviews (Merton & Kendall, 1946). The focus of a focused interview is the participant's subjective experience from a particular situation. To aid the participants' reporting and ensure that participant and researcher refer to the same aspects of the original situation, the researcher often re-exposes the participants to the situation, for instance by playing back a part of a film or showing photos from the situation. The researcher should have previous familiarity with this particular situation, and the topics of the interview and central questions are prepared in advance in the interview guide (Merton & Kendall, 1946).

In Paper 2 the particular situation in focus was continuous care management as part of surgical ward work. The re-exposure to this situation included simulating a surgical ward work scenario. The researchers endeavoured to provide not only a prototype with realistic contents, but also a realistic clinical environment and scenario (Alsos & Dahl, 2008). The researchers were already familiar with this situation through previous clinical experience, field work and in-depth interviews. An interview guide was utilised, and the subjective experience of the participating nurses from the simulated scenario and comparable real clinical situations served as the focus of the interview.

Focused interviews can be very useful whenever the topic of the interview is limited and non-sensitive for the informant; thus enabling the interviewer and informant to quickly establish an open and comfortable dialogue (Tjora, 2012). Like many other subjectivist approaches, focused interviews can be conducted at early stages of research to generate hypotheses applicable for subsequent quantitative research methods, or during late stages of research to interpret the results from quantitative research methods, specifying the effect and explaining why there might be deviations from anticipated effects or between subgroups (Merton & Kendall, 1946).

Focused interviews were also conducted in Paper 1 as part of the field work. These interviews were partly facilitated by the situatedness of the interview, but also by a montage of images representing various stages of a perioperative patient care process (Figure 5).

Figure 5: Montage of images representing various stages of a perioperative patient care process.

All images are released by U.S. federal government in the public domain (http://commons.wikimedia.org)

Design science research methodology

Design is "the act of creating an explicitly applicable solution to a problem" (Peffers, Tuunanen, Rothenberger, & Chatterjee, 2007, p. 47). In Paper 2 the researchers evaluated a specifically designed artefact that was intended to inform nurses about recent care activities without disclosing sensitive information. The design science research methodology (DSRM) is a model for how to conduct information systems and design science research (Peffers et al., 2007). This model does not define or restrict evaluation methods to any specific form. The evaluation of the designed artefact may just as well be based on subjectivist as objectivist approaches. However, DSRM outlines a process of six steps that should act as a guideline for effective design science research. The researcher does not have to follow these steps sequentially. Depending on the situation, the research entry may be a problem-centred approach (step 1), an objective-centred solution (step 2), a design- and development-centred approach (step 3) or observation of a solution (step 4). The model also illustrates how iterations of these steps can be integrated in the research process and advance the development and effectiveness of the artefact. The research entry of Paper 2 was a problem-centred approach that originated from the findings from studying coordination of care activities in the perioperative environment (Paper 1). The research agenda of Paper 2 was thus adapted to DSRM (Table 2).

Table 2: Design Science Research Methodology as applied in Paper 2.

DSRM	As applied in Paper 2
1) Problem identification and motivation	What information supports perioperative care management at a surgical ward, and how can that information be presented on a digital whiteboard without compromising patient privacy?
2) Definition of the objectives for a solution	A digital whiteboard that presents de-identified and abstracted patient care information without authentication, and that provides identified and specified patient care information upon authentication.
3) Design and development	Three prototypes (developed iteratively).
4) Demonstration	Simulated ward work with surgical ward nurses in a realistic environment, with a realistic clinical scenario and with realistic care activity information presented on the prototypes.
5) Evaluation	Focused interviews with participants.
6) Communication	Presentation at health informatics conference (HelsIT 2011). Publication in scientific journal (to be published).

Retrospective cohort study

A cohort study is an observational study, and it is commonly used in epidemiology. The main arguments for conducting observational studies compared to randomised controlled trials are that they can be conducted when randomised controlled trials would be unethical (e.g. the health effect of lifelong smoking) or impractical (e.g. very rare diseases) (Mann, 2003).

In Paper 3 cohorts were separated by differently timed trauma team activations and whether or not the team members received a trauma team notification before the activation. In a prospective cohort study, these cohorts would have been followed to observe the outcome of the dependent variables. In Paper 3 the dependent variables were already registered in the hospital trauma care quality registry before the onset of the study. Hence, the study was a retrospective cohort study. Compared to prospective cohort studies, retrospective cohort studies are cheaper and less biased because data are collected in advance for other reasons than measuring the particular outcome of the study (Mann, 2003).

The independent variables of Paper 3 were whether or not the team members were notified before activation, and the timing of activation measured in number of minutes before patient arrival. We grouped different timing of activation in intervals of five minutes from zero minutes (i.e. patient arrived before or at the same time the trauma team was activated) to 20 minutes pre-arrival activation. The last group included all activations that were done more than 20 minutes before patient arrival.

Time to activation was measured from the activation alarm was sent out, until the patient arrived. If the patient had arrived before the team was activated, then we set activation time to zero. We did this because we were mainly interested in how much time the team used with differently timed activations. We did not find it reasonable to add any time before the team was aware that they had a new patient even though patient management would probably suffer from having post-arrival trauma team activation.

Balanced, crossover experiment

In the evaluation of different visualisation techniques for presentation of laboratory results (Paper 4), we set up a balanced, crossover experimental design. Such design usually reduces variation as within-subject comparisons can be made, and these usually vary less than between-subject comparisons (Veierød, Lydersen, & Laake, 2012). All participants assessed all combinations of presentation format and patient case, avoiding any between-subject effects that can bias the results in studies with non-crossover designs. On the other hand, carry-over effects can bias the results with crossover designs, i.e. subsequent assessments of laboratory results are affected by previous ones. We tried to avoid or reduce any carry-over effects by displaying the presentation formats in different order for each participant according to latin square design (Table 3), by having all participants carry out a pre-experiment practice session (familiarising with the visualisation techniques), and by presenting patient cases in a specific non-repetitive order (chronic – complex – emergency – simple – complex – emergency – simple – chronic – emergency – simple – chronic – complex – simple – chronic – complex – emergency).

Table 3: Latin square design for presentation order of visualisation techniques to avoid specific order carry-over effects.

	Order 1,5,9,13	**Order 2,6,10,14**	**Order 3,7,11,15**	**Order 4,8,12,16**
Participants 1,5,9,13,17	Relative multigraph	Sparklines	Table	Absolute multigraph
Participants 2,6,10,14,18	Sparklines	Table	Absolute multigraph	Relative multigraph
Participants 3,7,11,15,19	Table	Absolute multigraph	Relative multigraph	Sparklines
Participants 4,8,12,16,20	Absolute multigraph	Relative multigraph	Sparklines	Table

The outcome measures of Paper 4 were the participants' assessment of laboratory data, their assessment times and their preferred presentation format for each of four patient cases. The participants had to assess whether the results for each laboratory test demonstrated a significant trend (increasing or decreasing) or not, and whether the results were beyond (above or below) reference ranges or not. Since there were no established gold standards for characterising such features of laboratory results, the focus of the analyses of the participants' assessments were on agreement and disagreement within-subject and between presentation formats.

Selection

In quantitative research the sample should represent the population from which it was sampled in order to be able to generalise the results back to the population, and randomisation is one of the most important means of ensuring a representative sample and avoiding selection bias (Clancy, 2002).

In qualitative research samples are usually much smaller and usually selected strategically or purposefully to be able to study a particular situation or phenomenon in depth and/or breadth (Malterud, 1996). A sampling strategy that would be regarded as selection bias and limitation of a quantitative study, can be the intended focus and strength of a qualitative study (Patton, 2002). Hence, sampling strategies in qualitative research might be to include those who fulfil a certain criterion, deviant cases, homogeneous groups and maximum variation (heterogeneity) (Patton, 2002). Unlike objectivist approaches, subjectivist approaches do not require and should not try to decide on a predefined size of the sample (Malterud, 1996). How many and who should be included in the sample is rarely decided before the onset of the study, but informed by preliminary analyses of the first collected data. Samples are usually small compared to quantitative studies, partly because large samples might make it difficult to achieve an overview of the material (which is necessity for carrying out ‘systematic text condensation’) (Malterud, 1996). There are no specific rules for sample size in subjectivist approaches, and even the smallest sample size, N=1, can be studied qualitatively (Patton, 2002; Sandelowski, 1996).

Paper 1

In Paper 1 participants were recruited from the perioperative environment upon direct request. Participants represented most of the different perioperative staff groups including anaesthesiologists, post-anaesthesia care unit nurses, operating theatre nurses, surgical and orthopaedic physicians, surgical ward nurses, cleaners, technicians, nurse anaesthetists and operating theatre coordinators (maximum variation sampling).

This heterogeneous sample reflected the objective of the study; a broad approach towards understanding how perioperative coordination was practised, focusing on how and when individual perioperative actors perceived when to contribute to the care process. Hence, breadth was valued more than depth in this study, and exploring perioperative care management from the point of view of various clinical and non-clinical professions was considered valuable.

Paper 2

In Paper 2 the participants were recruited from a gastrosurgical ward and an observation unit. All participants were nurses with experience with surgical patient care management. They participated during working hours in agreement with managerial staff. The observation unit was a short-term unit at which patients from most departments, including surgical departments, are admitted. Usually the patients' conditions are non-vital and admissions at the observation unit rarely last longer than 24 hours. However, during their stay at the unit patients usually undergo extensive diagnostic investigations including imaging and blood analyses.

The sample in Paper 2 was homogeneous compared to the sample in Paper 1. The deliberate choice of including only nurses with experience with surgical patient care management was based on the objective of the study; approaching in depth what information a surgical ward nurse needs, why and how that information can be presented to support care management without compromising patient privacy.

Paper 3

In Paper 3 the major sampling criterion was any trauma team activation during a period of time. The time period was a compromise between available data and avoidable biases. The data in the quality registry were not available for years preceding 2009. In addition we avoided including data from the years 2010 and 2011 due to large organisational modifications in the emergency department in 2010, and implementation of an automated countdown support tool at the emergency dispatch centre in 2011. Hence, trauma team activations during 2009 were included as they were believed to be complete and unbiased.

Any trauma team activations involving more than one patient (e.g. traffic accidents with two or more injured people) were not included because such situations could be affected by limitations in available personnel or other resources, and the relation between team notification, team activation and patient arrival for each of the patients was not obvious (decreasing the reliability of time interval calculation).

Paper 4

In Paper 4, 1st to 5th year medical students from a six year medical curriculum participated in the experiments. Participants self-recruited responding to campus advertisements including posters in student areas and e-mail to medical student e-mail lists. Medical students were considered to be sufficiently medically trained for the experiments based on knowledge of their integrated basic science and clinical teaching medical curriculum, and the fact that the experiments focused on ability to interpret non-clinical characteristics of numerical data presented in tables or as line graphs. The sample size could be kept quite small due to the crossover study design.

Analyses

Systematic Text Condensation

Compared to quantitative analysis of research data qualitative analysis depends more on the researcher's abilities to describe and interpret the data material (Tjora, 2012). However, the researcher may choose whether to put more effort in either interpretation – i.e. trying to make explicit what informants only have mentioned implicitly – or in description – i.e. communicating what the informants have said more directly (Malterud, 1996). In Paper 1 and Paper 2 interview transcripts and field notes were analysed systematically in accordance with the qualitative free text analysis method called 'Systematic text condensation' (Malterud, 2012). Systematic text condensation is "a descriptive approach, presenting the experience of the participants as expressed by themselves, rather than exploring possible underlying meaning of what was said" (Malterud, 2012, p. 796). The method can be summed up in four analytical steps:

1) *Overview*: Reading the complete data set and establishing preliminary themes based on the general impression of the data.

2) *Coding*: Identifying and coding meaning units. Meaning units are pieces of the data material (e.g. isolated sentences or sections of the textual material) that somehow address the research questions, whereas codes are explicit and decontextualised labels that are used to group meaning units that address similar aspects of the research questions.

3) *Condensation*: Abstracting meaning from each group of meaning units. In this phase some codes may need adjustments, and meaning units pertaining to the same code can be divided in subgroups to be able to make condensates that reflect all aspects of the meaning units.

4) *Synthesising*: Creating consistent and recontextualised descriptions that

reflect the contents of the data and address the research questions. As part of this final step the descriptions are also compared and validated against their original context (i.e. the raw textual material).

This method should not be confused with quantitative methods in which codes or themes are settled by the researcher in advance, and data are analysed based on the hypotheses that the codes were derived from. Although a researcher that applies systematic text condensation also has preconceptions, these preconceptions should be regarded as a threat to the analytical validity. By clearly stating the preconceptions before data acquisition and data analysis, and by adhering strictly to the systematic text condensation method, the researcher minimises this threat. 'Reflexivity' represents an active and critical reflection of the researcher's preconceptions and point of view (Malterud, 1996). Acknowledging that the researcher's previous knowledge and expectations might influence data collection and interpretation is the first important step towards avoiding this important source for bias in research.

The preconceptions pertaining to Paper 1 were stated in the project description of the multidisciplinary research project within which Paper 1 was conducted, i.e. 'Co-Operation Support Through Transparency' (Toussaint, 2008): "The basic assumption underlying our project is that deciding on a course of events in clinical problem solving is [a] cognitive problem, to be dealt with by health personnel, each from their own professional perspective and based on the information they have about the status of the collaborative effort. They need to be informed about the actions taken and results obtained by the others".

Similarly, the preconceptions pertaining to Paper 2 were also stated in the project description (Toussaint, 2008): "To achieve this by creating a shared work space that gives all the actors involved in the collaboration real-time insight into the work process, e.g its progress and possible deviations from the expected course".

Thus, the preconceptions comprised that providing information about some ongoing collaborative care activities at some level of detail to perioperative staff through a shared work space could improve clinical problem solving and care management. These preconceptions were quite vague with respect to what, at what level of detail, at what time, and in what format the information should be provided. Nevertheless, these preconceptions were kept in mind when collecting and analysing research data as part of the adherence to the qualitative method.

Pearson's Chi-squared test

Pearson's Chi-squared test, also known as Chi-Square Test for an RxC Contingency Table, tests the relationship (or independence) between two categorical variables (Rosner, 2006). The analysis compares observed values against expected values, and the more difference between these, the more likely there is some kind of dependence between the variables. E.g. in the study of trauma team activation we found no significant relationship between differently timed team activations and length of stay in the emergency department (Table 4), i.e. there were little difference between observed and expected values.

Table 4: Example of a contingency table with no statistically significant relationship between the variables ED LOS and TTA-time. TTA: Traumateam activation. ED LOS: Emergency Department Length of Stay.

	ED LOS	
TTA-time	≤ 25 min	> 25 min
≤ 0 min	6	5
0.01-5 min	13	13
5.01-10 min	48	51
10.01-15 min	41	38
15.01-20 min	18	14
> 20 min	9	3
Pearson Chi-Square	p = .649 (5df)	

Cohen's K (The Kappa Statistic)

The kappa statistic can be used to quantify the reproducibility of the same variable when measured multiple times (Rosner, 2006). Hence, it is a measure of the magnitude of concordance. The kappa statistic also accounts for having identical measurements by chance, hence, it provides a better indication of reproducibility than an agreement percentage. In Paper 4 we used the kappa statistic in two different analyses.

First, kappa was used to measure the reproducibility of the scores that the researchers produced by reading the participant's covariation comments (inter-rater agreement). Both researchers independently scored all covariations comments. Their observed concordance rate were then compared to what would be the expected concordance rate (by chance), and the subsequent calculation gives a kappa statistic between 0 (not reproducible, i.e. independent answers) and 1 (perfect reproducibility, i.e. the researchers score identically).

We also applied the kappa statistic in analysing reproducibility of laboratory test assessments, but the focus was shifted from the persons who performed the scores towards the four visualisation techniques. In other words, was it likely that the assessment of a laboratory result made with the relative multigraph was reproducible with that made with the absolute multigraph, sparklines or table (as assessed by the same participant)? Although this focus – inter-visualisation agreement – is different from inter-rater agreement, the statistical analysis is the same in both situations.

McNemar's test

McNemar's test is suited for analysis of differences between two sample, matched-pair data (Rosner, 2006). This test was applied to see whether there were any consistent features between the assessments of identical laboratory results whenever the assessments diverged between two visualisation techniques. The following example of diverging assessments made with the absolute multigraph and the table illustrates when and how McNemar's test can be applied, and how McNemar's test differs from Cohen's K:

In the experiment, each participant was asked to assess the trend of a patient's haemoglobin levels as either increasing, decreasing or neither. Without knowing, the participant assessed identical haemoglobin levels twice – first presented in an absolute multigraph and later in a table. The participant was expected to make identical assessments both times. However, some participants answered that they could see a clear trend with the absolute multigraph, but when presented in a table they did not see this trend (i.e. discordant assessments). If these differences in assessments were not dependent on the visualisation technique, it would be expected to be an equal number of assessments were haemoglobin levels were assessed as a trend with the absolute multigraph and as no trend with the table, compared to no trend with the absolute multigraph and trend with the table.

These two types of discordant pairs can be referred to as an ‘absolute multigraph trend’/’table no trend’ discordant pair versus an ‘absolute multigraph no trend’/’table trend’ discordant pair. McNemar’s test applies the binomial distribution and estimates the statistical significance for achieving the observed numbers of ‘absolute multigraph trend’/’table no trend’ pairs and ‘absolute multigraph no trend’/’table trend’ pairs by chance. For example, the experiments in Paper 4 revealed that there were significantly more discordant pairs in which a trend were found with the absolute multigraph and not found with the table compared to the opposite (Table 5).

Table 5: Example of inter-visualisation agreement and disagreement table (59 discordant pairs of the type 'absolute multigraph trend'/'table no trend', and 19 discordant pairs of the type 'absolute multigraph no trend'/'table trend').

		Absolute multigraph	
		Trend	No trend
Table	Trend	136	19
	No trend	59	146
McNemar’s test		$p < 0.001$	

Mixed model analysis

The analysis of the assessment time data in Paper 4 was done using a mixed model analysis. The building of the linear mixed model was conducted by a statistician. For details on linear mixed model analysis as a statistical method, the reader should consult books in statistics. However, here I provide a brief orientation of what linear mixed model analysis is and when it can be applied.

The term ‘linear mixed models’ refers to that the response variable is continuous (linear) and that there is a mix of fixed and random effects that explains variations of the response variable between observations. While traditional linear regression models assumes independent observations, linear mixed models can handle dependencies between observations, and thus are suitable for analysing data with repeated measurements on the same participants (Veierød et al., 2012).

In Paper 4, 20 medical students each made repeated assessments of laboratory test results presented with different visualisation techniques. The time spent on these assessments were recorded, and the experiment was designed such that all participants assessed the same laboratory test results and acted as their own control (i.e. a balanced, crossover design).

The difference between participants was regarded as random variation, and was not the focus of the study. Some participants would expectedly be quicker or slower than others. Rather, the focus of the analysis was on the fixed effects 'visualisation technique', 'patient case' and 'repeated exposure'. Whereas a traditional linear regression model can incorrectly result in less significant within-participant differences and more significant between-subject results, correctly identified random and fixed effects in a linear mixed model analysis, ensures that the computed estimates have standard errors that are corrected for the dependence among observations (Veierød et al., 2012).

Friedman test and Wilcoxon Signed-Rank test

Whereas the Wilcoxon Signed-Rank test is a non-parametric test for comparing differences between the ranks of observations in two paired samples, the Friedman test applies the same method for more than two samples. If the Friedman test is positive, Wilcoxon Signed-Rank test can be used to identify which samples differs significantly from each other. Both tests take into account the relative magnitude of the difference in observations.

In the experiment, for each set of laboratory test results, participants were asked to comment (in free text) if they saw any covariation between any of the tests in that set of test results. Afterwards the researchers read through the comments and scored how many tests the participant had found to be co-varying. As an example, the range of co-varying tests was found to be from 0 to 8, with 0, 2 or 3 covarying tests as the most common answers. By applying the Friedman test the differences in the number of covarying laboratory results identified with the four visualisation techniques were found to be statistically significant. Furthermore, the Wilcoxon signed-rank test located this difference to be most significant between the table and the relative multigraph, and between the table and sparklines.

Multinomial exact test and the uniform discrete distribution

The multinomial exact test may be regarded as a generalisation of the binomial test in that the number of outcome values of an observation may be more than just two discrete values. If the probability of observing each of these outcome values is identical, the values follow the discrete uniform distribution, e.g. a dice has six possible outcome values with an equal probability of 1/6.

In Paper 4 we applied the multinomial exact test to analyse whether the participants' preferred visualisation techniques for each patient case differed from a discrete uniform distribution (i.e. ¼ probability for each of the four visualisation techniques).

Validity, reliability and generalisability

'Reliability', 'validity' and 'generalisability' are commonly used terms in scientific literature and they represent important dimensions of research quality (Friedman & Wyatt, 2006; Tjora, 2012). Reliability is related to the reproducibility of the research findings and is a prerequisite for research validity, albeit insufficient in itself (Friedman & Wyatt, 2006; Malterud, 1996). Generalisability refers to the applicability of the study findings in other contexts, and may also be referred to as 'transferability' or 'external validity' (Malterud, 2001). Validity is related to the certainty of the inferences from a scientific study, and may be divided in two types: internal and external validity (Cook & Campbell, 1979; Lund, 2005). Internal validity refers to the certainty of inferring whether there is a relationship between observed variables (also known as as 'statistical conclusion validity'), and whether this relationship is causal or merely an association. External validity refers to the certainty of inferring that these variables represent some construct (also known as 'construct validity'), and the certainty of inferring that the study findings may be generalised across persons, contexts and times. Hence, in this validity system, reliability and generalisability are dealt with within internal and external validity respectively (Lund, 2005).

The level of validity is determined by critically evaluating all aspects of the study (e.g. study design, sampling strategy, data acquisition technique, data analysis). However, validity should not be regarded as a property of methods, data or results, rather validity should be regarded as a property of "the inferences that are drawn from these procedures, data, and results" (Lund, 2005, p. 121).

Compared to quantitative research the validity of qualitative research depends more on the researcher both during data acquisition (e.g. what the researcher notices during field observations) and data analysis (e.g. how the researcher interprets the qualitative data material). Unlike objectivist approaches, in which researchers should endeavour to be neutral and objective, subjectivist approaches do not acknowledge complete objectivity (Tjora, 2012). Although some researchers that conduct qualitative studies might claim that their findings emerged from the data alone; observations of phenomena, questioning informants and analysing data necessarily have to be done by a person whose perception of and interaction with the phenomena and the informants somehow is affected by previous experience and theoretical models (Malterud, 2001). Importantly though is to acknowledge that complete objectivity is not achievable in quantitative research either. Although data analysis may be conducted with statistical methods that ensure an objective analysis, the data may be based on subjectivity (e.g. survey data). In addition interpretation of research findings is always subjective and depending on the context of the research and the prevailing theories irrespective of research approach (Tjora, 2012).

Comparing independent interpretations of the same qualitative data material has been suggested as a quality improvement of qualitative research, however such "inter-rater reliability has become less credible as a measure of quality in qualitative research" (Greenhalgh, 2010, p. 166). More important is to carefully evaluate the research questions and the appropriateness of the research approach, to what extent the context and sample were purposeful, how data were collected, the preconceptions of the researcher, how data were analysed, and finally the practical relevance of the research findings (Greenhalgh, 2010; Malterud, 2001). In that respect, having more than one researcher may shed more light on the nuances and relevance of the data, rather than increasing the reliability of the findings (Malterud, 1996). The relevance of research findings are related to the external validity of the study findings. Although the sample of a quantitative study might be representative for the population, the findings may not be highly relevant for the population. For instance, randomised controlled trials might have high internal validity and a representative sample, but poor external validity as the trial context does not reflect the usual context, e.g. patients and clinicians are more engaged when part of a study (Clancy, 2002). The external validity of qualitative research may be even more difficult to recognise as the findings have derived from small, non-representative samples of the population. However, qualitative research can develop theories, models or concepts that may be relevant to other settings than the situation from which they were derived. This has been referred to as 'conceptual generalisation' (Tjora, 2012). According to Lund the paradigmatic distinction between qualitative and quantitative studies might be exaggerated, arguing for that the same validity system can be applied in both cases (Lund, 2005).

Results

Managing clinical activities (perceiving the clinic)

In Paper 1 the focus of the study was on when and how perioperative staff members perceived/knew when they should contribute to the care process. The findings of the study indicated that a surgical schedule was important, but insufficient for supporting continuous coordination of perioperative work. Much direct communication between perioperative staff members was necessary to ensure timely preparation and execution of perioperative activities. In addition, individual staff members employed various strategies to keep themselves aware of perioperative activities and used this awareness to project future status to proactively coordinate their own work. Some staff members monitored an updated electronic version of the schedule, others monitored the work environment directly, while others again depended on communication through pagers and phones.

In general, these findings suggested that perceiving and sharing information from ongoing perioperative activities was important for care management. The findings also suggested that clinical perception support not only should inform about current status but also include updated projections of current and future perioperative activities.

In Paper 2 the focus was on information needs for supporting perioperative care management at a surgical ward. The surgical ward nurse was chosen as a specific perioperative staff member and a digital whiteboard was used as a specific technological artefact for mediating updated perioperative care information.

The participating ward nurses valued having updated information from patient care activities displayed on the digital whiteboard. Even if the displayed information was abstracted and de-identified the nurses said that such information was likely to support clinical awareness and coordination of care at a surgical ward. In the simulated scenario the nurses were able to re-identify much of the de-identified and abstracted care information that was presented on the digital whiteboard. They also said that they expected to be able to do that in real life based on their knowledge of what their patients have undergone and what information or clinical activities their patients are awaiting. However, the nurses emphasised that a digital whiteboard should also render possible to unambiguously disclose patient identity and reveal full medical information related to specific care activities whenever needed. The nurses claimed that a digital whiteboard has the potential of reducing work-load by reducing the number of log-ins to the electronic health record and other clinical information systems – especially log-ins to check for availability of new information.

Projections of ongoing and future care activities were highly valued. Knowing when upcoming activities or information could be expected was considered useful for coordinating their own and their patients' activities. The nurses expected that good projections would support more timely management of patients with potential clinical benefits such as avoiding unnecessary fasting.

In Paper 3 the effect of projecting future care activities on patient management was evaluated. Management of trauma patients was chosen as a specific care activity since projection support already was established for the trauma team members. In general, the findings from Paper 3 demonstrated a statistically significant association between the timing of the projection of the patient arrival and the efficiency of the subsequent patient management. More specifically, the data suggested that trauma team activation should be done at least 10 minutes before trauma patient arrival, and perhaps as much as 15-20 minutes before arrival in order to achieve the fastest trauma patient management. Patient management was measured by time from patient arrival until chest X-ray was taken.

The data suggested no association between a pre-arrival, pre-activation trauma team notification and efficiency of patient management, nor was there any association between projection of the activity and length of stay in the emergency department.

Interpreting medical data (perceiving the patient)

In Paper 4 the presentation format of laboratory test results was the focus of interest. Patient category was also included as a factor in the experiment (i.e. simple, emergency, chronic and complex patients). The results demonstrated that there were statistically significant variations in assessment speed between presentation formats. With sparklines and relative multigraphs participants made faster assessments compared to absolute multigraphs and tables. This effect depended not only on presentation format, but also on patient category and the number of exposures. In addition the presentation format supported identification of covarying laboratory test results differently. With relative multigraphs the participants identified more covarying test results. Identification of trends were done more often by participants when perceiving laboratory test results mediated by absolute multigraphs, and when test results were mediated by sparklines participants more often assessed laboratory results to be within reference ranges. These findings illustrated that no single presentation format was superior to the others. Some presentation formats were advantageous for chronic or complex patients, while others were advantageous for simple or acute patients. This was also evident from the participants' preference of presentation format for each of the four patient categories.

Discussion

The main objective of this research project was to explore whether, how and to what extent supporting clinical perception has or might have an impact on clinical work. These questions have been approached through observing and interviewing perioperative staff members, simulating clinical work supported by novel information artefacts, comparing the timing of trauma team activations with subsequent patient management, and finally, comparing the effects of various data presentation formats on the assessment of laboratory test results and user preference.

Although these approaches do not answer the main objective to the full, the results of these studies indicate that supporting clinical perception might have an impact on care management and perception of medical data. Before concluding about the contribution of this thesis as a whole, I will address each of the specific research objectives individually.

How and when do individual perioperative actors perceive/know when to contribute to the collaborative care process?

The results of Paper 1 indicated that perioperative staff members needed to be informed about new care activities, delays and other unforeseen perioperative events in order to plan and execute their work in a timely manner. While some could monitor the perioperative environment or the updated electronic surgical schedule for such information, others depended on being notified by other staff members through mobile phones or pagers. Although such explicit communication could ensure timely execution of a particular collaborative care activity (e.g. an operation), it did not leave staff members with much room to adjust their other work. In addition, staff members could be preoccupied with other work when they were called upon.

Based on these findings, supporting perception of recent care activities as well as perception of expected future care activities were identified as potential means for improving perioperative awareness and management of clinical activities.

Limitations and strengths

The findings of Paper 1 cannot serve as a strong evidence of how and when perioperative staff members should be aware of clinical activities, nor what the effects of providing staff with such awareness would be. Rather, the findings may contribute to the general understanding of coordination in the perioperative domain and generate hypotheses that can be tested in future studies. A strength of Paper 1 was that multiple researchers participated in data collection, avoiding that the theoretical model or preconceptions of only one researcher influenced the data that were collected. In addition Paper 1 included a combination of qualitative methods (in-depth interviews, observations and focused interviews), and the data were analysed in accordance with the qualitative analysis strategy 'systematic text condensation'. Two researchers analysed the data separately to add diversity to the analysis and enable a fruitful discussion between the researchers when the results were interpreted and explicated.

A potential limitation of the study was that is was conducted at a single hospital, and no scientific method was applied to ensure equally distributed and representative sample of perioperative staff members as informants. However, random sampling of participants is rarely relevant in qualitative studies, and (as I have described in the methods section) purposeful sampling is more of a strength rather than a limitation of qualitative studies.

Without a representative sample of the total population in a qualitative study, it is legitimate to question the external validity of the inferences from Paper 1. The answer to that lies in the description of the study context with relation to the questions that the study set forth to answer (Malterud, 2001). The main research question was related to how and what information was perceived by perioperative staff members in order to manage their own and their patients' activities. Initially, interviews were open and loosely structured, but later focus and structure of the interview were more specific. This was partially facilitated by a montage of images representing several situations in perioperative care and relating the interview to the informant's information needs in those situations. Representants from most aspects of perioperative care process were included, and they were asked to describe their own work situation including their information seeking and management strategies. This heterogeneous sample was purposive in Paper 1 since the goal was to understand how and when perioperative staff perceived or knew when to contribute to the collaborative perioperative care management. Trying to transfer specific findings from this study beyond the environment of these particular informants cannot be recommended. However, conceptual generalisations of the findings may be applicable to other settings as well. Thus, constructs such as coordination by means of scheduling, explicit communication, perception of the environment and projections of the future might be viable in other environments with coordination challenges.

What information supports surgical ward nurses in managing perioperative care, and how can that information be presented on a digital whiteboard without compromising the privacy of their patients?

Nurses valued having updated information about their patients' recent care activities displayed on an electronic whiteboard. The nurses said that such an artefact could support their awareness of ongoing care activities, reduce their workload and render possible a more timely preparation of patients and execution of clinical work. The nurses expected that they often would be able to "read" the electronic whiteboard correctly even if the information was de-identified and abstracted (e.g. "One of your patients was transferred to the post-anaesthesia care unit").

Limitations and strengths

The study was conducted at a single hospital, and 15 nurses from two different wards participated as informants. Compared to the multidisciplinary sample in Paper 1 the sample in Paper 2 was homogeneous. In Paper 1 both male and female, nurses, physicians and non-clinicians were represented, but in Paper 2 all participants were ward nurses, only one of which were male. The sample was thus non-representative, but – I will argue – purposive. This choice of sample was related to the objective of the study; to identify specific information needs for a specific perioperative actor at a specific site within the perioperative environment. In other words, Paper 2 valued depth more than breadth. However, the inclusion of nurses both from an observation unit and a surgical ward unit added some breadth to the sample. Whether the same results would have been found if the study was conducted at another department or another hospital remains uncertain. It seems likely that the usefulness of such a digital whiteboard depends on how care is organised. For instance, if nurses are not involved in monitoring for new blood test results, presenting such information is less likely to be valued by the nurses.

Some of the study findings were based on these nurses' expected value of the information artefact. These expectations might have been coloured by the course of events in the simulated scenario. The scenario was designed to demonstrate some surgical ward situations in which the artefact could come into use. Such a study design runs the risk of transferring the preconceptions of the researchers to the participants who in turn might exaggerate the usefulness of the artefact. In the focused interview the researchers emphasised the participants' experiences from actual clinical work rather than their experience from this particular simulated scenario in order to minimise this kind of intervention bias. Participants were encouraged to provide real life examples to illustrate and explain what they felt towards the usefulness of the artefact (e.g. "Could this system have supported you in your work? In what way?").

Participants were presented with one of three different artefacts (different design), but most of the information content was identical between these artefacts. Even with this variation in design participants in general were positive towards the digital whiteboard and the information content. Thus, having included different designs sequentially in the study can hardly be regarded as a limitation of the study. It might even be regarded as a strength, especially with respect to identifying information needs for managing care at a surgical ward. That is, irrespective of the three different designs, the participants valued similar information content.

The textual data of both Paper 2 and Paper 1 were analysed by two researchers and in accordance with the 'systematic text condensation' method. Although having two researchers does not necessarily mean that the analysis becomes more valid, the two together might have contributed with more nuances compared to what a single researcher would have done. Systematic text condensation is a qualitative method that "offers the novice researcher a process of intersubjectivity, reflexivity, and feasibility, while maintaining a responsible level of methodological rigour" (Malterud, 2012, p. 795). A quantitative analysis of the same data could have provided a different overview of the content. However, such a quasi-statistical analysis is not recommended on textual materials derived from interviews with open-ended questions, especially if questions were not asked in a standardised way to all participants (Malterud, 2001).

In Paper 2 the sample of participants was small and the focus of the interview was quite narrow compared to Paper 1. Although the focus of both studies was more or less on personal information needs and individual management of clinical work, the interviews in Paper 2 were facilitated by concrete, tangible artefacts with specific information contents. This more specific approach can partly explain why a sufficient level of saturation was achieved with a smaller sample compared to Paper 1. Retrospectively it is evident that already after the first iteration of the study in Paper 2 the participants provided a coherent description of what information they needed, why they needed it, and how providing such information could influence care management. Second and third iterations to a less extent provided new insight into information needs, but rather verified the information needs. In addition these iterations were carried out with alterations to the artefact in order to enrich the feedback on information disclosure and authentication mechanisms.

Generalising the results from Paper 2 must – as with any research findings – be done with great caution. The specific information needs that were identified in Paper 2 may not be relevant to all kinds of hospital departments and hospitals. It is reasonable to think that information needs are dependent on context (e.g. the available clinical information systems) and organisation (e.g. the role and responsibility of the ward nurse). However, conceptual generalisations of the findings might be applicable other contexts as well (e.g. easier access to updated care information may improve care management). One important conceptual generalisation was followed up particularly in Paper 3, i.e. being able to project a future care activity may improve care management.

What is the effect of projected perception of a care activity on patient management?

The findings of Paper 3 demonstrated that the timing of perception of a future patient care activity was associated with the efficiency of the management of that patient. Optimal timing seemed to be at least 10 minutes in advance, and perceiving the future patient care activity more than 20 minutes in advance did not demonstrate any certain management improvements for that particular patient. However, data were scarce for such cases. Notifying the trauma team members before the team activation was not associated with any improvements in care management for that patient, but notifications may have improved the management of collateral clinical activities for the involved staff members, but the study was not designed to evaluate any such effects.

Limitations and strengths

The data represented only one year of trauma patient management at one hospital. Many of the variables were based on manually recorded data that obviously were biased by human measurement. The outcome variables were soft in the respect that no patient outcome measures were included. Such measures would constitute important variables when evaluating the quality of the total trauma patient management including a holistic analysis of trauma patient management efficacy. However, such a study would require much more data than what were available at the time.

269 of 352 trauma team activations were included (74%) in the analysis. Although these cases showed a statistically significant association between differently timed trauma team activations (TTA) and time from patient arrival to chest X-ray was taken (CXR-time), it is disputable whether this association is clinically relevant. Median CXR-time was 8 minutes for TTA after patient arrival or between 0 and 5 minutes before patient arrival, compared to 5 minutes in median CXR-time for TTAs between 10 and 20 minutes before patient arrival. For most patients it seems likely that an improvement in 3 minutes is clinically non-relevant, however, for a few patients it is also plausible that 3 minutes more might be a matter of life and death.

Confounding variables can mislead the analysis of data in retrospective cohort studies. For instance, in Paper 3 we can not exclude that more seriously injured patients lead to more proactive measures generally, i.e. that the trauma team was activated more than 10 minutes before patient arrival, and that the team members prepared better and were more on their toes when severely injured patients arrived. These are only speculations as the study design did not permit controlling for such. However, this should be controlled for in a follow-up study.

Imprecise time data may also have had an effect on the study findings. For instance the box-plots of time until chest X-ray for each group of differently timed trauma team activations did not demonstrate any obvious difference between having no pre-arrival activation of the trauma team and having 0.01-5 minutes pre-arrival activation. More accurate time data might have revealed a more obvious linear or logarithmic "time-response-relationship" with less time between team activation and patient arrival associated with more time from arrival until chest X-ray was taken. On the other hand, we cannot rule out that trauma patients that arrive at the hospital before the trauma team is activated might generate even more attention and somehow trigger team members to respond more efficiently than usual.

We tried to avoid bias by not including multi-patient traumas. Multiple patients would possibly strain the care management capacity compared to having only one patient. In addition, the trauma team notifications and activations were not easily associated to each of the multi-patient trauma patients as these patients could arrive at the hospital at the same time or separately. Furthermore we avoided inclusion of patients from periods during which there were known large organisational changes that could have caused bias.

The external validity of the specific findings in Paper 3 is probably low. That is, what might seem to have been an optimal timing for trauma team activation in this particular study, cannot be generalised directly to other times and settings. Actually it might not even be generalisable back to the hospital at which the study was conducted due to large organisational changes after the time the data were collected. Thus, it is not possible to state that all trauma teams in general must be activated at least 10 minutes before patient arrival. Rather the study's contribution beyond its context is as an example of how projection of future care activities might influence patient management. Hospitals should analyse their own data on this to establish internal guidelines for trauma team activation founded on empirical data. In addition, researchers and health care managers should follow up with similar studies in other areas of health care as well. Perhaps providing clinicians with an alert 10 to 20 minutes in advance of other kinds of care activities might bring about significant enhancements in patient management?

What is the effect of presentation format on perception and interpretation of laboratory test results?

The four presentation formats supported perception and interpretation of laboratory test results differently with respect to assessment speed, assessment of trends and overall features and detection of covariation among two or more tests in a test set. Although agreement analyses showed a moderate to high degree of agreement between most presentation formats, some of the presentation formats also demonstrated a statistically significant propensity for interpreting trending or overall features in a particular way.

The variation in assessment speed depended on the characteristics of the laboratory test set (i.e. the patient category), repeated exposure and presentation format. User preference also varied with respect to the characteristics of the laboratory test set with the sparkline format as a preferred format for test sets consisting of many tests and many samples, relative multigraph format for sets of few tests but many samples, and table format for patients with few samples.

The most important finding was that the study does not support the existence of a single presentation format that can mediate an optimal perception for all kinds of patient data. A combination of presentation formats or integration of some of the features of these presentation formats into more advanced interactive presentation format are possible solutions that should be followed up.

Limitations and strengths

The analysis of the data from the experiments did not permit any measurement of assessment accuracy. Future studies should include accuracy assessments. However, with respect to the role laboratory results have in clinical practice and with respect to what is known about clinical reasoning, such studies should include more than just laboratory data (e.g. include the patient's history of present illness). Furthermore, participants should be experienced physicians that have developed pattern recognition skills for comprehensive clinical data. In Paper 4 the laboratory data were not accompanied by related clinical information. This ensured that the focus was on the laboratory results and the presentation format rather than on the associated clinical information. However, this is different from how laboratory data are used in a real clinical situation, and thus must be kept in mind when interpreting and generalising the study findings. On the other hand, consistent assessments of laboratory results is probably a prerequisite for reliable and accurate assessment of such information in a clinical context.

A strength of Paper 4 was that the laboratory data that were presented were authentic (compared to presenting random or constructed data). However, it is not likely that the four sets of laboratory results that were presented in this study represented all kinds of data structures that laboratory test results of patients might have. Thus, it is possible that presenting the data of patients with other laboratory results might result in other findings.

The study included four distinct presentation formats. It is unknown how other formats or minor changes to these four formats (e.g. opposite direction of time, other colours, fonts, line thicknesses) might have influenced assessment efficiency, quality and preference.

The within-subject balanced crossover latin-square design of the experiment should have contributed to reducing the impact of confounding variables. The presentation order of patient cases was the same for all participants, and might have influenced the results somewhat by introducing carry over effects that benefited cases that were presented later compared to those that were presented first. However, the order of patient cases were organised in blocks of four patients so that all four patient cases were presented within each block with varying order within each of the four blocks.

The participants in Paper 4 were medical students. Although they on average had studied medicine for more than three years (i.e. more than half of their 6-year program of medical school), it is unlikely that they had acquired a comparable level of clinical reasoning and pattern recognition skills as experienced physicians. On the other hand, the patterns they were asked to recognise were quite simple. It is uncertain whether physicians would have performed differently. It is also possible that physicians would have been biased by those presentation formats they usually perceive laboratory data with. Further studies should follow up on this.

The assessment time results indicate that the participants improved throughout the experiment. Hence, pre-experimental training was probably not sufficiently long to be able to demonstrate an “expert user potential” in the experiments. It is thus uncertain whether the differences between the presentation formats would be significant if participants had even more experience with all formats.

It is not easy to generalise the findings from this experimental and artificial set-up to a clinical context. The reader should not try to extrapolate these study findings to estimate how much time can be saved or any potential accuracy improvements of clinical reasoning. Rather, the study should inform future development and research on presentation formats for laboratory results. In that respect, it is reassuring that the results in Paper 4 are comparable to those found in Bauer et al. (Bauer et al., 2010).

General remarks on choice of study designs

The relation between research questions and data collection is an important issue in all research, independent of whether the researcher took a subjectivist or objectivist approach (Tjora, 2012). Lund claims that the distinction between the qualitative and quantitative approaches within empirical research is exaggerated, and that both might be applied and validated according to a common validity system (Lund, 2005). The study designs of Paper 1, Paper 2, Paper 3 and Paper 4 were chosen primarily because they were expected to be adequate for approaching their respective research questions, irrespective of the qualitative-quantitative distinction. Here 'adequate' implies that choice of study design is not only the choice of an optimal design, rather it is a balance between what would be regarded as optimal and what is achievable. That is, how much time and effort can and must researchers (and participants in particular and society in general) spend to ensure a sufficient level of truth? The optimal research design might not be economical or ethical (Mann, 2003).

Would other designs have been preferable for any of the studies on which this thesis is founded? That is, is it likely that other methods would have provided more trustworthy answers to the research questions than the methods that were applied?

In Paper 1 and Paper 2 most of the data were collected as interviews. The choice of focused interviews in the late phase of Paper 1 and in Paper 2 was related to the more specific research focus in those phases, our familiarity with the domain at that time and the relatively non-sensitive topics of the interviews. Much research has been conducted in the perioperative domain already, so conducting a literature review could be a viable alternative to interviews and observations. This is also reflected in that most of what was found in Paper 1 has also been found in other studies (e.g. that the perioperative domain is uncertain and that trajectory awareness is important in the coordination of work). Paper 1 may however also be regarded as a necessary pre-study of Paper 2. While Paper 1 was more open and inclusive, Paper 2 (and the information artefact in the simulation in particular) may be regarded as an instantiation of what was found in Paper 1. The combination of these two studies within the same perioperative domain might strengthen the internal validity (albeit the external validity of specific findings in the two studies legitimately should be questioned).

That the participants in general acknowledged the information content that were presented on the artefact in Paper 2 does not mean that no other kinds of information might be just as or even more important. Field observations of surgical ward nurses could contribute to identifying more information needs. On the other hand, non-existing or inaccessible information might be difficult to reveal through observations. Nevertheless, it is likely that other approaches would contribute to the understanding of what information a ward nurse needs to coordinate care, but the actual add-on value of additional approaches remains uncertain. At some point in time the information artefact also should be implemented and evaluated in a real clinical environment. Through frequent interaction with users the artefact (and the understanding of information needs) could be modified and re-evaluated formatively. In that respect, Paper 2 provided formative insight rather than summative answers to what should be presented on such an artefact. Such insight can advance the artefact and the research questions leading to a new iteration of the study. At some future stage of development and evaluation an objectivist approach (e.g. a randomised trial) could be carried out to evaluate the organisational impact in terms of measurable improvements in efficiency (e.g. patients' length of stay at a surgical ward).

A randomised trial would possibly provide a more trustworthy causal inference compared to the retrospective cohort study design of Paper 3. However, based on our findings this could be regarded unethical, at least grouping activations in 0 and 10 minutes before patient arrival. A possible follow-up study could group activations in activations 10 and 20 minutes before patient arrival since 10 minutes is the current practice and the results of Paper 3 indicates that 20 minutes might be even better. A prospective cohort study could have included more variables and introduced more accurate time measurements, but prospective cohort studies can also introduce bias by people having expectations to the study as it unfolds and deliberately or undeliberately affecting patient management or trauma team activation. In-depth interviews with trauma team members could reveal their thoughts about the timing of the team activation and also shed more light on the effect of pre-activation trauma team notification.

Other data collection options in Paper 4 could have been between-subject design, including clinicians as participants, focusing on less, but more thorough analyses of laboratory test results in relation to other clinical information, including eye-tracker in the experiment, establishing gold standards for accuracy and more. More radical changes in study design could also have been made, for instance not including any quantifiable measures and including interviews on perceived usefulness, facilitating participatory design or conducting a literature or product review of information presentation formats. Most of these alternative approaches would not address the research questions of Paper 4, but would provide complementary contributions. The discussions of students versus clinicians and laboratory data alone versus accompanied by other clinical information are the most important ones, and they have already been discussed.

Other recent literature

A recent study of perioperative communication demonstrated that failures in communication and information transfer are common in the perioperative environment and may stress the staff or even lead to patient harm (Nagpal et al., 2012). Although information and communications technology have developed rapidly over the last decades – including the introduction of pagers, mobile phones and wireless computing – there is “limited evidence suggesting improvements in the ability of health professionals to communicate effectively” (Wu et al., 2012, p. 723). Hence, more studies of the effect of various information and communications technologies on communication, care management and patient outcome should be conducted.

A recent systematic review of electronic whiteboards in emergency medicine identified 21 studies that individually demonstrated how such technology can affect communication, coordination and work practice. However, the study findings were mostly based on anecdotal evidence. Hence, the most trustworthy conclusion was that more specific studies are needed "into the areas of display format, interface design, integration to other systems and user involvement seems relevant in order to increase our knowledge regarding the development and implementation of electronic whiteboards" (Rasmussen, 2012, p. 491).

Presentation of individualised health information is inevitably hampered by privacy concerns. Such concerns may be complied with by regular authentication mechanisms, and that may be adequate in situations where a clinician wants to review a patient's medical record alone at a desktop computer. However, such a solution is not adequate when dynamic groups of clinicians collaborate and health information is presented on a large display in an open area; "a one-size-fits-all privacy policy cannot accommodate the group dynamics in medical practices" (Chen & Xu, 2013, pp. 550–551). Chen et al. further suggest that privacy technologies and policies are aligned with users' dynamic and contextual needs for data access, and that all-or-nothing access to a patient's medical information does not reflect the actual information flow in medical practice. The Paper 2 approach with abstracted and de-identified information is one potential alternative to the all-or-nothing approach. Some of the participants said that patient privacy was better managed with the Paper 2 artefact compared to current whiteboard practice at the hospital. However, such a statement does not prove that the Paper 2 approach was good enough (in legal terms). This should be further studied, and the external validity should also be assessed by conducting such experiments in other departments and hospitals.

More recently, the situation awareness framework has been applied to various medical domains. Applying it to primary care has been suggested as a means for understanding diagnostic errors, including analysing the interaction between the physician and the electronic health record (Singh et al., 2012). Increasing the focus on situation awareness and supporting proactive detection of clinical deterioration with quite simple tools have been found to be associated with reduction in transfer from non-intensive to intensive care in a children's hospital (Brady et al., 2013). Similarly, an integrated display of vital signs, fluid balance, ventilator settings and current medication improved intensive care unit nurses' situation awareness and decreased their task completion time compared to traditional non-integrated displays (Koch et al., 2013). Furthermore, a recent study conducted in the operating department of a large Australian hospital found that self-talk, closed-loop communication, and overhearing conversations may support staff in the operating theatre to coordinate their actions with each other (Gillespie, Gwinner, Fairweather, & Chaboyer, 2013).

In my review of the literature regarding clinical perception support I divided the literature in two subtopics: perceiving care activities and perceiving the patient. This seemed reasonable to do since the first regarded perception and awareness of care activities of multiple patients, while the latter regarded perception and awareness of a single patient's medical status. However, this distinction may be factitious and disadvantageous. Deteriorations in patient status may affect care management and thus require re-prioritisations among care activities such as postponing scheduled operations to the next day. There are also examples of clinical awareness tools that have integrated information about perioperative care activities and the medical status of individual patients. Vanderbilt University Medical Center's Iphone app, VigiVU, provides anaesthesiologists with a mobile access to live video from four operating rooms (Lane, Sandberg, & Rothman, 2012; Rothman, Sandberg, & St Jacques, 2011). Through the app the anaesthesiologist can perceive the vital signs of the patients and access laboratory values, patient history and physical information. Alarms may be set so that the anaesthesiologist is actively and immediately notified whenever vital signs deteriorate. In addition, the app provides a graphical overview of the updated surgical schedule including rooms, surgeons, procedures, room status and more. Anecdotally, this tool has simplified operating room management, prioritisation of secondary care tasks and perception and projection of patient status.

'Automated critical laboratory results alerting' is another example of how technology-mediated perception of patients' medical data may require re-prioritisations of clinical activities. Such alerts (e.g. a pager service) can hardly be regarded as an information visualisation – definitively not as a graphical overview. Nevertheless, the intention of such technology is to extend the clinician's perception so that critical laboratory results are perceived and managed more timely. To do that, computer-based event monitors continuously analyse laboratory results and identify all new critical values. Whenever such values appear, the responsible clinician is automatically notified through a mobile phone or pager (Kuperman et al., 1999). The tool may even be more sophisticated, by integrating information from laboratory results and medication lists, and alerts may also be accompanied by decision support on how to manage the situation (Etchells et al., 2011). A recent systematic review of the evidence available of automated notification methods to improve timeliness of critical value reporting could not find sufficient evidence to recommend automated systems (Liebow et al., 2012). Those who have implemented critical laboratory results alerting technology have experienced that it is not as straight forward as implementing comparable alerting services that are used in our day-to-day lives (B. M. Wong & Etchells, 2012). One challenge is to heed the clinical processes and organisational structure at the site of implementation. Another is to arrive at the optimal set of rules and technologies that increase awareness without leading to alert fatigue and without disrupting other sensitive clinical processes. A case report of a patient dying after a neurosurgical procedure without intra-operative complications, illustrates the importance of awareness of *non-critical* laboratory results as well (Freundlich, Grondin, Tremper, Saran, & Kheterpal, 2012).

In Paper 4 only data from single patients were presented simultaneously. However, a graphical and interactive overview of patient record contents and important clinical events of *multiple* patients – Lifelines2 – has been developed "for the purpose of (1) obtaining quality assurance measures, (2) assessing impact on patient care due to hospital protocol changes, (3) replicating published clinical studies using in-hospital data, and (4) simply searching for patients with interesting medical event patterns" (Wang, Wongsuphasawat, Plaisant, & Shneiderman, 2011, p. 1136). Physicians that have used Lifelines2 have stated that it saves time, that it is an important diagnostic tool and that it enables the user to understand the patient record contents more reliably (Wang et al., 2011).

Other studies of redesigns of traditional presentation formats of clinical information (with focus on integration of information) have also shown promising results with respect to users' satisfaction, nurses' speed of detecting changes in patient status and physicians' agreement about patients' diagnoses (Eghdam, Forsman, Falkenhav, Lind, & Koch, 2011; Miller, Scheinkestel, & Steele, 2009). Moreover, combining numerical statistical information with visualisations of the same information has been shown to improve the accuracy of physicians' interpretation of medical tests, increase the perceived usefulness of the information and decrease perceived task difficulty (Garcia-Retamero & Hoffrage, 2013).

The wider context: theory and practice

How can we understand the relation between these emerging technologies and clinical work, and what will be the consequences of information visualisation technology on clinical reasoning and management? This thesis does not provide a final answer to these questions. However, working within this field of science and the process of making my work explicit have introduced me to a theory of technology that seems relevant to understanding how clinicians may relate to technology. Furthermore, the work with this thesis has nourished my imagination of future developments of clinical information systems, giving rise to new hypotheses on clinical perception support in the future.

A theory of clinical perception support?

Technology theory has been influenced by philosophers such as Martin Heidegger, Maurice Merleau-Ponty and Don Ihde (Svanæs, 2013; Verbeek, 2001). They were all inspired by phenomenology – claiming that we cannot think independently of mind and body, subject and object, human and world. Heidegger rejected to view technology neither as a neutral tool nor as an independent force capable of changing culture. According to Heidegger, tools did not exist by themselves, but only in a relation to a context (Heidegger, 1927). Heidegger exemplified this with a craftsman's hammer. A skilled craftsman does not concern with the hammer as he hammers a nail into a piece of wood. The hammer is "withdrawn" from the experience of hammering – it is embodied.

Merleau-Ponty focused on perception in his analysis of technological artefacts (Merleau-Ponty, 1945). He argued that perception is embodied and should not be regarded as passive reception of external stimuli, rather as an active process. He exemplified how perception can be extended by technological artefacts with the story of a blind man and his stick. Having learned how to use the stick, the blind man no longer perceives the stick as a piece of wood in his hand, instead the blind man perceives the world by interacting with the stick – the stick is embodied.

Drawing on the work of Heidegger and Merleau-Ponty, Ihde distinguished between two types of perception: microperception and macroperception (Ihde, 1990). Microperception is immediate and focused bodily sensory perception (e.g.

seeing and hearing). Macroperception, on the other hand, is cultural or hermeneutic perception. Macroperception discloses meaning as it contextualises and interprets whatever is microperceived. Ihde argued that micro- and macroperception cannot occur separately. “A bodily perception can no more exist without being interpreted than an interpretation can exist without something to be interpreted” (Verbeek, 2001, p. 124).

With this understanding of perception in mind, Ihde explained how technology can mediate humans’ relation to the world, i.e. ‘Relations of mediation’:

unmediated perception → I–world
mediated perception → I–technology–world

According to Ihde there is a continuum of technology-mediated relations between humans and the world. At one extreme a technological artefact almost becomes a part of the body (e.g. wearing eyeglasses), and at the other extreme a technological artefact may provide a representation of the world which differs very much from unmediated perception (e.g. spectrogram). The first extreme Ihde referred to as an embodiment relation, while the other a hermeneutic relation.

- Embodiment relation (e.g. eyeglasses):

(I–technology) → world

- Hermeneutic relation (e.g. spectrogram, thermometer):

I → (technology–world)

Embodiment relations mediate perception that strongly resembles what we can perceive unmediated by technological artefacts, and thus puts little restriction as to how the world can be perceived. Hermeneutic relations, on the other hand, deviate from what can be perceived unmediated by technological artefacts, and limit the possibility for reality to express itself. “A hermeneutic technology, after all, provides a representation of reality, which implies that the design of such a technology predetermines which aspect of reality is to be made perceptible by it and in which ways” (Verbeek, 2001, pp. 128–129). However, both embodied and hermeneutic technologies may render possible perceiving what is impossible unmediated by technological artefacts, and between these extremes, Ihde argues there is a continuum of technology-mediated relations:

embodiment relation - - - - - - - - - - - - hermeneutic relation
(- - - eyeglasses - - - - - telescope - - - - - spectrogram - - -)

Unquestionably, Heidegger, Merleau-Ponty and Ihde have developed a new perspective on technology and perception. This philosophy of technology argues that perceiving should be regarded as an active and interpretive experience that can be mediated by technological artefacts. By augmenting our senses or providing us with representations of reality, these technological artefacts influence how we experience reality and, ultimately, what decisions we make and how we act. On that account, this perspective on technology and perception should be kept in mind whenever designing clinical perception tools such as graphical overviews of health record contents or interactive visualisations of a surgical ward's floor plan. It is not unreasonable to claim that current electronic patient record systems are located closer to the hermeneutic extreme of the technology-mediated relation continuum. Patient record contents has to be *read* by the clinician. However, as Paper 4 and other similar studies indicate, alternative presentation format may facilitate perception (i.e. facilitate reading). The findings in Paper 4 and other studies indicate that technology-mediated perception may improve with repeated exposure resulting in more experienced users (Meyer et al., 1999). Thus, clinical perception tools should probably not be regarded as different from other tools such as Heidegger's hammer or a musical instrument which both can be embodied by learning according to this technology theory (Ihde, 1990). Perhaps experimental studies in which participants use a perception tool for only a couple of minutes or hours do not reveal the true potential of such technology?

Clinical perception in the future?

A decision tool is "an active knowledge resource that uses patient data to generate case specific advice, which support decision making about individual patients by health professionals, the patients themselves or others concerned about them" (Liu et al., 2006). Whereas a clinical perception tool may be regarded as a sensory resource that mediates clinical data in formats that support the clinician's awareness of the clinical problem. With inspiration from situation awareness theory, one might say that clinical perception tools should help answer the three questions “What?”, “So what?” and “Now what?” (Strater et al., 2004). Just like proper performance is more likely to result from proper decisions, a proper decision is more likely to result from proper perception.

Future information visualisation technology should present clinical data in formats that support the clinician’s perception and understanding of the clinical problem. Perhaps, with proper information presentation formats and extended experience (both clinically and technologically) clinicians can be able to *perceive and comprehend* the diagnosis of the patient by using the patient record as a graphical overview without explicitly reading the record contents? This would be comparable to seeing the diagnosis of the patient based on a patient-clinician encounter without analysing every symptom and sign individually (e.g. applying pattern recognition skills). Likewise, new technology might enable the clinician to project future care activities more accurately and thus carry out care activities more timely.

This thesis (and other relevant research and development) raises more questions than it answers. One major issue is the conflicting choice between having standardised tools for large groups of clinicians or creating highly customisable tools perfectly designed for a particular role or even a particular person. While a surgical schedule might very well support coordinating work at an operating theatre, such a schedule might not support the individual surgeon or ward nurse in executing their work as it depends on what takes place beyond the walls of the operating theatre as well. Future research and development must try to answer what kind of information should be presented on shared large screen status boards, and what should be mediated through individual mobile units (e.g. smart phones)? How much information should be pushed out as an alert, and how much should only be provided passively (i.e. ‘pull’)? Would it be better to provide clinicians with projections of expected outcomes and expected care trajectories just like a weather forecast, or would it be better to provide clinicians with indisputable historical and real-time data so that clinicians can integrate information independently and generate their own projections? Should we try to develop a optimal one-solution-fits all way of presenting clinical data, or should we provide clinicians with tools to perceive the data in more than just one way? These questions certainly call for more research on this topic.

Conclusions

By approaching various clinical processes in the perioperative environment, collecting different kinds of data and applying multiple methods in the analysis of that data, I have illustrated how clinical perception and management may be supported. To some extent these findings also indicate what effect perception support has on perception of medical data, management of patients and perioperative coordination of patients' and clinicians' activities.

The perioperative environment is an uncertain environment. To be able to cope with the uncertainty, perioperative staff members must try to perceive how perioperative activities unfold including paying attention to new patient information. Technological artefacts have the potential of extending the abilities to perceive. Such artefacts may also enable perception of forthcoming care activities, which in turn may improve care management. However, perception and interpretation of clinical information may differ depending on the format with which the technological artefact mediates the information. This must be thoroughly investigated before clinical perception support is implemented in clinical practice, so that avoidable unintended disadvantages are identified and ruled out (and unintended benefits are kept).

This thesis is a small contribution to the advancement of the field of clinical perception support and medical informatics, but with respect to the studies on which this thesis is founded and other studies of the kind, I feel quite comfortable claiming that more research and development is still needed.

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Paper I

CONTINUOUS COORDINATION
IN PERIOPERATIVE WORK

Abstract

Coordination of perioperative work is challenging. Advancements in diagnostic and therapeutic possibilities have not been followed by similar advancements in the ability to coordinate care. In this paper we report on strategies for continuous coordination in perioperative work. The purpose of this study was to explore the nature of continuous coordination as practiced by perioperative staff in order to coordinate their own activities with respect to those of their colleagues.

We conducted in-depth interviews (14 interviewees), and combined observations and focused interviews (31 interviewees) with perioperative staff (physicians, nurses, technicians and cleaners) at a major university hospital. Data were analysed qualitatively with systematic text condensation.

The results indicate that a surgical schedule was important for informing staff members about the cases and tasks they had been assigned. Staff also depended on ad hoc, explicit communication to ensure timeliness of particular perioperative activities. This, however, left little room for adjustments of other activities. Hence, to be able to proactively coordinate their own work some staff tried to anticipate future perioperative activities by observing the workplace, monitoring the surgical scheduling software for changes, and sharing their colleagues' progress updates and anticipations. These findings could be important for those developing support for perioperative coordination.

Keywords

Qualitative method, Patient care management, Personnel staffing and scheduling information systems, Interprofessional collaboration, Awareness, Co-ordination

INTRODUCTION

Coordination of activities is a significant problem in health care (Strauss, Fagerhaugh & Wiener, 1985). Our ability to deliver integrated health care services is challenged by increasing specialisation and fragmentation (Stange, 2009). More than ever, hospitals stand as complex institutions, within which the perioperative environment holds the most challenging coordination needs with its highly specialised staff, equipment and procedures (Sandberg, Ganous & Steiner, 2003).

One way to manage coordination challenges is to standardize the work (e.g. providing the worker with a detailed description of what he is supposed to do, including when he is to hand over his task to a co-worker), but this mechanism typically falls short in hospitals (Glouberman & Mintzberg, 2001). When difficult coordination takes place, work is more likely to run smoothly when people are able to stay aware of and adapt to each other as their work progresses (Glouberman & Mintzberg, 2001). However, maintaining awareness of hospital work may require much effort by those having to adapt to it due to their inability to directly perceive what they have to adapt to (Randell, Wilson, Woodward and Galliers, 2010).

Situational awareness has been defined as “the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future” (Endsley, Bolté & Jones, 2003, p.13). According to Endsley et al. achieving situational awareness may require active perception of the environment directly or indirectly through information technology (Endsley et al., 2003, p.14). In accordance with this, it has been suggested that improving awareness by increasing the visibility of information through information technology is a possible means to support coordination of hospital work (Randell et al., 2010). Despite this, recent studies have indicated that advancements in hospital information and communications technologies have not enabled health professionals sharing information more effectively (Wu et al., 2012), and that health personnel spend much time on the coordination component of work (Hendrich, Chow, Skierczynski & Lu, 2008). Hence, there is a need for more research on how to support coordination of perioperative work.

This study was conducted as a part of a multiprofessional research project called 'Co-Operation Support Through Transparency (COSTT) (Seim, Landmark, Lillebo, Faxvaag & Sandberg, 2010). COSTT hypothesized that «providing health actors with an overview of relevant patient trajectories will improve their ability to self-coordinate» (Seim et al., 2010, p. 2). The aim of COSTT was to support perioperative coordination by providing involved actors with real-time insight into perioperative work processes by visualising perioperative work on shared digital spaces based on automatic sampling of data obtained from the work environment (Toussaint, 2008).

The objective of this particular study was to characterize how perioperative coordination was achieved at a modern hospital with emphasis on how and when each actor perceived/knew when to contribute to the collaborative care process.

METHODS

Study site

The study was conducted at a major Norwegian university hospital. The hospital is an 800-bed urban academic teaching hospital which both serves as a local hospital and as a regional hospital and level 1 trauma centre. Perioperative patients typically arrive at the emergency department or the outpatient clinics where they undergo initial investigation before they are admitted to a surgical ward or the intensive care unit for further treatment. Patients in need of an operation are transferred to an operating room (OR), and after surgery they are monitored at a post-anaesthesia care unit (PACU) before returning back to the ward and eventually being discharged. This typical perioperative patient trajectory illustrates how caring for perioperative patients depends on the activities of multiple staff members. Coordination of these activities is necessary to ensure smooth flow of work.

The hospital had several clinical information systems aimed at supporting perioperative coordination, including surgical scheduling software (SSS) that had been developed at the hospital's IT-department. The main functionality of the SSS included scheduling of operations and operating rooms. Details about the surgical procedure, the diagnosis and any special preparations could be found in the SSS. It also informed in what sequence the operations should be carried out, including an expected duration of each operation. Finally, the SSS enabled electronic logging of some selected perioperative milestones such as 'patient in OR' and 'operation finished'. More information about this software and other perioperative information systems at this hospital can be found elsewhere (Iversen, Melby, Landmark & Toussaint, 2012).

Data collection

Data were collected in two phases during 2009-2011 (Table 1). First, in-depth interviews with open-ended questions were conducted. The topics of these interviews were general work-flow, coordination practices and the importance of awareness of care activities in general. Nurses, coordinators and secretaries from various perioperative units were included in this phase since they were expected to take part in coordination. Second, field work were conducted consisting of a combination of unstructured participant observations and focused interviews. The observations included demonstrations of how the participants obtained information through information systems or exchanged information by communicating with others (e.g. phones, pagers, intercoms or the SSS). We chose to carry out focused interviews during the final data collection phase since our familiarity with the domain based on previous in-depth interviews and observations made it possible to confine each interview to particular situations that the interviewee were known to have been involved in (Merton & Kendall, 1946). Additionally, the interview topic was non-sensitive, thus trust could be established quite rapidly between researcher and informant (Tjora, 2012). In addition, being able to conduct short focused interviews on site as part of the field work served to ensure that the researcher and the informant referred to the same aspects of a particular perioperative situation (Merton & Kendall, 1946). Lastly, focused interviews could be conducted while clinicians had short breaks. This enabled recruitment of informants and performing interviews without disrupting clinical work. The main reason for carrying out observations was to improve our understanding of what the informants had stated in in-depth interviews, and to identify particular situations to be explored in more detail during the focused interviews. We developed interview guides for both the in-depth and the focused interviews. In addition, the focused interviews were facilitated by a montage of pictures from different situations in a perioperative patient trajectory. This representation also contributed «to insure that both interviewer and subject are referring to the same aspects of the original situation» (Merton & Kendall, 1946, p. 550). During this phase of the study, with a defined perioperative patient trajectory in focus, we recruited informants from many different professions to gain insights into the perspectives of all perioperative staff members that contributed to the progress of such a patient trajectory.

The in-depth interview data have served as part of the material in two previously published studies on coping strategies and information technology support for coordination in the perioperative environment (Melby & Toussaint, 2011; Iversen et al., 2012). Preliminary analyses of the field work data have also been reported previously (Lillebo, Seim & Faxvaag, 2010; Lillebo, Seim & Faxvaag, 2011). However, the field work data have not previously been systematically analysed, nor have the combined data been presented in light of continuous coordination and situational awareness in perioperative work.

Table 1: Characteristics of the two phases of the qualitative data collection.

	Phase 1: Coordination practices	Phase 2: Information needs
Objective	To describe how perioperative coordination was practiced (actors, artefacts, activities)	To describe how and when individual perioperative actors perceived/knew when to contribute to the care process
Sampling strategy	Maximum variation (nurses)	Maximum variation (multiprofessional)
Sample size	14	31
Participants	Ward nurses, OR coordinators, secretary, OR nurses, nurse anaesthetists and PACU nurses	Anaesthesiologists, PACU nurses, OR nurses, surgical and orthopedic physicians, ward nurses, cleaners, technicians, nurse anaesthetists and OR coordinators
Data collection	In-depth interviews (audio recorded)	Observations and focused interviews (field notes)
Data size	8 hours (22-80 min/interview)	24 hours (5-120 min/session)
Example questions	"How are patient transfers between perioperative units coordinated?" "How do you use the surgical scheduling software?"	"How do you know when you should contribute to the care process? When do you know it?"
Interviewer(s)	5 different interviewers contributed (each interview was carried out by two interviewers)	1 (author BL)

Data analysis

The data were analysed in accordance with the systematic text condensation (STC) approach (Malterud, 1993). STC was developed as a pragmatic analysis of free text. It is claimed to be simple and rigid, and it does not differ much from other qualitative thematic analyses (Malterud, 2012). STC can be divided in four sequential steps: 1) Overview: establishing preliminary themes based on the general impression of the data; 2) Coding: Identifying and coding meaning units; 3) Condensation: Abstracting meaning from each group of meaning units; and 4) Synthesising: Creating consistent descriptions that reflect the contents of the data. In general the method intends to present "the experience of the participants as expressed by themselves, rather than exploring possible underlying meaning of what was said" (Malterud, 2012, p.796). Both authors read the complete data set and identified and coded meaning units. Subsequently, codes were abstracted into more general terms. The insights gained from these abstractions were integrated into descriptions of coordination practices, and validated against the original context from which they were derived (searching for disproving data). The authors had experience in hospital working; BL as a resident in gastroenterological surgery, and AF as a specialist in rheumatology.

Ethics

The study was approved by The National Committee for Medical and Health Research Ethics in Norway. All participants gave their informed consent prior to data collection.

RESULTS

Consistent descriptions of continuous coordination in perioperative work were synthesised from the data. These descriptions were related to three themes: 'Informing staff of what to do: The schedule', 'Informing staff of when to act: Explicit communication' and 'Anticipating when to act: Individual strategies for keeping aware'. The following subsections present these descriptions with some illustrating quotes.

Informing staff of what to do: The schedule

The surgical schedule was an important artefact for interprofessional coordination in the sense that it made the staff aware which cases and tasks they had been assigned and therefore could expect to carry out. The OR coordinator was responsible for creating and updating the schedule. Elective (planned) cases were scheduled at least one day ahead, while emergency cases were reported to the OR coordinator and scheduled continuously according to their medical priority. OR nurses were also able to update the schedule with progress information such as 'patient arrived' and 'operation started'. A common practice was looking up the schedule when coming to work, either the software version of it, a paper copy or both. Some also reported that they monitored the SSS throughout the day to get to know about any emergency cases and other changes to the schedule.

> *"We print out today's surgical schedule to know what elective [planned] patients we will be working with. Additionally we continuously monitor the surgical scheduling software to see what add-on emergency patients are being operated as well. If the OR nurse updates the OR status in the surgical scheduling software, then we know approximately how things are going." (PACU nurse (phase 2)).*

In addition to patient name, diagnosis, procedure and any special preparations needed, the schedule also provided estimates on the duration and timing of each operation. However, apart from the timing of the first operation in the morning, staff considered these estimates unreliable:

> *"The other day the schedule said 120 minutes, but it turned out to be more than four hours." (OR nurse (phase 1))*

Staff considered the time estimates unreliable because they regularly experienced that preoperative preparations or the surgery itself could take more or less time than anticipated or because new, more urgent operations were added to the schedule. Delays could also be caused by patients recovering slower than expected:

> *"It might last longer before the patient can be transported to the operating room suite. Perhaps the previous operation did not go as planned, or they haven't been able to empty the recovery unit so the patient has to wait in the operating room until a bed is available." (Ward nurse (phase 1))*

Some schedules were too optimistic from the beginning. They would explicate the intended work, but rather serve as ambitions rather than a time table that could be relied upon:

> *"Many of the surgeons are very ambitious. They operate on many patients and say 'We will manage this. Schedule five patients!', but in the end there is only enough time for three." (PACU nurse (phase 1))*

Hence, the SSS enabled the sharing of information of what ought to be done, and to some extent what already had been carried out. However, in order to inform staff when to act other practices and artefacts were predominating.

Informing staff of when to act: Explicit communication

Timely execution of staff members' contributions to the collaborative work depended largely on phones, pagers, intercom or face-to-face communication rather than reading and updating the SSS. The participants explained that they would often be paged or called, upon which some immediate action was expected. For instance, the coordinator would call the ward nurse when the next patient had to be brought to the OR. Surgeons were paged when they needed to scrub in, cleaners were paged when the operation finished, and when a patient had recovered sufficiently from surgery, the PACU nurse would call the ward nurse to come and get the patient.

Although ad hoc communication and short notice requests seemed to be a quite common method for informing when to act, staff also emphasised the benefits of being able to anticipate when their own actions would be required:

> *"Personally, it would have been nice to be notified one hour before I should be there, since that would give me enough time to, for instance take care of one of the newly admitted patients."* *(Surgical resident (phase 2))*

Not being able to anticipate when the patient would be handed over did not create much room for the staff to adjust other components of their work accordingly.

> *"We like to prepare equipment and make sure all other things are done before the patient arrives from the OR. Yesterday that didn't happen, three patients suddenly appeared here without us being aware they were on their way... It works out anyway though, but we prefer knowing it in advance." (PACU nurse (phase 2)).*

Anticipating when to act: Individual strategies for keeping aware

Many reported of the importance of knowing at what time certain milestones of an ongoing perioperative activity would be reached for coordination of their work. However, obtaining those insights were difficult, especially for those not directly involved in the relevant activities. To accommodate to this, staff employed various strategies. The schedule could give an indication of when an operation would end based on when it started, but operations would often last longer than scheduled. Estimates provided by those who carried out the work (e.g. the surgeon performing an operation) were considered the most reliable. Thus, if needed, the coordinator could call the OR and ask for such information and pass it on to other staff members.

> *"[Are they any good at estimating remaining time?] Yes, mostly they are able to give quite specific feedback on that. So that you know approximately how you are doing." (OR coordinator (phase 1)) Others sought to anticipate when the next milestone would be reached by observing the work (i.e. non-verbal communication). An OR technician reported to walk around and look through the OR windows in order to anticipate when each operation would finish. This enabled him to coordinate his work proactively and avoid "nagging" on his pager.*

Finally, for at least one handover situation, staff members had agreed upon sharing their anticipations with those supposed to recieve the patient to give them time to prepare and make room for the handover. Thus, the OR team usually notified the PACU nurses a few minutes before the operation ended, allowing them to make sure that they were not busy with other tasks when the patient arrived. This routine was not common in other handover situations:

> *«What we find a bit frustrating sometimes, is when they call us from PACU. They want us to come and get the patient before they go off duty. Our shifts end 3 or 10 pm, and they call us 02:50 or 09:50 pm and request that we pick up the patient so they can finish their work on time, this leaving us working overtime (...). If we could have been called and told that the situation is like this and that, then we could have agreed on a handover time that would suit the both of us.» (Ward nurse (phase 1))*

Hence, not being able to anticipate when and what would happen next could cause frustration and possibly suboptimal coordination of perioperative work.

DISCUSSION

In this study, we have identified and described some of the practices that are involved in continuous coordination of the activities of perioperative staff. The results indicate that a surgical schedule –

although important as a goal descriptor – did not sufficiently support timely execution of work. Instead, timeliness depended largely on ad hoc explicit communication between staff members. The results also demonstrate how some staff members actively tried to stay aware of perioperative activities by paying attention to their colleagues and the workplace, by monitoring the SSS for any changes, and by sharing others' progress updates and projections.

These findings correspond well with the three different kinds of coordination described by Bardram (Bardram, 2000): scripted coordination is coordination according to a schedule, communicative coordination is when staff members tell each other when to act, and instrumental coordination is when a staff member acts based on what s/he perceives in her/his working environment (i.e. non-explicit communication). In addition, our findings emphasise a particular aspect of coordination: the projection of the future situation in order to proactively coordinate work. Some of the participants described how they managed to anticipate the near future by monitoring perioperative work, whereas others reportedly failed to do so. According to Endsley's model of situational awareness projection of future status is the highest level of situational awareness, and being able to project assumes being able to perceive the situation as it unfolds or through verbal or non-verbal communication with others (Endsley et al, 2003). This study contributes to the field by suggesting that the notion of situational awareness as proposed by Endsley et al. might be applicable to continuous coordination in perioperative work as well. This raises some new questions regarding how perception, comprehension and projection of perioperative activities can be supported, and what effects such support might have.

The schedule is not enough.

According to the participants, they could not rely on the schedule for timely execution of their work as many perioperative activities were unpredictable. Quantitative studies of perioperative scheduling have also demonstrated large mismatches between what is scheduled and what actually gets done (Bardram & Hansen, 2010; Wright, Kooperberg, Bonar & Bashein, 1996). While it has been demonstrated that certain estimation techniques have the potential of improving operating list planning (Pandit & Tavare, 2011), estimating the duration of single operations has not proven to be very precise (Wright et al., 1996; Macario & Dexter, 1999). It remains uncertain whether it is possible to achieve more accurate perioperative schedules, or whether perioperative work always will be unpredictable by nature, leaving timeliness of perioperative work to be based on other coordination practices than scheduling. However, in our study ad hoc explicit communication appeared as the predominating coordination practice for ensuring timeliness, compensating for the weaknesses of the schedule.

Ad hoc explicit communication ensures timely execution of certain activities

Physicians, nurses and technicians reported that they typically would be phoned and requested to do some immediate action (e.g. get patient at PACU, or scrub in). Although such a practice could ensure timely progress of certain activities, not knowing when they would receive such a call made it difficult to decide whether to postpone or commence other activities. Interestingly, in the handover situation between the OR and PACU explicit communication was applied somewhat before the actual handover should take place, providing the PACU nurse with some time to finish off other tasks. Widespread use of synchronous communication has been shown to be common in other, comparable hospital environments as well (Weigl, Müller, Zupanc, Glaser, Angerer & Mu, 2011; Moss & Xiao, 2004), but it is also associated with less efficient work and negative impact on patient safety (Coiera & Tombs, 1998; Westbrook et al., 2010). However, the use of synchronous and explicit communication can also have the opposite effect. A study of OR staff found that "efficient communication of clinical decisions heightened team members' awareness of actual or potential problems, building shared situational awareness and assisting them to respond appropriately" (Gillespie, Gwinner, Fairweather & Chaboyer, 2013).

Being able to project the future situation may improve coordination

While the combination of a schedule and ad hoc explicit communication ensured that scheduled activities (e.g. the operations) took place in a timely manner, the ability to project future situations could enable better management of non-scheduled activities. Projections enabled staff to prepare their work in time and if possible fill in with additional activities while awaiting being called upon. Thus, it is not unlikely that inconvenient interruptions would occur less frequently and that more work could be done. We also found that some staff members were precluded from perceiving what they needed to project, and that this could have a negative impact on their non-scheduled work.

In our study staff members reported that those directly engaged in a particular activity were considered to have the most reliable projections. It might be possible that other staff members may be enabled to generate just as good projections if they were provided with sufficient status information, for instance through distribution of real-time information about OR events to digital whiteboards or their mobile phones. Another option is to continuously share the projections made by those carrying out a particular activity. This has been demonstrated as part of a continuously updated surgical scheduling software in which the updated schedule reflects a joint projection of the expected future OR trajectory (Bardram, Hansen & Soegaard, 2006). In a related research project we have designed and conducted a small validation study of a system that displays information about ongoing perioperative events on a wall-mounted screen. Although preliminary, the feedback from the clinical test persons adds support to our hypothesis that a fully functional verson of such a system may enhance the users ability to project and thereby improve coordination of work (Gjære and Lillebo, Manuscript submitted, 2013)

Strengths and limitations

The limitations of this study were that the study was conducted at a single hospital, and that focused interviews not were audiotaped. Also, the results might have been coloured by the preconceptions of the researchers, relating to design and development of support for perioperative coordination. However, these preconceptions were challenged by including more than one researcher conducting interviews, by having two researchers analysing the same data (contesting each other's interpretations), and by applying a rigorous data analysis technique (Malterud, 2012). According to Malterud systematic text condensation is a qualitative method that offers the researcher «a process of intersubjectivity, reflexivity, and feasibility, while maintaining a responsible level of methodological rigour" (Malterud, 2012, p. 795). Other strengths included the application of several data collection methods, collecting data through an extended period of time, and involving participants from multiple perioperative professions. Finally, our findings seem to be consistent with several other studies and methodologies.

Based on these aspects and in light of qualitative criteria for juding credibility, dependability, confirmability and transferability, we consider our inferences of the results to be trustworthy (i.e. not a result of random or misleading data) and substantial. Although, this study does not prove any causal relationship between level of situational awareness, continuous coordination in perioperative work and the effects thereof on patient care, the descriptions provided by the participants indicate that such a relationship might exist. Furthermore, as with most qualitative research the results cannot be extrapolated to the population at large (Malterud, 2001). Even generalising the results to other perioperative environments has to be done with caution as there are many contextual factors that might have influence on continuous coordination of care. However, coordination by means of scheduling, explicit communication, perception of the environment and projections of the future are (in our opinion) viable constructs that conceptually can be transferred to similar settings. Supporting one or more of these areas by novel information technology might have an impact on the efficiency of perioperative work or quality of care by reducing time spent on coordination or increasing the time clinicians spend with their patients. Improved coordination might also provide other benefits directly to the patiens such as avoiding uneccessary fasting periods before surgery.

CONCLUSION

This study indicates that schedules alone do not support timely execution of perioperative work. Although explicit communication between perioperative staff members may ensure timeliness of particular activities, such practice does not provide staff with much room to adjust other work (except from routinely communicated projections). Individual projection of future activities or sharing of other's projections might enable staff to proactively coordinate their work. These findings could be important for those trying to develop support for perioperative coordination. How such support can be provided and what effect it will have on perioperative coordination should be further studied.

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Paper II

Designing Privacy-Friendly Digital Whiteboards for Mediation of Clinical Progress

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- Hospital Information Systems
- Awareness
- Computer Security
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- Confidentiality

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Abstract

Background: In hospitals, digital versions of dry-erase whiteboards are increasingly becoming more common. One of the purposes with such whiteboards is to support coordination of care by increasing visibility and availability of clinical information. However, much clinical information concerns patients and is regarded as sensitive personal health information, meaning that it should be access controlled.

Objective: To explore how digital whiteboards can be designed for supporting coordination of care, by providing clinicians with useful information in a usable way, and at the same time protect patient privacy.

Method: A demo application was designed, demonstrated and evaluated iteratively. In total, 15 professional ward nurses role-played a scenario in which the application played a central part. Afterwards, the participants were interviewed. All interviews were recorded, transcribed verbatim, and analysed qualitatively.

Results: The participants valued having updated clinical information presented on a digital whiteboard – even if the information was de-identified and abstracted. According to the participants such information could possibly improve inter-departmental communication, reduce the number of electronic health record-logins, and make nurses more rapidly aware of new information. The participants expected that they would be able to re-identify much of the de-identified information in a real situation based on their insight into their patients' recent and expected care activities. However, they also valued being able to verify patient identities and to access more detailed information through the same digital whiteboard. While a two-factor combination of ID-card and PIN-code was regarded efficient and secure for such purposes, the nurses also pointed out the importance of having control over what can be seen by patients and passers-by while logged in.

Conclusions: Presenting updated information from patient care activities on a digital whiteboard in a de-identified and abstracted format may support coordination of care at a hospital ward without compromising patient privacy.

1 Introduction

Many advances in modern health care can be attributed to the rise in specialisation. However, this fragmentation, in a sense where more people and professions are required for the treatment of every single patient, has not been without side-effects [1]. Staying aware of what colleagues have done, what they have planned, what patients have gone through and where they are located, has become more challenging – resulting in a more complex coordination of care. Digital whiteboards represent a novel way of distributing information used for multidisciplinary coordination [2–12], artefacts which should be strategically located where personnel are likely to be or often pass by [13, 14]. While such whiteboards can enhance the visibility and availability of information to many users at once they are also recognized as potential threats to patient confidentiality [15, 16]. Hence, sensitive information that concerns patients and their care must somehow be protected from unauthorised disclosure.

Manual encoding of information that needs special protection, seems to be a feature that has been lost in the transition from analogue to digital whiteboards. Such protection could for instance be expressing some particular condition with an arbitrary-looking red dot, that only individuals in the specific care-providing team know the meaning of [16]. Instead, the screen's contents would normally be protected using computational access control mechanisms, which can indeed be much more secure. However, by requiring authentication before any disclosure, users are prevented from simply obtaining a quick overview when passing by or looking from a distance. Conventional authentication techniques may also take time and attention away from the user's original task, and do not fit well into the nature of clinical work [17].

Rather than relying on traditional authentication techniques alone, or even bypassing the entire patient privacy issue by only having shared digital whiteboards in restricted areas [12, 13], we wanted to investigate how de-identified *and* abstracted pieces of information can be used to attract timely attention from its relevant recipients. By abstraction we mean that the clinician is informed about the occurrence of a clinical activity (e.g. "Imaging results are available") rather than the specific content of that activity (e.g. "The CT-scan reveals necrotic pancreatitis"). De-identification is usually associated with the scrubbing process applied to medical data before such data can be disclosed from a health care organisation to an entity not being directly involved in patient care, e.g. researchers. This involves the removal of patient identifying information from the data set, e.g. by removing names and birth dates, or by removing entire entries that are unique beyond a certain threshold (k-anonymity) [18]. De-identification hence intends to balance utility value and protection of information. A concept of *flexible* de-identification has been proposed as a possible solution to patient privacy issues when information is shared in real-time between collaborating health care personnel [19]. The flexibility lies in that whenever any de-identified piece of information is found to be relevant, more information – including explicit patient identifiers – can be accessed through secure authentication mechanisms. An analogy for this is the lock screen on a smart-phone, displaying icons to notify the user about a new message and possibly its sender, and then requiring a PIN-code for accessing the full message. The question of information relevance, however, becomes more difficult when the screen is shared and the recipients are not known to the system. In addition, the sensitive nature of the information effectively halts any kind of open broadcasting that could give patients doubts about sharing their personal stories with their health care providers.

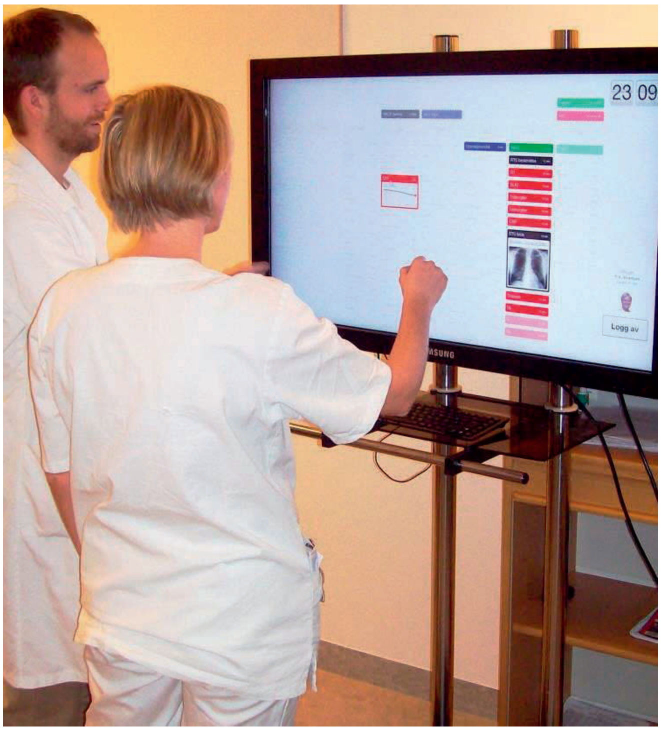

Figure 1: De-identified clinical information presented on a digital whiteboard during a demonstration session.

In some early interviews [20], we had found that clinicians who discuss a patient and do not want to be overheard, initially may try to identify the patient to each other by using non-explicit identifiers, such as medical problem, age group and gender. Treatment history, the current situation and expected future care activities, could also be utilised approaching precise identification during a conversation, e.g. ‘he who had a gastric bypass yesterday’. Likewise, we hypothesized that digital whiteboards that display de-identified information may be useful if the patients are known to the clinician – while not being meaningful to others. This study was conducted to understand more specifically the information needs related to patient management at a surgical ward, and explore how such information can be presented on a digital whiteboard. The objective of the study was to understand what information supports surgical ward nurses in managing perioperative care, and how that information can be presented on a digital whiteboard without compromising the privacy of the patients.

2 Methods

In this study we adhered to the Design science research process (DSRP) model [21]. We conducted three iterations of design/redesign, demonstration and evaluation. The rationale for having three iterations was to explore different methods for protecting and disclosing sensitive information. The main differences between these three iterations are highlighted in *Table I*.

Our main design artefact was a large screen that displayed an overview of recent and future patient care events pertaining to eight patients at a surgical ward unit. This screen was intended to hang in a non-restricted area where the ward nurses easily would see it, and provide the nurses with sufficient information to support coordination of their nursing activities. On the other hand, the screen could also be exposed to unintended users such as patients and passers-by, requiring special attention to what information was disclosed and how it was presented. As recommended through a preliminary risk-based evaluation of access control approaches for groups [22], we tested several mechanisms for extending access to the information that is available on the large screen at any time. During our demonstrations, the large screen was hence supplemented by either a desktop computer (first iteration), a mobile phone (second iteration) or interactive functionality (third iteration), as a means of providing the nurses with full disclosure of information and patient identities after authentication.

Table I: Comparison of the three iteration cycles in our study.

	First iteration	**Second iteration**	**Third iteration**
Prototype runtime	PowerPoint	Web browser	Web browser
Source for full disclosure	Desktop computer	Mobile phone (+ basic interactive functionality on touch-screen)	Interactive functionality fully integrated in the touch-screen
Authentication	Username + password (on desktop computer)	ID-card (on the digital whiteboard) + mobile phone	ID-card + PIN-code (both on the digital whiteboard)
Feed orientation	Horizontal	Horizontal	Vertical
Event organisation	One combined feed (all patients)	One combined feed (all patients)	Individual feeds for each patient
Participants	4	3	8
Particular focus in interviews	Information needs + Comparison of different de-identification levels	Information needs + Authentication alternatives	Information needs + Disclosing sensitive health information on a large screen

2.1 The artefacts

The first artefact consisted only of static graphics. It was developed with graphical software (Inkscape), and demonstrated as a series of static images (Microsoft PowerPoint) with stepwise disclosure of new information in correspondence with a clinical scenario.

The second and third artefacts were developed using HTML, CSS and JavaScript, and demonstrated using a standard web browser (Google Chrome). Demonstrations were primarily mediated through a 40" touch-enabled screen with 1080p resolution (Full HD), infrared-based touch technology and 178º viewing angle. The screen was mounted on a foot stand with wheels, approximately 140 cm from the ground.

The information conveyed by the artefacts was abstractly differentiated through five categories of events with corresponding icons and colours. Lab events (red) were represented with a blood drop icon, representing a new blood test/lab result. Imaging events (black) used a small radiologic image, indicating progress for X-Ray, CT, MRI, Ultrasound, or availability of the radiologist's report. Medical record events (blue) had a paper sheet icon, and could arise whenever something was recorded in a patient's electronic health record (EHR). Operation events (green) displayed a knife icon, stating real-time progress at certain perioperative milestones. We also added ‘comment events’ (yellow) which were intended to resemble post-it notes, i.e. short messages between collaborating clinicians regarding events or activities that would not be included in the other event categories.

Figure 2: First iteration: This multi-patient, de-identified trajectory of care activities was displayed on a large screen located in the simulated ward corridor.

2.1.1 First iteration: Overview on a large screen, details on a desktop

computer

In our first iteration we visualised a multi-patient, de-identified, horizontal trajectory of recent care events on the screen in the corridor (Figure 2).

In addition, a desktop computer (PC) with a multi-patient, identified, vertical trajectory of recent and future events for the same patients was available at the central desk (Figure 3). The PC required users to be authenticated by user name and password. Although the desktop computer prototype had more information than the large screen-prototype, none of them included what we would refer to as 'medical information', e.g. actual values of blood test results or medical record notes. On request, related medical information was provided verbally by the test facilitator.

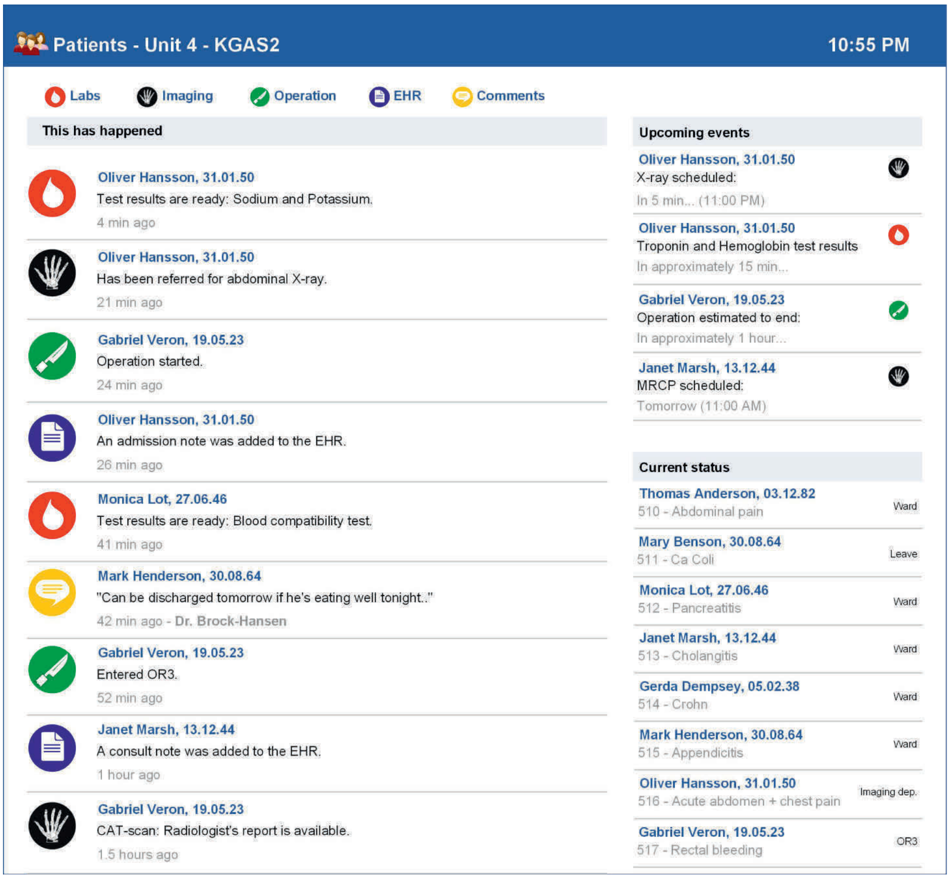

Figure 3: The desktop computer view of the prototyped application (first iteration).

2.1.2 Second iteration: Overview on a large screen, details on a mobile phone

This large screen prototype offered some interaction. Participants could authenticate themselves by swiping an identification card and touching events on the screen, after which the name of the patient would appear (Figure 4, notice the fifth event from the right). The PC was now replaced with a mobile phone that could receive medical information whenever requested by the participant (Figure 5). Requests were made on the large screen, by dragging the finger from an event to an emerging envelope below it (after authentication with an ID-card).

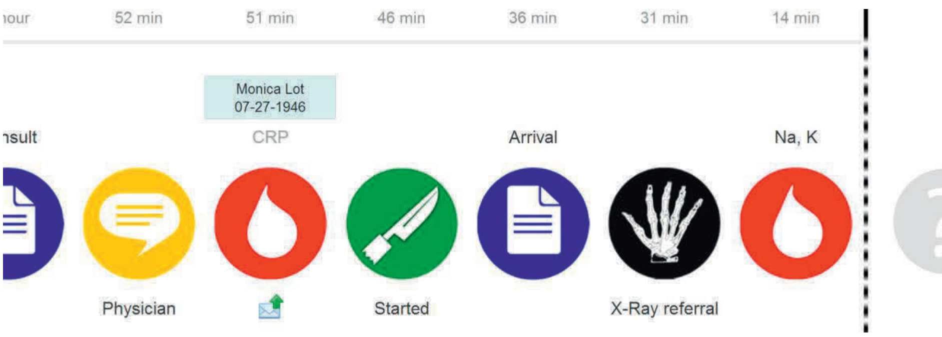

Figure 4: Second iteration: By swiping their ID-card and touching an event icon, the participants could identify the patient and request more details to be sent to their mobile phone.

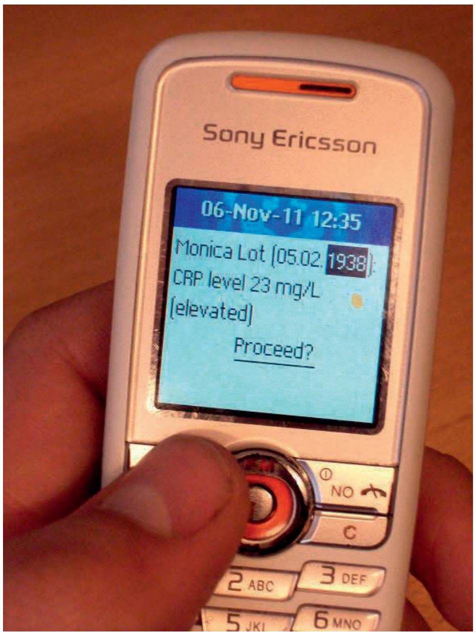

Figure 5: Example of message received on mobile phone, disclosing relevant medical

information.

2.1.3 Third iteration: Both overview and details on a large screen

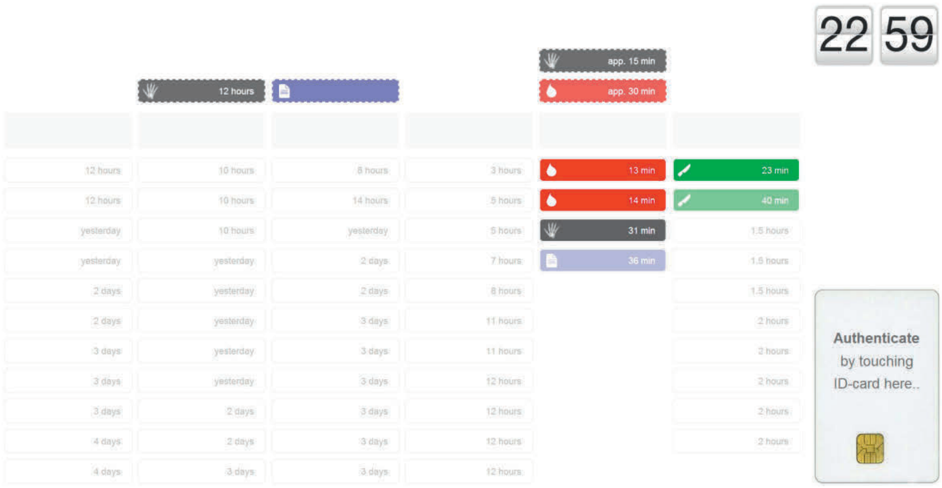

Figure 6: Third iteration: Vertical layout with one column for each patient trajectory, de-identified by default.

In the third iteration we changed from a horizontal, multi-patient trajectory, to vertical, single-patient trajectories. Thus, each patient at the unit had a designated column where new information would be presented (Figure 6). The most recent care events were now located above older events, and expected future events were in addition placed at the very top of each column. Past and future events were separated by a grey placeholder row that could contain more explicit identifiers such as room number or patient name. Still, neither of these identifiers were presented on the screen by default, and only event categories (e.g. lab event, imaging event) and time-stamps were displayed by default. A corresponding colour and icon were shown only for events that had occurred during the last hour (older information was grey).

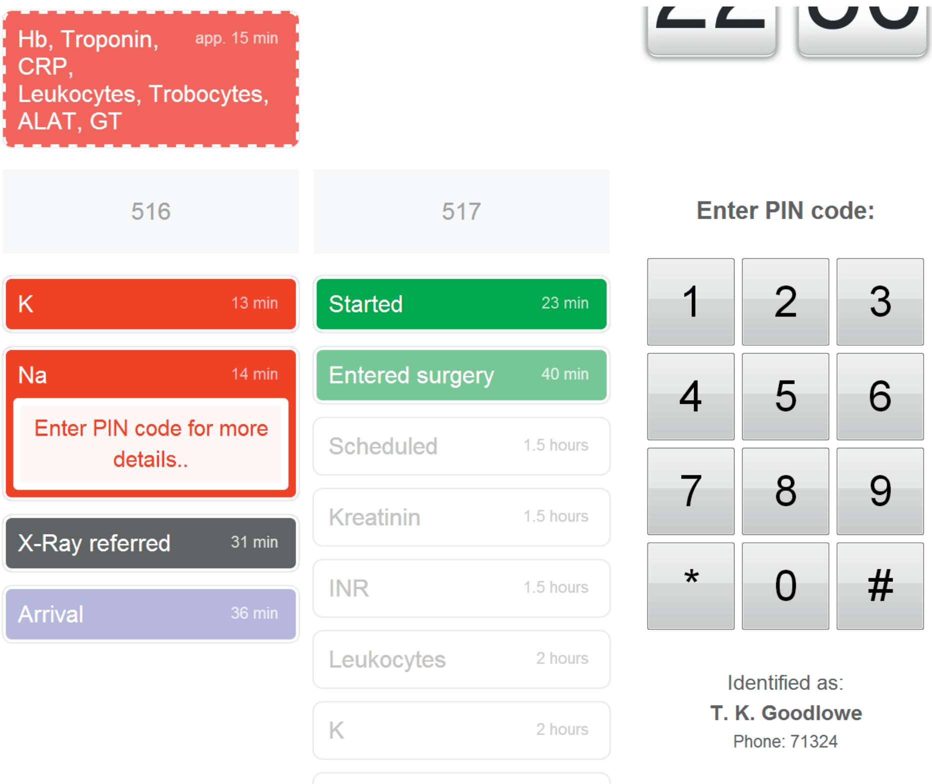

Figure 7: Authentication with ID-card revealed more information about events, but explicit identifiers and further details were hidden until the PIN-code had been entered.

By swiping their ID-card, participants could see room numbers and a specification of the event (e.g. below room number 516 in Figure 7 – a lab event for sodium results). To see patient names and medical information participants had to enter their PIN-code via a panel appearing to the right. Patient names would subsequently appear if the participant touched the room number label, and disappear when untouched. Moreover, when tapping a particular event, the 'event-box' would expand to reveal the medical information (e.g. "Sodium 140 mmol/L"). For lab results we also included a trend graph if there were more than one result for that particular analysis. Imaging events would open the associated image(s) or report on the large screen, while the medical record events would reveal the complete record note. Operation events could similarly reveal a note on the planned or performed operation.

2.2 Demonstration

2.2.1 Participants

All participants in the study were nurses at an 800-bed Norwegian university hospital. Participant sampling was purposive rather than representative. Each participant had at least one year of experience from ward work, and were recruited from either a gastro-surgical ward or an observational unit. The observational unit employs a high-flow policy, admitting only patients expected to be discharged within 24 hours. Organisationally, these patients belong to multiple departments, including the gastro-surgical. At both of these wards two or three nurses usually collaborate in units that comprise eight patients. These nurses share working environment and assist each other whenever needed. The nurses have frequent contact with the patients, and they often communicate with other departments to coordinate care. Whenever important changes in patient status occur or new test results are available, the nurses notify the responsible physician who is usually not co-located with the patients.

Participation was voluntary and was carried out during working hours in agreement with managerial staff. None of the nurses participated in more than one demonstration throughout our study.

2.2.2 Procedure

Demonstrations took place in a setting configured to resemble a surgical ward unit, including a corridor, a central desk and patient rooms. In addition, we started each demonstration session by simulating a realistic handover meeting at the beginning of a night shift at a surgical ward. The participant played the role of an incoming nurse, and one of the investigators (BL) played the outgoing nurse. During such handover meetings the outgoing nurse usually informs the incoming nurse about the patients at the ward in order to ensure proper continuity of care. If the incoming nurse is not already familiar with the patients at the ward, the outgoing nurse gives a summary of each of the patients' history of present illness, what has been done, what to pay attention to and what care activities await. A printed patient list with room numbers, tentative diagnoses and treatment plans usually supplements the oral report.

We had no actual patients in the experiment, but eight fictive patients with realistic surgical problems were presented both orally and on a printed patient list with authentic layout compared to the lists in use at the hospital from which the participants were recruited (Table II).

The participants were encouraged to take notes, ask questions and do whatever they were used to from actual handover meetings.

Table II: List of patients admitted at the fictive ward unit (on imagined date 18th January).

Room	**Patient**	**Diagnose/Problem**	**Most recent events**	**Current plan**
510	Thomas Anderson, 03.12.82	Abdominal pain	Normal blood test results. Normal abdominal ultrasound.	

511	Mary Benson, 12.04.76	Colon cancer	Ultrasound kidneys 15th Jan.	Operation 20th Jan.
512	Monica Lot, 27.06.46	Pancreatitis	MRCP 19th Jan. Control CRP and Amylase every day.	Drainage
513	Janet Marsh, 13.12.44	Cholangitis	Has a urinary catheter.	Ampicillin i.v.
514	Gerda Dempsey, 05.02.38	Crohn	TPN since 13th Jan. CT 14th Jan.	Ordered gastro-enterological consult.
515	Mark Henderson, 30.08.64	Appendicitis	Operation 18th January	Abdominal X-ray 18th Jan. Can eat from 9 pm.
516	Oliver Hansson, 31.01.50	Abdominal pain; chest pain	Is at the moment at the imaging department for chest X-ray.	Fasting, awaiting blood test results and imaging.
517	Gabriel Veron, 19.05.23	Rectal bleeding	Known AAA. Gastroscopy 17th Jan.	Operation.

The demonstration proceeded with a simulation of ward work where the nurse would actively use the artefacts. During this simulation a pre-defined sequence of activities unfolded accompanied by new information made available through the artefact:

1. Handover meeting

2. The nurse was told to look for more information about the patients on a digital whiteboard in the corridor.

3. The sodium (Na) and potassium (K) results for Oliver Hansson's blood test were ready. Both levels were within reference ranges (normal results). Gabriel Veron was at the operating room, and the prototype communicated that his operation had started.

After having consulted the prototype the nurse was ordered to visit patient rooms.

Instead of meeting real patients in the rooms, the nurse was told that time advanced 5-10 minutes while working inside that room, and the next time the nurse looked at the digital whiteboard, the clock had been adjusted and new information could be available. This cycle repeated several times with the following sequence of information updates on the prototypes:

4. No new information.

5. New troponin and haemoglobin results for Oliver Hansson. Other laboratory results were expected to be available any minute. Chest X-ray was expected within 5 minutes.

6. Chest X-ray and radiology summary report of Oliver Hansson were available. More laboratory results were also available (ALAT, GT, Platelets, WBC, CRP). Gabriel Veron's operation was to be finished within 30 minutes.

7. A referral for urgent surgery was available for Oliver Hansson. New haemoglobin results for Gabriel Veron. Additionally, a nurse had written a comment on Mark Henderson.

2.3 Evaluation

After each experiment a focused interview with each participant was carried out. The interview focused on information needs, level of information details, information overload, future events, expected effects, patient privacy, and the nurses' ability to re-identify patients based on contextual knowledge. Interviews were facilitated by having printed copies of the prototypes available, including several alternative levels of de-identification, or by using the large screen actively for recapitulating and exploring scenario and functionality. The focus of the interviews was slightly modified throughout the study, in accordance with the iterations of the design artefacts. All interviews were either audio or video recorded. The audio from all recordings was transcribed verbatim and analysed qualitatively in accordance with *systematic text condensation* (STC) [23]. This is a descriptive approach that focuses on the participants' experiences as expressed by themselves, rather than interpretations of any underlying meaning of what they say. There are four distinct steps in STC: 1) Overviewing: The complete data set is read to establish preliminary themes based on the general impression of the data. 2) Coding: All meaning units are identified and coded. Meaning units are isolated sentences or sections of the text that somehow address the research questions. The codes given to these units are explicit and de-contextualised and they enable grouping of similar meaning units. 3) Condensing: The meaning from each group of meaning units is abstracted. In this phase some codes may need adjustments to be able to make condensates that reflect all aspects of the meaning units. 4) Synthesising: In this final step consistent and re-contextualised descriptions of the data are created. These descriptions should reflect the contents of the data and address the research questions. The descriptions should also be compared and validated against their context from which they have derived (i.e. the raw textual material).

2.4 Ethics

All participants were introduced to the objective of the study and the methods both by information letter and verbally before the simulation began, and written consent forms had to be filled out. The project was approved by the Data Protection Official for Research for Norwegian universities.

3 Results

The participants found the clinical scenario to be realistic, and the qualitative analysis of the interview data resulted in six main themes: 1) The digital whiteboard as a medium; 2) patient privacy; 3) contextual re-identification; 4) access control; 5) information value; and 6) expected effects. Consistent descriptions pertaining to these themes are presented in the following subsections in addition to some related quotations.

3.1 Theme 1: The digital whiteboard as a medium

Participants appreciated being able to discover from a distance that new information regarding one of their patients was available. Sharing the same screen with collaborating nurses was also regarded positive since they could discover new information for each other.

> Nurse 6: “By a quick peek I saw that something had happened […]”

> Nurse 8: “When you're going to be in touch with patients as well, and apart from that have a bunch to do also, it is, as mentioned, incredibly neat to just take a quick glance at a screen, and go on like just: ‘OK’.”

Being able to access medical information through the same screen (third iteration) was highly appreciated. Displaying updates about the patient, including concise medical information was regarded as one of the most important functionalities of the prototype.

Quick access to actual blood test results and radiology summary reports – rather than only knowing that such information was available – was considered useful. While the same could apply to the other medical information as well, the participants did not see a justified need for accessing complete patient history on this kind of screen. Some had experienced that computers at the ward were often occupied, and feared that adding more detailed information to the digital whiteboard (e.g. long EHR notes) could result likewise.

> Nurse 5: "Blood test results, imaging, referrals that have been sent – that's okay. For instance that a medical consult has been ordered – that's okay. (…) If you're sort of going to study them closely, it's more logical to sit down by a desktop computer and do it."

Participants pointed out that the screen should be visible in areas where they spend most of their time. In general the screen size was regarded to be appropriate. Some, however, argued that a smaller screen would be better in terms of patient privacy, while others argued that it would be hard to hide the screen entirely from passers-by and at the same time retain its visibility and usefulness for those working there. Ensuring that the contents of the screen were not breaching patient privacy was considered more fruitful than finding a restricted place for the screen.

3.2 Theme 2: Patient privacy

With the highest level of de-identification applied (e.g.: "One of the patients has a new laboratory test result"), the participants said they would be comfortable with having the screen located almost anywhere. Specifying the information presented – and not the patient – could also be acceptable (e.g.: “One of the patients has new results for sodium level analysis”). This could, however, depend on what kind of test that was specified. Although the screen would not reveal neither the patient's identity nor the actual test results, participants would in particular be less comfortable with displaying the availability of an HIV-test than they were with more common tests such as sodium.

In general, participants did not regard direct patient identifiers such as name, initials, or birth-year as viable alternatives due to their interpretation of privacy legislation. Room numbers could be accepted if the information category was presented alone without further specification (e.g. “A blood test result for patient in room 518 is available”). One remark, though, was that patients could easily find content having their own room number, and that this could be intimidating if patients were unaware of the limitations for what is shown on the screen. Random pseudonyms were considered safe and precise (e.g. “Patient X24B has a new blood test result”), but also slightly ineffective, difficult and non-intuitive to use. In addition, they would most likely require introducing written lists with pseudonyms and corresponding patient names, and thus constitute a new risk for unwanted disclosure if misplaced or lost.

> Nurse 4: “No, I would be sceptical to including that [birth-year and initials of patient]. It is better to log on the computer. You have to follow up on that information, anyway, but of course for me personally it would have been useful to know which patient that new information pertained to. But patient privacy-wise it is probably not completely acceptable. Patients can see each other in the corridors, and they realize who is old and young, and may understand who that information pertains to.”

Some participants commented that our approach with de-identification would respect patient privacy better than their current analogue whiteboard systems. Nevertheless, whenever accessing and reading medical information, the participants emphasized the necessity of controlling what could be seen over their shoulder. Patients, especially, could be looking through open doors. Hence, participants suggested smaller font size and minimising the area of the screen where medical information would be presented. Additionally, the screen should not be used for presenting text that would require prolonged reading.

3.3 Theme 3: Contextual re-identification

With a minimum of practice, the participants were able to see whenever new information was available on the large screen prototype. Most often they were also capable of re-identifying the de-identified patient, even if no explicit patient identifiers were disclosed (e.g. “one of the patients at this ward has taken new X-Ray images”). While this ‘capability’ could be caused by the design of our simulated clinical scenario, the participants commented that they usually know what their patients have undergone and that they have expectations to what information and activities they are awaiting. There could be problems with the accuracy of such re-identification though, for instance if several patients have similar problems and synchronous care plans.

> Nurse 1: “With eight patients at my unit, I will understand who that information relates to. (…) Patients are never operated the same time. (...) I would probably have checked it out anyway if I was uncertain about whether the patient was mine or not.”

Even if the participants did not understand which of their patients the information pertained to, they considered the large screen as useful as it reduced the number of wasted checks on information that was not yet available.

> Nurse 2: "The overview without names is better than having a black screen. We see whether something new is there that may be important to check; if something is going on – because there might be long periods when nothing happens. We see that it hasn't happened, and thus we don't have to log on when no new information is available."

An idea of contextualising each piece of information with the clinician who produced the information, or the location where that information was produced, was not considered useful. Either such information would not provide any additional distinction between patients, or it would not intersect with the recipient's knowledge about the patient's history. However, one of the participants suggested that new information could be labelled with the name of the responsible nurse, rather than any patient identifiers or room numbers. In that way the nurses would know when the information would be relevant for them.

> Nurse 10: "Yes, for instance, they could be labelled with the responsible nurse above there. I don't care, really, as long as I understand that they're mine. Something that tells me they're my patients, and that can just as well be my name instead of room numbers, actually."

3.4 Theme 4: Access control

Participants wanted to be able to disclose full patient identification and read concise medical information via the large screen interface. The approach of swiping an ID-card and entering a PIN-code was considered quick and simple, without substantial add-ons to their current workload. However, if the card would have to be inserted somewhere, rather than swiped, some argued that ID-cards would be less convenient.

> Nurse 6: “At a first glance I saw that something had happened without entering the PIN-code. And if it regards my patient and is interesting for me, I would naturally log on and see more.”

> Nurse 11: “And if it is possible to swipe your card and enter your PIN-code just like we already do all day long wherever we are, then I think that would be great.”

In general, participants would accept user authentication measures as long as they were perceived proportional to the information they got access to. The authentication approach based on receiving sensitive information via SMS on a phone, was in this respect considered satisfying, but not optimal. One advantage, though, was that the phone could be brought along for reading the information elsewhere. On the contrary, it required much effort sending and then browsing through several messages, and a lost phone could reveal sensitive information if not protected by additional authentication.

Biometric techniques such as fingerprint, iris scanning or facial recognition through video capture were questioned during the interviews, but not tested in practice. The participants said that such methods could work, but their implementation had to be solid, quick, and not cause any additional clutter for the user.

The participants agreed on the need for an automatic mechanism for logging out. Some told that they sometimes did not log out when leaving a computer, for instance in emergency situations or due to time-consuming authentication mechanisms in their current systems. Specifying a particular time limit for automatic logout was challenging, and the participants' suggestions varied between ten seconds and two minutes – balancing patient privacy with annoying unintended session time-outs.

> Nurse 9: "If the screen is inactive for so and so long and then it logs off automatically, that would of course be a kind of must-have. Because suddenly something happens, and you've just got to run without considering the fact that you are still logged in."

> Nurse 12: "Now, imagine I'm a little busy, but still in front of the screen waiting to take a look at it, and then I talk to someone. And then, when looking at the screen again I'm logged out again. That's very annoying!"

3.5 Theme 5: Information value

In general, information that would require some kind of follow-up action was most valued, e.g. being informed when new blood test results or radiologic summary reports were available, knowing when the patient should be pre-medicated, or when the patient should be transported to the operation room (OR) and back from the post-anaesthesia care unit. Likewise, knowing that an operation had ended was considered less valuable, since that did not prompt any particular action. However, that information could be useful in another sense, i.e. informing the relatives of the patient about the progress in the OR. Importantly, the participants pointed out that time critical information should not be presented on the screen without other measures as well. The nurses could be pre-occupied and not see the screen for some time, so such information had to be communicated directly.

Projections of future events and activities were highly valued. Knowing what the next step would be was considered useful both for planning of their own activities (including preparing patients more timely) and for verifying the current status of the patient.

> Nurse 1: "This is great! For instance, regarding imaging, we don't have an overview over imaging referrals or scheduled appointments, or if there has been any rescheduling. In particular, a patient that is scheduled for abdominal CAT-scan is supposed to drink contrast before the scan, and we often must call the imaging department and ask when the scan is scheduled because the patient is supposed to fast four hours before that. If that information was here, I think it would spare us much work."

When confronted with a trajectory with many information updates from the operating room versus a version with few updates, participants preferred having few updates in combination with projections, rather than having many updates (that possibly could readjust their individual projections of future events). The accuracy of expected future events had to be reliable, yet did not necessarily need to be perfect. Some reckoned having estimates that were a bit too short were better than the opposite, and that continuously updated estimates could improve communication within the hospital.

> Nurse 1: "We're at a hospital, so you have to accept everything. Nothing turns out the way it was planned for (…) If the screen states that the X-ray is scheduled to be taken 11:00 am and the clock is 11:30 am when it gets done, that's no crisis. But perhaps I would have phoned and asked 'what is it with this delay?'. But they could as well have updated the time on the screen (…) That would be a nice way of communicating – just updating the screen. We wouldn't have to make phone calls all the time."

3.6 Theme 6: Expected effects

Participants explained that their current information systems did not provide any indications as to when new information would be available, so repeated checking was obligate. Hence, they expected that a system similar to the prototype would reduce work-load, ease recognition of new information, and possibly speed up patient management. Although some information would still have to be communicated through phones or EHR, the participants expected reductions in the number of log-ins and log-outs in the EHR, improved overview of patient care activities, more proactive coordination of care and improved information to patients and their relatives.

> Nurse 6: "We spend quite much time logging in and checking for new blood test results and imaging reports, so we would save a lot of time there."

> Nurse 14: " (…) when you get used to using this screen, and get used to the colours and what it means, I believe this would be great to work faster, get faster aware of things."

4 Discussion

4.1 Summary of main findings

This study demonstrates how professional ward nurses can exploit patient centred, de-identified and abstracted clinical information presented on a digital whiteboard for coordination of care. The study indicates that ward nurses might be capable of re-identifying much of the de-identified information based on their knowledge of their patients' recent and future care activities. However, even if not completely able to do so, de-identified information has the potential of reducing work-load by reducing the number of log-ins to the EHR. This includes log-ins that could very well be avoided, such as simple checks for availability of new information. Potentially, the nurses could also become more rapidly aware of new information. In addition to displaying recent clinical events on such a large screen, the nurses could benefit from having estimates of future events as well. Given a sufficient level of reliability of future estimates, such information might improve communication and coordination of work, according to the nurses.

These results also indicate how combinations of privacy enhancing design techniques can provide a level of patient privacy that is acceptable while maintaining a useful system. However, nurses should also be able to verify patient identity and access associated (condensed) detailed medical information through the same interface. A two-factor combination of ID-card and PIN-code was regarded efficient and secure enough for authentication. In addition, it is important for the user to be able to effectively control what can be seen by patients and passers-by whenever disclosing full identity and medical information.

4.2 Strengths and limitations

Our findings are based on the subjective experience and expectations of professional ward nurses after using a prototype in a simulated ward setting. This study design obviously does not provide any final conclusions on the usability of the chosen design features nor the effects of an implemented system at a real ward. However, we consider these results as both relevant and important as input for understanding ward work and developing support for coordination of care.

The clinical scenario in our experiments was designed with two purposes in mind: First, to provide a realistic context for the prototype, and second, to demonstrate the functionalities of the prototype. Hence, the scenario also reflected the preconceptions of the researchers. According to the participants we succeeded with creating a realistic clinical scenario. To avoid verifying our preconceptions during the interviews we emphasised participants' opinions on the effects and applicability of such a system during a typical day at work. We asked them to exemplify their opinions with descriptions of situations from actual ward work. Thus, we took advantage of their experience from actual ward work rather than asking how they valued the prototype as part of our simulated scenario. The data from the interviews were analysed separately by the authors (contesting each other's interpretations), each applying a rigid qualitative data analysis technique. The authors represent different backgrounds, professions and positions. Having taken these measures, we consider the internal validity of our findings to be good, and the confounding effects of the researchers on these findings to be sufficiently low. The chosen sample does not permit uncritical and direct generalisation of the results to other ward settings. It is very likely that the findings are related to experience of the ward nurses and their organisation of work (e.g. who is responsible for following up blood test results). However, conceptually, some of these results can be generalised to other settings (e.g. increasing visibility of de-identified and abstracted new clinical information, or providing clinicians with estimates of future clinical events), at least as interesting hypotheses that could and should be followed-up in future studies. Finally, it must be kept in mind that novel technology and organisational changes might introduce unexpected side-effects to current work-flow and care. This has not been investigated sufficiently in this study.

4.3 Comparison with existing literature

We have not found any systematic reviews of the effects of shared digital whiteboards on clinical awareness and coordination of care in hospital environments. While some studies have identified negative consequences and properties of digital whiteboards compared to dry-erase whiteboards [4, 5], several studies and implementation reports suggest that such artefacts contribute positively to communication and coordination [2,6–12,14]. Overall, the participants in our study had a positive attitude towards our prototypes, and expected it would have a positive impact on coordination and inter-departmental communication.

While projection of future situations has been considered the highest level of situation awareness [24], and predictive aids are considered valuable in aviation [25], this has not been the main focus in the literature on shared digital whiteboards for coordination of care. One exception, though, is the continuously updated operating room schedules, potentially with visualizations of expected operating room utilization [12,26]. Our participants were positive to having continuously updated projections of clinical events for which no schedule typically has been available (e.g. expected availability of blood test results). We would like to hypothesize that with modern technology – including automated laboratory techniques – it is possible to make such predictions in real-time with sufficiently high reliability. This should, however, be further studied.

How to balance patient privacy against user requirements and legislative requirements is another aspect of shared digital whiteboards that has rarely and barely been focussed on in the context of coordination of healthcare activities. While Scupelli et al. [13] suggests to place whiteboards in staff-only areas to avoid leaving out information due to privacy legislation, Aronsky et al. [7] ask patients to sign a waiver for displaying their names on the whiteboard, and include screen savers, aggressive time-outs and authentication for enhanced privacy protection. Bardram and Bossen [27] have suggested authentication mechanisms based on physical proximity, and like us, they argue that "some information and some views on this information may not be subject to user authentication". Since there could be several levels of security/privacy needs depending on the importance and quality of the disclosed information, physical surroundings and time of day [28], in addition to available functionality (i.e. read-only or also write/edit access), it becomes evident that the common "all or nothing" approach should be reconsidered for access control implementations in digital whiteboards. While authentication of users can be done by something the users either *know* (e.g. a password), *have* (e.g. a smart card) or *are* (e.g. fingerprint, iris pattern or other biometrics) , it was not the scope of this study to explore all these techniques in detail. Studies have nevertheless shown that common access control implementations can pose a threat to security in collaborative environments, e.g. clinicians may share passwords or access with colleagues or avoid logging out if they do not understand the user interface or if security measures do not match their needs [29, 30]. This emphasises the importance of a holistic approach to privacy and information security design for digital whiteboards, taking the end users' actual usage scenarios into account from the start. Rather than focusing solely on authentication, focus should be shifted towards security as a combined product of the interactive system and the people who use it [31]. It might be fruitful to develop systems that allow users to "understand the consequences of their actions and develop new forms of practice" [32], although it has been argued that it may be risky to expect this from users [15, 22]. Still, our results show that the nurses wanted to control what can been seen over their shoulders while interacting with the digital whiteboard. With our last prototype, the nurses had to tap each event, one by one, to reveal the attached medical information, an approach that resembles what has been referred to as ‘privacy blinders’. Although this may require more time compared to having no blinders, it can still be accepted if it provides “levels of privacy that would otherwise not exist” [33].

An alternative to privacy blinders is coding of information with colours, shapes, etc. [33]. Users are able learn how to use such codes. However, in itself such ‘security by obscurity’ is not a secure approach since codes always run the risk of being decoded by others. Although we used colour coding of the event categories in our prototypes, our approach is fundamentally different from ‘security by obscurity’. Rather than coding information, we removed medical information from the default view (all prototypes) and introduced ambiguity in the identification of individuals (prototype 1 and 2). Only the event categories were visible in the default view in prototype 3. These were colour coded, but not to obscure information, rather to make that information readable from a distance. Our participants did not consider visualizing event categories room-wise as breaching privacy rights (e.g. “the patient in room 512 had an imaging event”). However, this probably depends on how broad the event categories are. Reintroducing ambiguity in identification of individual patients increases the level of security (e.g. visualize events per nurse, rather than room).

The use of mobile devices for accessing more details is a security alternative that we only marginally have explored with this study, and hence we do not discuss that any further. Other aspects of privacy design related to policy, system and interaction issues in privacy sensitive systems can be found elsewhere [34]. To our knowledge, the usability of most of these design patterns have not been evaluated for shared display systems in hospital contexts. This calls for more research on the balance between patient privacy and clinician requirements.

5 Conclusions

Real-time display of patient centred, de-identified and abstracted recent and expected clinical events on a digital whiteboard is a promising technology for supporting coordination of care activities at a hospital ward. This study indicates that such technology has the potential to reduce workload of ward nurses, speed up patient management and enable a more proactive coordination of care – without compromising patient privacy. However, this privacy enhancing design approach remains to be applied and evaluated in real clinical work, and it is unknown whether other technological alternatives to digital whiteboards are more effective.

Authors' contributions

Both authors have contributed equally in designing the study, conducting the experiments and analysing the results. Both authors have revised all parts of the article critically for important intellectual content, and given their approval of the final manuscript. Hence, they both contributed equally to this work and share first authorship.

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Statement on conflicts of interest

Both authors declare that they have no competing interests to declare.

Summary table

What was already known on the topic:

- Coordination of care in modern hospitals is complex, involving many actors in the care of a single patient.
- Providing clinicians with access to patient care information through wall-mounted whiteboards is a widely used approach for supporting communication and coordination of care in hospitals.
- Patient privacy requirements influence what and how information can be presented on such whiteboards, especially for digital implementations.

What this study added to our knowledge:

- De-identified and abstracted information presented on a digital whiteboard was perceived useful for coordination of care at a surgical ward.

- Ward nurses are likely to be able to re-identify to whom the de-identified information pertains for patients they have a particular responsibility for, based on their contextual knowledge.
- De-identified information can communicate both availability and non-availability of new information.
- De-identified and abstracted information should be accompanied by means for trustworthy verification of contents and identity.

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Paper III

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ORIGINAL RESEARCH

What is optimal timing for trauma team alerts? A retrospective observational study of alert timing effects on the initial management of trauma patients

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Background: Trauma teams improve the initial management of trauma patients. Optimal timing of trauma alerts could improve team preparedness and performance while also limiting adverse ripple effects throughout the hospital. The purpose of this study was to evaluate how timing of trauma team activation and notification affects initial in-hospital management of trauma patients.

Methods: Data from a single hospital trauma care quality registry were matched with data from a trauma team alert log. The time from patient arrival to chest X-ray, and the emergency department length of stay were compared with the timing of trauma team activations and whether or not trauma team members received a preactivation notification.

Results: In 2009, the trauma team was activated 352 times; 269 times met the inclusion criteria. There were statistically significant differences in time to chest X-ray for differently timed trauma team activations ($P = 0.003$). Median time to chest X-ray for teams activated 15–20 minutes prearrival was 5 minutes, and 8 minutes for teams activated <5 minutes before patient arrival. Timing had no effect on length of stay in the emergency department ($P = 0.694$). We found no effect of preactivation notification on time to chest X-ray ($P = 0.474$) or length of stay ($P = 0.684$).

Conclusion: Proactive trauma team activation improved the initial management of trauma patients. Trauma teams should be activated prior to patient arrival.

Keywords: emergency medical service communication systems, trauma centers, patient care team

Background

Trauma patients constitute a heterogeneous group whose injury mechanisms and premorbidity require rapid and systematic diagnostic and therapeutic measures.[1] Most Norwegian hospitals that receive severely injured patients have established predefined multidisciplinary trauma teams.[2] As an integrated part of regionalized trauma systems such teams have been shown to improve outcomes of severely injured patients.[3] However, trauma team activation can cause ripple effects throughout a hospital, as team members have to set other work aside. For instance, imaging resources and operating rooms can be put on hold in advent of the patient's potential need for them. Hence, much research has focused on developing optimal criteria for activation of the trauma team.[4–8]

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Whenever a patient en route to the hospital meets trauma team activation criteria, hospitals typically use a trauma alert system to notify all team members. The intention of such a system is to ensure that team members meet on time in the resuscitation room. Liberman et al demonstrated that prehospital notification led to lower odds of death, however the effect was only for patients with mild injuries (injury severity score < 12) and not for the more severely injured (injury severity score 12–75).[9] Optimal timing of trauma alerts could improve team preparedness and performance while also limiting adverse ripple effects throughout the hospital. We are not familiar with any further research on trauma alert systems and how they affect the initial management of trauma patients. Thus, the objective of this study was to evaluate the effect of prehospital trauma team notification (TTN) and differently timed trauma team activation (TTA) on in-hospital trauma team performance. We hypothesized that both prehospital TTN and proactive TTA (trauma team is activated before patient arrives) would improve the initial management of trauma patients compared to no TTN and reactive TTA (trauma team is activated when or after patient arrives).

Table 1 Trauma team activation criteria at St Olav's University Hospital

Physiological and anatomical criteria
Airway obstruction
Respiratory rate: >29 or <10 breaths/min
Systolic blood pressure: <90 mmHg
Glasgow Coma Scale of <14 and one criterion of mechanism of injury
Severe injury to two or more organ systems
Severe hemorrhage
Flail chest
Dislocated pelvic injury
Fracture to two or more long bones
Penetrating injury proximal to knee/elbow
Traumatic neurological injury
Crush injury/amputation proximal to wrist/ankle
Burns to body surface area of >15% in adults and >10% in children
Increased airway obstruction
Increased abnormal respiration
Increased cyanosis
Mechanisms of injury
Ejection from vehicle
Injury caused by electricity
Pedestrian run over or thrown over vehicle at impact
Children hit by vehicle at >30 km/h
Fall of >5 m, adults
Fall of >3 m, children
Fatality in same vehicle
Entrapment
Roll-over
Vehicle speed of >60 km/h
Vehicle compartment compressed by >30 cm or substantial deformation
Entrapment in avalanche
Hypothermia
Interfacility transfer
Transfer from other hospital within <24 hours of injury

Methods

Design

We used data from a single hospital quality registry of trauma care to conduct a retrospective observational study of trauma team activation.

Study context

St Olav's University Hospital is a 742-bed academic, tertiary trauma referral center, serving a mixed urban and rural regional population of approximately 646,000 people. In the region of mid-Norway, seven other hospitals also admit severely injured patients; however, these hospitals have no neurosurgical, cardiothoracic or pediatric surgical services. The regional emergency communication center (ECC) is located within the hospital and is responsible for the coordination of prehospital emergency medical services (EMS), as well as communication between pre- and in-hospital services. Basic prehospital care is provided by on-call general practitioners, ambulance crews, and paramedics. Whenever advanced life support is required, a crew consisting of paramedics and an anesthesiologist responds separately by helicopter or rapid-response car.

The ECC is staffed by trained nurses and paramedics who activate the trauma team when predefined criteria are met (Table 1). Predefined criteria are based on physiological variables, sustained anatomic abnormalities, and mechanisms of injury. The trauma team is one-tiered and consists of 12 mandatory members and additional facultative members.[1]

When a trauma incident occurs, the ECC informs and activates trauma team members by sending out two separate alerts on their pagers. The first alert is a TTN, sent out as soon as possible whenever trauma team criteria are met, usually after the prehospital EMS has arrived on scene. As a response to the TTN, team members call back to the ECC for more information about the incident. The intention of the TTN is to alert the involved clinicians in order to allow for timely preparations before the patient arrives. The second alert is the TTA. According to the hospital protocol, trauma team members should receive the second alert approximately 10 minutes before the patient arrives. This mandates immediate attendance in the resuscitation room. Rapid assessment and therapeutic measures according to trauma management principles are initiated upon arrival, including a structured physical examination, blood sampling, chest X-ray, and abdominal sonography.[10,11] Figure 1 illustrates a typical trauma care process including the relevant time intervals for this study.

Deviations from this typical chain of events may occur. For instance, the trauma incident may occur very close to the hospital, necessitating immediate TTA, leaving no time for first sending out a TTN. Sometimes transportation is faster or slower than expected, shortening or lengthening the expected 10-minute interval between the TTA and patient arrival. Occasionally patients might even arrive at the hospital before the TTA, and on arrival, trauma teams may, for some reason, choose not to follow the initial management protocol, for instance, not sending all patients for a chest X-ray.

Main measures

Data from the ECC paging service were matched with trauma registry data based on date and time of incident, alert pages, and patient arrival. The trauma registry consisted of manually registered data (first handwritten on paper during trauma team activation, and later manually entered into an electronic database), while the ECC paging service log was generated automatically. The primary outcome variable was time to chest X-ray (CXR-time). A secondary outcome variable was length of stay in the emergency department (ED LOS). Time intervals were calculated from patient arrival, but for situations where a patient arrived before the trauma team was activated, time was calculated from the TTA. This was performed to compare team performances (not ECC paging timeliness) between situations where the team was activated before or after patient arrival, that is, proactive and reactive TTAs. We excluded TTAs if the registry data did not permit calculation of dependent (neither CXR-time nor ED LOS) or independent (neither TTN nor TTA) variables. We also excluded multiple trauma patient instances as they usually had only one common TTN and TTA, and in such cases, hospital resources and prioritization mechanisms most likely had a significant impact on initial management.

Statistical analyses

Both outcome variables (CXR-time and ED LOS) were categorized as either efficient or inefficient. Threshold values were based on the median so that the number of efficient and inefficient teams was approximately equal. Independent variables were also categorized. Teams either did or did not receive a TTN in advance. TTAs were categorized into six groups based on the timing of the TTA in relation to patient arrival. We compared outcomes between groups using Pearson's Chi-squared test. *P*-values less than 0.05 were considered statistically significant. Data analysis and graphical representations were done with statistical software (SPSS Statistics, Release 19.0.0.1; SPSS Inc, Chicago, IL) and spreadsheet software (Openoffice.org, version 3.2.1; Oracle Corporation, Redwood City, CA).

Ethics

The exported data from the quality registry did not contain any patient characteristics. The research protocol was presented to the regional research ethics committee, which regarded the project as a clinical audit not needing further approval.

Results

The trauma team was activated 352 times in 2009. Eighty-three of these times were excluded from our analysis, 72 of which involved multiple trauma patients, seven that had no documented time of patient arrival, three with no registration of

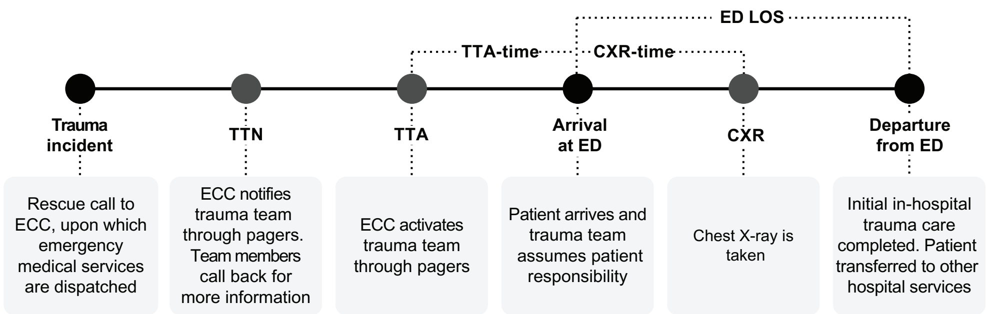

Figure 1 Pre- and in-hospital trauma care process model including definition of time intervals.
Abbreviations: ED, emergency department; LOS, length of stay; TTN, trauma team notification; TTA, trauma team activation; CXR, chest X-ray; ECC, emergency call center.

TTN or TTA, and one with no registration of CXR-time or ED LOS, which left 269 for analysis (Table 2). Sixty-six percent of all TTAs were preceded by a TTN. Eleven patients (4%) arrived at the hospital before the trauma team was activated (reactive TTA).

We found no association between TTN and CXR-time or ED LOS (Table 3). Similarly, timing of TTA was not associated with ED LOS, but there was a statistically significant association between the timing of TTA and CXR-time (Table 4). Box plots of this association demonstrated an inverse relationship between CXR-time and time from TTA to patient arrival, median CXR-time decreasing from 8 minutes to 5 minutes with increasing TTA time (Figure 2).

Data quality

Analysis of data quality showed that amongst the manually recorded time data (incident, arrival, chest X-ray, and departure from ED) there were considerably more 5-minute interval recordings compared with the automatically registered time data (TTN and TTA). That is, for manually recorded data, the last digit was more often 0 or 5, while for automatically recorded data the last digit was evenly distributed between all numbers from 0 to 9 (Figure 3).

Discussion

Summary of main findings

The results from this study demonstrate that proactive TTA improved the initial management of trauma patients as measured by a reduction in CXR-time. We are not aware of any other study that describes the association between timing of trauma team activation and trauma team performance.

A preactivation TTN did not have any effect on team performance as measured by CXR-time. ED LOS was not associated with TTN or the timing of TTA, indicating that other factors are more important for determining the ED LOS. Visual inspection of the data indicates that trauma teams at our hospital should be notified at least 10 minutes before the patient arrives at the resuscitation room, perhaps even as much as 20 minutes prearrival. This finding is probably not directly transferable to other hospitals as composition, coordination, and experience of trauma team members may vary both between and within hospitals.[12–14] It is reasonable to assume that the ideal time between TTA and patient arrival, at least depends on hospital architecture and organization. To identify the ideal time between TTA and patient arrival for a particular hospital, one can plot local CXR-times against TTA time. Trauma care quality registries should include these variables.

Other studies

There are few other studies to compare and contrast our results with. Driscoll and Vincent found through both observational and interventional studies, that proactive measures such as preallocation of tasks and the establishment of horizontal organization improved trauma patient resuscitation times compared to ad hoc allocation and the sequential execution of tasks.[15] Although different from our study, their results point in the same direction, namely that proactive measures improve team performance.

Several efforts must be undertaken to achieve adequate proactivity in trauma management. To ensure that necessary knowledge and skills are present on patient arrival, trauma teams should be multidisciplinary. Written procedures and simulation training support shared understanding of what should be done, when and by whom, instead of coming to an ad hoc understanding of how to cooperate.[16,17] Finally, appropriate communication between prehospital and in-hospital teams is vital in mounting an adequate clinical response to the arrival of the trauma patient. Interestingly we found no association between TTN and CXR-time or ED LOS, thus questioning the need for prearrival communication for preparation of trauma teamwork. Even though the TTN had no effect on our measures, it does not mean that the TTN did not have any effect at all. A TTN may have enhanced trauma team members' situational awareness and enabled them to better sequence their nontrauma clinical activities, so as to

Table 2 Descriptive statistics from trauma team activations in 2009

Total n = 269	Valid n	Median (minutes)	25-percentile (minutes)	75-percentile (minutes)
From incident to ED	263	76.0	39.0	125.0
From TTN to ED	177	40.7	28.6	62.6
From TTA to ED	268	9.4	6.7	13.0
CXR-time	247	5.0	5.0	7.0
ED LOS	260	25.0	20.0	31.5

Abbreviations: ED, emergency department; TTN, trauma team notification; TTA, trauma team activation; CXR, chest X-ray; ED LOS, length of stay at the emergency department.

Table 3 The effect of trauma team notification

	CXR-time		ED LOS	
	≤5 min	>5 min	≤25 min	>25 min
Without TTN	45	38	45	44
With TTN	81	83	91	80
Pearson's Chi-squared	0.474 0 cells (0%) have expected count less than 5. The minimum expected count is 40.66		0.684 0 cells (0%) have expected count less than 5. The minimum expected count is 42.45	

Abbreviations: CXR, chest X-ray; LOS, length of stay; ED, emergency department; TTN, trauma team notification.

Table 4 The effect of differently timed trauma team activations on CXR-time and ED LOS

	CXR-time		ED LOS	
	≤5 min	>5 min	≤25 min	>25 min
TTA–time ≤ 0 min	2	7	6	5
TTA–time 0.01–5 min	8	21	13	13
TTA–time 5.01–10 min	48	49	48	51
TTA–time 10.01–15 min	42	32	41	38
TTA–time 15.01–20 min	21	6	18	14
TTA–time 20 min	5	6	9	3
Pearson's Chi-squared	0.003 2 cells (16.7%) have expected count less than 5. The minimum expected count is 4.41		0.649 0 cells (0%) have expected count less than 5. The minimum expected count is 5.27	

Abbreviations: CXR, chest X-ray; LOS, length of stay; ED, emergency department; TTA, trauma team activation.

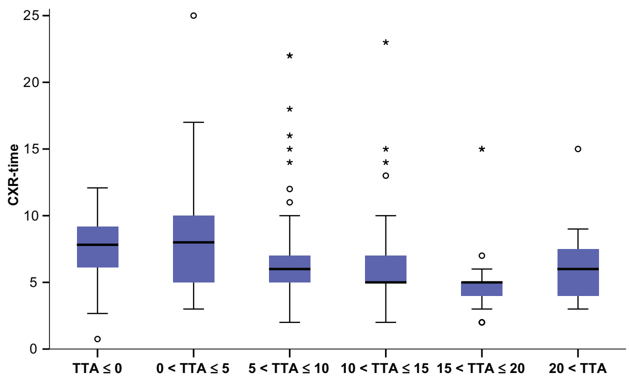

Figure 2 Box plots of CXR-times (minutes) for groups of differently timed TTA (minutes).
Notes: *More than three box lengths from the box; °between 1.5–3 box lengths from the box.
Abbreviations: CXR, chest X-ray; TTA, trauma team activation.

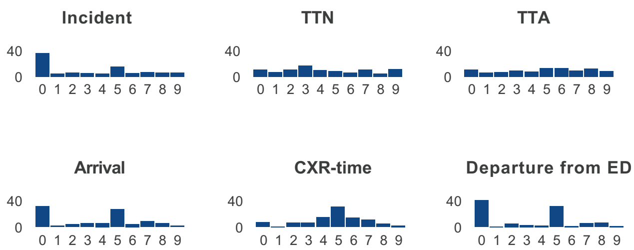

Figure 3 Distribution (%) of last digits in recorded time data.
Notes: Incident, arrival, CXR-time, and departure from ED were recorded manually. TTN and TTA were recorded automatically.
Abbreviations: ED, emergency department; TTN, trauma team notification; TTA, trauma team activation; CXR, chest X-ray.

minimize adverse ripple effects through the hospital when the TTA required their presence in the resuscitation room (or it might have stressed them and maximized ripple effects!). The TTN may also have been more important when several trauma patients arrived simultaneously, requiring more resources and preparations than usual. Furthermore, the TTN might have improved the quality of work and potentially improved patient outcomes in other measures not reflected through CXR-times or ED LOS. An alternative to sending a TTN to all team members could be to notify only the team leader who subsequently could choose who else should be notified before the TTA.

Strengths and limitations

We used a single hospital trauma care quality registry as our main source for data, supplied by an automatically generated trauma paging alert log. The data in the quality registry was documented on paper by an emergency ward nurse during the initial management of trauma patients, and later entered into an electronic database by a secretary. In terms of data quality, the manually recorded data clearly illustrated the human propensity to smoothen data. We have only succeeded in finding one scientific article mentioning this particular phenomenon pertaining to registration of time data,[18] but many studies have demonstrated smoothing and inaccuracies in manually recorded medical data.[19] Although this phenomenon impedes data quality, we are of the opinion that it is more likely that this reduction in data granularity would mask any differences rather than produce artificial ones between groups of differently timed TTAs. Regardless of this particular study, we think trauma care quality registries should endeavor towards automatic sampling of time data.

Our outcome measures were not directly related to patient outcomes, but were measures on how fast the trauma team managed the patient within the resuscitation room. There is poor scientific support for the validity of trauma care time measurements as indicators of patient outcomes, as for other proposed quality indicators for evaluating trauma care.[20,21] However, time or time savings from patient arrival to radiological investigations have been reported in previous studies of trauma team quality.[15,22,23]

Conclusion

Proactive activation of the trauma team improved trauma team performance. For this particular hospital trauma team activation 10–20 minutes before arrival of the patient was associated with a statistically significant reduction in CXR-time. More research on the effects of notification and proactive activation of trauma teams is needed. Such research has the potential to improve the quality of trauma management, reducing the adverse ripple effects of trauma care on other hospital activities.

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Disclosure

The authors report no conflicts of interest in this work.

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Paper IV

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Presentation of clinical laboratory results: an experimental comparison of four visualization techniques

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ABSTRACT

Objective To evaluate how clinical chemistry test results were assessed by volunteers when presented with four different visualization techniques.

Materials and methods A total of 20 medical students reviewed quantitative test results from 4 patients using 4 different visualization techniques in a balanced, crossover experiment. The laboratory data represented relevant patient categories, including simple, emergency, chronic and complex patients. Participants answered questions about trend, overall levels and covariation of test results. Answers and assessment times were recorded and participants were interviewed on their preference of visualization technique.

Results Assessment of results and the time used varied between visualization techniques. With sparklines and relative multigraphs participants made faster assessments. With relative multigraphs participants identified more covarying test results. With absolute multigraphs participants found more trends. With sparklines participants more often assessed laboratory results to be within reference ranges. Different visualization techniques were preferred for the four different patient categories. No participant preferred absolute multigraphs for any patient.

Discussion Assessments of clinical chemistry test results were influenced by how they were presented. Importantly though, this association depended on the complexity of the result sets, and none of the visualization techniques appeared to be ideal in all settings.

Conclusions Sparklines and relative multigraphs seem to be favorable techniques for presenting complex long-term clinical chemistry test results, while tables seem to suffice for simpler result sets.

BACKGROUND AND SIGNIFICANCE

The importance of laboratory test results in clinical work is unquestionable. In hospital settings, laboratory test use seems to be increasing considerably,[1] and in primary care, physicians may receive as many as 1000 test results each week.[2] Physicians have to stay aware of new results, comprehend the results and ensure proper follow-up based on assessment of single and multiple values and systematic changes over time. Studies have shown that these tasks are not straightforward. Physicians may be unaware of abnormal test results, and abnormal results may be left unrecognized without proper follow-up.[3–5]

A single clinical laboratory test result may consist of a numeric value—representing the concentration of a substance in for example, the patient's blood—accompanied by the name of the test, the unit of measurement, the date of the sampling and a reference range. The reference range is commonly defined as the 95% central range of values observed in healthy individuals. Clinicians may compare individual test results with the reference range for the test, in order to establish whether the result is high or low compared to healthy individuals.

The laboratory report is a vital link between the laboratory and the physician, and the presentation format can have major impact on the clinical action taken.[6] Traditionally, laboratory results have been presented as tables. This has probably been related to use of paper based patient records, and the simplicity of adding new entries of laboratory results into a table. However, electronic health information systems permit visualizing these results in alternative ways. One study showed that laboratory data presented with one particular line graph visualization—'sparklines'—were assessed faster than when presented in a conventional table,[7] while non-clinical studies have come to the opposite conclusion.[8 9] A problem with comparing studies of visualization techniques is that there are numerous ways to present laboratory results.[10 11] Additionally, clinical contexts differ, and it is not certain that one technique fits all clinical situations.

OBJECTIVE

In this study we evaluated how four different visualization techniques—three line graphs and one table—performed when presenting numerical clinical chemistry test results from four patients, each representing a distinct patient category: the emergency patient, the chronic patient, the simple patient, and the complex patient. We focused on how trends, overall levels and covariation were assessed with different visualization techniques, including assessment times. In addition we evaluated subjective user preferences with respect to the four techniques.

Two of the visualization techniques, the table and the absolute multigraph, were based on solutions implemented in hospital and primary care systems in our region. The third visualization technique—sparklines—has been described and studied by others and was thus highly relevant for comparison with the other techniques.[7 11 12] With the fourth technique—the relative multigraph—we tried to solve some of the problems with simultaneous visualization of multiple tests with the absolute multigraph. This was somewhat inspired by the unit-independent technique,[10] but rather than scaling results by test SD and using a logarithmic time axis, the relative multigraph had a (partially) logarithmic value axis and a linear time axis.

METHODS AND MATERIALS

Study design

Deidentified clinical chemistry test results from four patients were presented to each participant using the four visualization techniques in a balanced, crossover experiment. The study was conducted during May 2011 at The Norwegian EPR Research Centre at the Norwegian University of Science and Technology (NTNU).

Participants

A total of 20 medical students (9 women) at the NTNU were recruited through mailing lists, posters and direct contact. Participation was stimulated by a gift coupon that would be given to one of the participants. Their mean age was 25.3 years, and their mean length of studying medicine was 3.4 years (range 1–5 years). The medical faculty at NTNU has an integrated curriculum that involves problem-based learning and student–patient and student–physician sessions from the first year of studies. Thus, all included students were expected to have general knowledge about assessment of laboratory test results.

Visualization techniques

The four visualization techniques that were studied are illustrated in figure 1.

In the table, the names of the laboratory tests together with their respective reference ranges were listed as separate rows in the first column. Subsequent columns listed test results for individual samples in reverse chronological order (ie, most recent samples to the left). The column headers displayed the date and time of sample collection. Values outside the reference range were colored red and labeled either 'H' (high) or 'L' (low). When results from many samples were presented in the same table (the chronic and the complex patient cases), the user had to scroll horizontally to see all results within the boundaries of the display.

The sparklines visualization displayed laboratory data as miniature line graphs in separate miniature reference systems with vertical axes adapted to the range of results, and horizontal axes representing a common time frame. This technique has been referred to as 'word-sized graphics'.[12] Each sparkline included a line representing the results and a shaded field representing the reference range for that particular test. A label above the sparkline stated the name of the test.

The absolute multigraph also visualized laboratory data as line graphs with reference range fields for each line, but unlike sparklines all lines and reference range fields were plotted within the same reference system with the horizontal axis representing time and the vertical axis representing the total range of numerical values in the data. Both axes were linear. This technique had some obvious problems. For instance, a serious drop in hemoglobin levels (reference ranges 13.4–17.0) would hardly be visible when plotted within a reference system with a vertical axis from 0 to 500 (eg, together with platelet counts). This problem could be circumvented through interaction with the visualization by displaying only those tests that were of interest, since the vertical axis synchronously adjusted to fit the values of the selected tests only. This interaction was performed by clicking on the name of the tests in the legend below the visualization, which had color coding to facilitate identification of the tests in the plot. Problems with visualization of multiple tests with different ranges plotted together in a common reference system has been discussed elsewhere.[7]

Finally, we constructed a relative multigraph. Like the absolute multigraph it visualized laboratory data as separate line graphs within a common coordinate system, and it had a similar interactive and color-coded legend. But unlike the absolute multigraph all test values were transformed according to the width of each test's reference ranges, in order to fit a common scale and reference range on the y axis. In addition, the y axis was linear within the reference range and logarithmic outside.

No numerical values were visible in any of the line graph visualizations, and all line graphs were plotted in the opposite chronological order to that of the table (ie, line graphs had

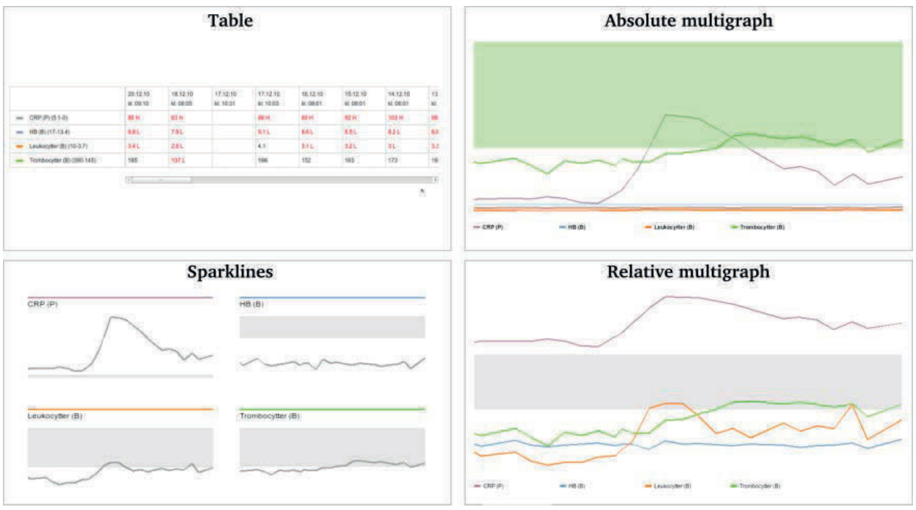

Figure 1 Four visualizations of the same laboratory data (the chronic patient case).

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most recent results to the right). We chose to do this based on our experience with presentation formats of laboratory reports in existing patient record systems.

Patient cases

Each visualization was applied to laboratory data from four patients (table 1). The laboratory data were chosen to reflect different patient categories for which laboratory test results would have to be interpreted. No other information pertaining to the cases were given.

Procedure

Before the experiment each participant was informed about the project and the four visualization techniques. Participants practiced approximately 10 min on how to interact with the visualizations and how to submit their answers using keyboard and mouse. They were told to answer correctly and as fast as they could. The tests were performed with a desktop computer. The software was programmed in php and JavaScript using a MySQL database. Visualizations were shown sequentially in a 950×450 px area on a 1920×1080 px monitor. Participants were told that they would see laboratory data from many patients with varying visualization techniques. They were not told that there were only four different sets of laboratory data each visualized with four different techniques and presented in a predefined mixed order making each participant his or her own control. The presentation order of the visualizations was changed between each participant to avoid ordering effects (relative-sparklines-table-absolute, sparklines-table-absolute-relative, table-absolute-relative-sparklines or absolute-relative-sparklines-table). The order of cases was the same for all participants (chronic-complex-emergency-simple-complex-emergency-simple-chronic-emergency-simple-chronic-complex-simple-chronic-complex-emergency).

After the experiment participants were informed that there were in fact only four different cases, and they were interviewed on their preference among the four visualization techniques for each of the four cases. Each experiment lasted approximately 1 h.

Table 1 Overview of laboratory data that were presented in each patient case

Patient case	No. of results	No. of samples	No. of tests	Tests
Simple	10	3	4	P: alanine aminotransferase, C reactive protein, creatinine, potassium
Emergency	35	3	15	P: alanine aminotransferase, albumin, alkaline phosphatase, amylase, bilirubin, C reactive protein, creatinine, γ-glutamyl transferase, glucose, PT-INR, potassium, sodium
				B: hemoglobin, platelet count, white blood cell count
Chronic	101	26	4	P: C reactive protein
				B: hemoglobin, platelet count, white blood cell count
Complex	233	23	15	P: alanine aminotransferase, C reactive protein, creatinine, γ-glutamyl transferase, glucose, magnesium, potassium, sodium
				B: basophil granulocyte count, hemoglobin, neutrophil granulocyte count, platelet count, white blood cell count
				VB: bicarbonate, carbon dioxide partial pressure

Not all tests were run for each sample.
B, whole blood; P, plasma; PT-INR, prothrombin time/ international normalized ratio; VB, venous whole blood.

Table 2 Questions that the participants had to answer

Category	Question	Answer
Trend	Do you consider the results of 'test X' to have increased/decreased significantly during the period?	Increased Decreased Neither
Overall levels	Overall, do you consider the results of 'test X' to be above/below the reference ranges?	Above Below Neither
Covariation	When you consider all tests for this patient, can you see any covariation between any of the results?	Free text

Outcome measures

For each combination of case and visualization technique the participants had to answer three questions (table 2). Answers were automatically recorded in a database together with the time the participant spent from the question appeared on the screen until a submit button was clicked. For assessments of trends and overall levels, a mean assessment time per test was calculated by dividing the recorded time with the number of tests covered by each question (only 5 of the 15 tests had to be assessed for the emergency and complex cases as opposed to all 4 for the simple and chronic cases).

After all experiments were completed, the free text comments on covariation were coded independently by two of the authors blinded for what visualization that triggered the comment. We only considered covariation comments for the complex patient case (many tests and many samples). Our definition of covariation was synchronous changes of two or more tests (eg, 'C reactive protein (CRP) and leukocytes increase at the same time'). The coders gave each test mentioned in a covariation comment 1 point.

Statistical analysis

Because there were no valid criteria for how the laboratory results should be assessed with respect to trends and overall levels, our focus was on pairwise analyses of agreement (Cohen's κ) and disagreement (McNemar's test) between visualization techniques—that is, intervisualization agreement and disagreement (comparable to inter-rater agreement in reliability studies). That is, to what extent assessments of identical laboratory data were identical or consistently different between visualization techniques.

Assessment times for trends and overall levels were analyzed using mixed model analysis with participant as a random effect and visualization technique, patient case and repeated exposure as fixed effects. Repeated exposure referred to repetition of visualization technique and patient case due to the balanced, crossover design of this study.

Differences in covariation scores between visualization techniques were tested for statistical significance with the non-parametric Friedman test.

Finally, preferred visualization techniques for each patient case were analyzed with the exact multinomial test, presuming a uniform distribution between visualization techniques. Statistical analyses were performed with IBM SPSS Statistics (V.19; SPSS, Chicago, Illinois, USA), R 2.01 software (www.r-project.org) and SAS V.9.3 (SAS Institute Inc., Cary, North Carolina, USA).

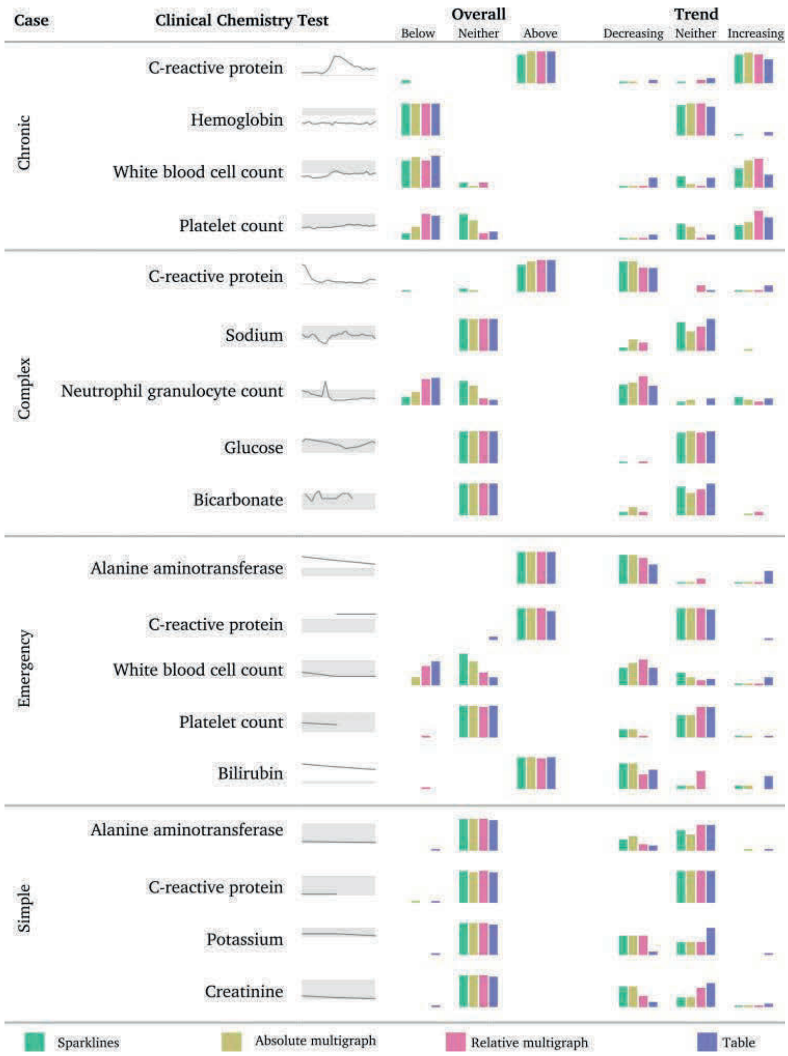

Figure 2 Laboratory test results for the four different patients are displayed as sparklines. Relative distributions of answers to questions about trends and overall levels for these tests are displayed as vertical bars for the four visualization techniques.

Ethics

The Data Protection Official for Research for Norwegian universities (NSD) was consulted before the study and concluded that no further approval was required since only anonymous data were collected.

RESULTS

Assessment of trends and overall levels

In total the 20 participants made 2880 assessments of trends and overall features of laboratory test results (figures 2 and 3). In general, agreement between visualization techniques was higher for overall level assessments than trend assessments. Pairs consisting of the table and any other line graph visualization had statistically significant poorer agreement with respect to assessment of trend compared to pairs of two line graph visualizations (CI not overlapping in figure 3).

Inspection of the data indicated that some participants had wrongfully assessed the time course in the table as going from left to right (figure 2), causing lower agreement between table and the line graphs for the trend assessment (figure 3). For instance, eight participants assessed the bilirubin levels of the emergency case presented with the table as an increasing trend although the values clearly demonstrated a decreasing trend (in reverse chronological order the bilirubin levels were 161, 195, and 231). Similar flaws were observed for other assessments as well (figure 4). However, the trends of some of these tests had increasing and decreasing segments, thus complicating any certain conclusions as to whether the participant misinterpreted the time course or merely assessed the trend differently. Additionally, the trend features of tests presented with the other visualization techniques were sometimes wrongfully assessed as well (figure 4).

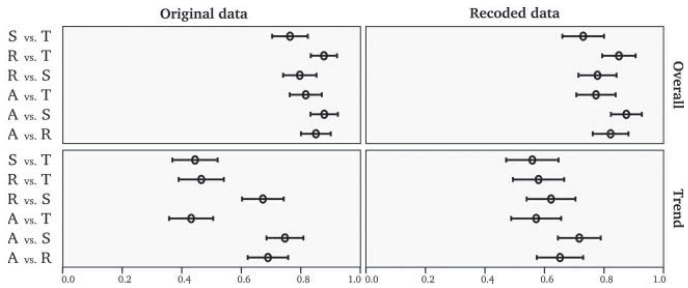

Figure 3 Pairwise Cohen's κ with CI between all six possible pairs of the four visualization techniques (intervisualization agreement) regarding questions about trend and overall levels. Original data (trinomial) and recoded data (binomial) are presented (recoding is further explained in the text). A, absolute multigraph; R, relative multigraph; S, sparklines; T, table.

There was no apparent pattern in the results that allowed us to adjust for this misconception, hence we chose to recode our data from a trinomial assessment (decreasing, increasing and neither) to a binomial (any trend vs no trend). In this way, our data was not affected by participants misinterpreting the time. Correspondingly, we also recoded the overall assessment data from trinomial (above, below and neither) to binomial (within vs beyond reference ranges) (figure 3).

Whenever laboratory results were assessed differently between visualization techniques (disagreement), laboratory data presented with absolute multigraph were consistently more likely to be assessed as a trend (increasing or decreasing) compared to the other techniques (McNemar test: table $p<0.001$; sparklines $p=0.005$; and relative multigraph $p=0.002$). Additionally the absolute multigraph was less likely to be assessed as being beyond reference ranges compared to table ($p<0.001$) and relative multigraph ($p<0.001$). Laboratory results presented with sparklines were consistently less likely to be assessed as beyond reference ranges compared to the other visualization techniques (absolute multigraph $p=0.001$; relative multigraph $p<0.001$; table $p<0.001$). There were no statistically significant differences between relative multigraph and table with respect to assessments of overall levels ($p=0.248$) and trend ($p=0.106$), nor was there any significant differences in trend assessments between relative multigraph and sparklines ($p=0.716$), or between sparklines and table ($p=0.043$, Bonferroni correction requires $p<0.008$).

Assessment times

Assessment times differed between visualization techniques as well as between patient cases, questions and repeated exposure. The shortest assessment times were achieved with sparklines and relative multigraphs presenting the laboratory results for the emergency and simple cases as the third or fourth exposure (figure 4). The experiment was not designed to identify differences between question types as overall levels were always assessed right before trends—favoring trend assessments.

By mixed model analysis we found significant interaction between visualization technique, patient case and repeated exposure ($p<0.001$), indicating that the visualization techniques had different effects on assessment time based on which case they presented, and the degree of repeated exposure to that case and visualization technique (ie, a differentiated learning effect). The association between assessment time and visualization technique was statistically significant for the chronic ($p<0.001$) and complex ($p<0.009$) cases, but not for the simple ($0.082<p<0.713$) and emergency ($0.145<p<0.742$) cases. This effect was consistent through all repeated exposures.

Due to small sample sizes when broken down into all possible combinations of visualization technique, patient case and repeated exposure—and because analyzing each exposure and case combination separately would break the within-subjects, repeated measures design—we did not do any further post-hoc statistical analyses. However, visual inspection of the data demonstrates that the most evident differences in assessment times are between the table and the three other visualization techniques for the chronic and the complex patient cases (figure 4). The figure also indicates that variation in assessment times decreased through repeated exposures. Sparklines and relative multigraph performed quite well through all repetitions, the table performed poorly, and the absolute multigraph somewhere in between.

Assessment of covariation

The agreement between the two investigators performing the coding of free text covariation comments was good (Cohen's κ 0.91) indicating valid interpretation of free text comments about covariations. The relative multigraphs generated the highest covariation score (table 3). The differences in covariation scores were statistically significant (Friedman test, $\chi^2(3)=10.853$, $p=0.013$). Post-hoc analyses with Wilcoxon

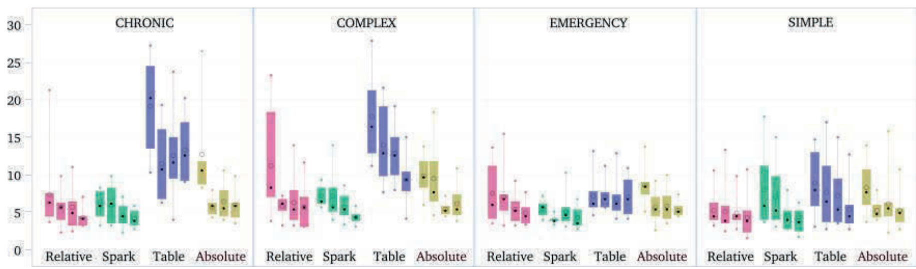

Figure 4 Boxplots of assessment times per patient case, visualization technique and repetition (increasing repetition from left to right among adjacent boxplots with identical color). Bars: 1st to 3rd quartile. Whiskers: minimum to maximum. Circle: mean. Dot: median.

Table 3 Number of tests commented as covarying with each other

Output	Covariation score
Table	18
Absolute multigraph	31
Sparklines	38
Relative multigraph	47

signed-rank tests for all six possible pairs of visualization techniques demonstrated statistically significant differences only between table and relative multigraph ($p=0.003$) and table and sparklines ($p=0.013$).

User preferences

The table was preferred by most participants for the simple patient case and was also one of the most preferred techniques for visualizing the emergency patient case. Because values outside the reference interval were written in red letters, they were easy to spot. Many participants felt that graphical visualization models in general lost their usefulness with low number of samples.

The relative multigraph was the most preferred technique for visualizing the chronic patient case. Participants explained that the relative multigraph provided the best overview when few tests were to be presented, and that the common timeline facilitated perception of covariations. Many participants also preferred the relative multigraph for the simple patient because they could immediately see that all test results were within reference ranges when no lines went beyond the fixed reference area. With more tests, many participants felt that the relative multigraph became too clogged up with lines and therefore preferred sparklines. Sparklines were characterized as easy to understand and as giving a good overview of laboratory results irrespective of patient case. No participants preferred the absolute multigraph for any patient case.

Multinomial exact tests found statistically significant deviations from uniform distribution of preference for each patient case (table 4).

Although participants assessed only four different sets of laboratory results, it was very difficult for them to know this for certain. A majority of the participants said that they suspected that some of the 16 visualizations presented the same laboratory results, but they did not believe that this affected their assessments.

DISCUSSION

This study demonstrates that there are differences between visualization techniques with respect to how laboratory results are assessed and how fast the assessments are made. Additionally, the characteristics of the laboratory data presented with these techniques affected user preference and assessment times. To our knowledge, this is the first time different patient categories have been included in an evaluation of visualization techniques for presentation of clinical laboratory results, and the first time several line graph techniques have been compared with each other.

For small sets of laboratory data, a table seems to be sufficient and preferable—especially for few samples as with a new emergency patient. However, whenever repeated tests (many samples) have to be assessed—for example, monitoring glucose or creatinine levels in chronically ill patients—line graph visualizations are assessed approximately twice as fast and are more preferred than a table. We observed only moderate variation in assessment times between different line graph techniques, but the relative multigraph and sparklines provided faster assessments than the absolute multigraph.

In general, agreement between visualization techniques was good for assessments of trend or overall levels. However, whenever assessments disagreed, the techniques demonstrated different propensity for how they were assessed. Laboratory results presented with the absolute multigraph were more often interpreted as decreasing or increasing trends, and results presented with sparklines were less often interpreted as beyond reference ranges. These differences are not surprising. The absolute multigraph was not suitable for presenting several tests simultaneously on a common value axis. However, through interaction it was possible to visualize tests one by one. In that way, each test was presented using maximal screen estate. Thus, even small increasing or decreasing trends would be more noticeable compared to the other techniques. With the table, red color on laboratory results that were beyond reference ranges gave an immediate impression of overall levels. Even though results would be barely outside of reference range, the red color was striking to the eye. This contrasts the line graph techniques, especially sparklines, which provided the lowest resolution per visualized test among the line graph techniques. A small deviation from the reference range would not be easily spotted with sparklines since the line graph would be located on the edge corresponding to the reference range. No similarly consistent features were related to overall levels and trend assessments made with the relative multigraph, but it was the technique with which the participants most frequently indicated covarying results. An explanation for this could be that the relative multigraph presented the results with relation to a common timeline and a common reference range.

It seems very likely that some participants misinterpreted the time course of the table and assessed decreasing trends as increasing and vice versa. Such misinterpretations can obviously affect how patients are managed and should therefore be given much attention. However, in a clinical setting the laboratory results have to be combined with other clinical information and any pretest expectations, clinicians are able to actively choose the visualization technique they want based on what question they need to answer, and finally clinicians are probably more accustomed to the systems they are using. Thus, we think that this kind of error is less likely to occur in a clinical setting, yet this is a subject for further study.

One of the strengths with this study was that we included clinical chemistry test results from patients that represented different clinical problems, rather than presenting test results from similar patients. Additionally, we used a multimethod evaluation, including quantitative and qualitative approaches. However, this study also has limitations in that we did not ask any questions related to single numeric values, nor did we require the participants to combine laboratory data with clinical information in order to make more complex medical decisions on diagnosis, prognosis or therapy. Thus, the results should not be uncritically generalized to clinical settings. The

Table 4 Participants' preferred visualization technique for each case

Patient case	n	Table	Relative multigraph	Sparklines	Absolute multigraph	p Value
Simple patient	20	10	7	3	0	0.004
Emergency patient	20	9	2	9	0	0.001
Chronic patient	20	1	14	5	0	<0.001
Complex patient	20	2	2	16	0	<0.001

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use of medical students as participants could also be regarded a limitation. However, the assessment they had to do did not require deep medical knowledge.

Bauer *et al* performed a similar experiment with a table and a sparkline visualization technique.[7] Their main results correspond with our results, namely that humans assess line graphs faster than tables and that interpretation of laboratory results may vary between visualization techniques. As we did, they also found that values slightly beyond reference ranges were more often identified with a table compared to sparklines. Similar experiments with graphical representations of numerical data from monitoring anesthetized patients have found that graphical displays can improve presentation of medical information.[13–15]

Bauer did not find any significant effect of repeated exposure to the cases, while in our results the learning effects of repeated exposure were statistically significant. This difference could be caused by the variations in experimental design between the studies. In the experiment by Bauer *et al*, 12 physicians interpreted 11–13 tests pertaining to each of 4 rather similar cases (ie, pediatric intensive care unit patients with identical test sets) visualized with 2 techniques (ie, 2 exposures) and submitting their answers through talk aloud technique. In our experiment 20 medical students interpreted 4–5 tests pertaining to each of 4 different cases visualized with four techniques (ie, 4 exposures) and submitting their answers in a computerized form. Our data does not provide any further insight into why our participants made faster assessments towards the end of the experiment. Possible explanations could be recognition of cases, familiarity with visualization techniques or merely improved mastering of the experimental situation.

As our results demonstrated, the characteristics of the data that were visualized had significant effects on how it was assessed. This makes it difficult to compare the results from different studies even though the visualization techniques are identical. Perhaps standards should be developed (standard laboratory data, standard patient cases) for how visualization techniques for laboratory—and even clinical—data should be experimentally evaluated to ensure sufficient methodological rigor?

Our results are not clear on what is the optimal visualization technique for laboratory data, rather they demonstrate advantages and disadvantages with different techniques. Before making more specific recommendations we would like to encourage studies with more complex questions and gold standards for comparison. Nevertheless, as Bauer *et al* and Tufte have shown, sparklines are easy to integrate in composite visualizations of tables and line graphs.[7 12] Additionally they consume little screen estate. On the other hand, a relative multigraph can more easily be integrated with a timeline oriented patient record, facilitating covariation analysis of laboratory data with other clinical information.[16] More research on such integrated views of laboratory data and non-laboratory clinical data should be performed in order to optimize clinical data presentation techniques.

This is the first time the relative multigraph is included as a visualization technique in an experiment with authentic laboratory data, and we are not aware of any clinical information system that presents laboratory results as a relative multigraph. A similar technique we have found described in literature is the unit-independent technique.[10] This technique has SD units on the value axis and a logarithmic time axis. A logarithmic time scale provides a long-term overview together with a more detailed presentation of recent results, but comparing time intervals may be more difficult than with linear time scales. Moreover, some problems are common to both of these techniques. One problem is presenting many tests together which may result in a clutter of lines that can be hard to separate from each other. Another problem is understanding the absolute values of a test by looking at the position on the y axis. These issues call for more research.

CONCLUSIONS

This study demonstrated that different techniques for visualizing and presenting numeric laboratory results influenced on how the results were assessed. For simple and acute patient problems with short time spans and few blood samples, a table seemed to suffice, but for more complex patient problems with long-term monitoring a relative multigraph or sparklines seemed favorable. More development has to be undertaken to improve these techniques and integrate them with other clinical non-laboratory information.

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List of errata

After submission of the thesis (December 2013), the following typographical and language errors have been identified and corrected before final printing (April 2014) (errors are demonstrated in parentheses):

p.05 - practising (practicing)
p.12 - favourable (favorable)
p.23 - referred (refered)
p.23 - user-centred (user-centered)
p.35 - benefited (benefitted)
p.37 - characterise (characterize)
p.39 - professional (professioinal)
p.39 - intuitionist-pluralist (intutionist-pluralist)
p.41 - task (tasks)
p.41 - much (quite much)
p.43 - objectivist (objectivst)
p.43 - objetive-centred (objective-centered)
p.44 - problem-centred (problem-centered)
p.46 - decreasing (deacreasing)
p.47 - quantitative (quanititative)
p.47 - fulfil (fulfill)
p.47 - homogeneous (homogenous)
p.47 - orthopaedic (orthopedic)
p.47 - practised (practiced)
p.47 - heterogeneous (heterogenous)
p.48 - personnel (personell)
p.48 - homogeneous (homogenous)
p.48 - preceding (preceeding)
p.50 - similarly (similary)
p.53 - Table reference error repaired
p.55 - reproducibility (reproducability)
p.55 - validity (valdity)
p.59 - digital (digitial)
p.59 - management (managment)
p.60 - use of 'anyhow' inappropriate, too informal, therefore removed ‘anyhow’
p.64 - staff members (staff members')
p.64 - description (descripton)
p.64 - set forth (sat forth)
p.64 - patients' (patient's)
p.64 - loosely (loosly)
p.64 - heterogeneous (heterogenous)
p.65 - homogeneous (homogenous)
p.65 - physicians (physcians)
p.66 - were presented with (were presented for)
p.67 - needs that were (needs that was)
p.68 - the respect that (that respect that)
p.68 - chest X-ray (chest-X-ray)
p.69 - bias by not (bias not)
p.69 - alert (omen)
p.71 - benefited (benefitted)
p.72 - empirical (empicirical)
p.72 - Much (Quite much)
p.72 - has been (have been)
p.73 - inaccessible (unaccesible)
p.73 - nevertheless (anyhow)
p.76 - perception of patients' medical (perception of patient's medical)
p.79 - referred (refered)
p.81 - diagnosis of the patient (diagnose of the patient)