TELEMEDICINE IN PRACTICE

From operating theatre to operating studio – visualising surgery in the age of telemedicine

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Summary
The introduction of communication technology into operating theatres involves significant changes and challenges. We have conducted a telemedicine project between two of Norway's largest hospitals (Rikshospitalet and Ullevaal hospital) with a focus on image-guided surgical and radiological procedures. Video was broadcast using a 34 Mbit/s ATM network. This resulted in changes in the local work practice to accommodate and facilitate the communication. It also required changes in the surgeon's work situation with regard to teaching in order to improve communication with remote viewers. These changes were non-trivial, and we see them as signs of a shift towards a more public kind of surgery and interventional radiology brought about by the technology.

Introduction

Once an operating theatre was literally a theatre, where dissections and operations were performed for the audience who were seated in the room around the table. This public aspect of surgery has for a long time (and for good reasons) been downplayed and limited to the teaching hospitals or to defined training programmes. However, visualisation of the surgical performance may be re-emerging as telemedicine is introduced into surgery. In this case the audience's presence is virtual, being mediated by the technology. This increases the flexibility immensely, because the audience may be distributed in space (remotely located) or in time (e.g. by broadcasting stored material from a database). The effect is that the operating theatre once more becomes a real "theatre", or perhaps "operating studio" would be an appropriate term.

This paper reviews our experience with telemedicine in image-guided therapy. The paper's main focus is on the local context of the operating theatre and on the challenges and disturbances that occur there. However, telemedicine is a network technology (as opposed to a single, isolated system) and as such it also introduces other issues and problems beyond the local context.

Methods

A telemedicine project was established with five participants: the two largest hospitals in Norway (Rikshospitalet and Ullevaal Hospital), industry (Telia, Ericsson) and research (University of Oslo). It was an experimental project to assess the suitability of broadband technology for image-guided surgery and interventional radiology. The first subproject, which focused on distant learning, was carried out from September 1998 to June 1999[1]. In the project we used a 34 Mbit/s ATM network, and 37 transmissions of different types (operations, meetings and lectures) were produced, the duration ranging from one to eight hours. Several operating theatres, as well as lecture halls and meeting rooms were networked and utilised in the transmissions.

Evaluation and assessment were based on recording the activities (i.e. the transmissions), interviews with the surgeons, anaesthetists, nurses and technicians. Data collection and analysis methods from the field of interpretative information systems research were used (mainly participant observation and ethnographic analysis)[2,3]. For further description of the methodological issues, see reference[4].

The specific demands of the medical context

Image-guided surgery, due to its reliance on images, puts large demands on the image quality of transmitted video. Important information may be related to subtle textures and colour variations, as well as delicate structures such as nerves and small vessels. Compared to ordinary surgery, this visual information is the only source of visual feedback from the operation field. Introduction of digital video often entails information reduction and consequently potential quality reduction as compared to the original video. A crucial point in the project was thus the determination of adequate image quality for teaching and consultation purposes within image-guided surgery. This focus on image quality led to the choice of a broadband network, 34 Mbits/s ATM (Asynchronous Transmission Mode). MPEG2 compression with 6-8 Mbit/s was found to be satisfactory in regard to the image quality assessed by an expert panel of surgeons. Other strategies to maximise the transmitted image quality were to minimise movements of the camera, accomplished by using a robotic arm (AESOP, Computer Motion, CA, USA), and to use close-up images when particular details were in focus.

Apart from the bandwidth, the Quality of Service (QoS) of the transmission medium is also important (e.g. delay, delay variations, stability and security). The ATM network was found to have sufficient QoS. In general, surgery work has low tolerance for disturbances, and adverse effects on the primary object of work (i.e. the surgical procedure) and on patient safety are not acceptable. The traditional organisation of surgical work also restricts the placement of equipment inside the operating theatre. Factors to consider are sterility, hygiene and regulations relating to electrical equipment in operating theatres (e.g. the IEC 601.1, and the relevant European Union directives, like EU 43/92).

Communication technology in the operating theatre

The following description of the technical solutions relates to the Interventional Centre[5] at Rikshospitalet; the other operating theatres were similarly, but not identically equipped. Two remote controlled overview cameras were present, one in the ceiling above the operating table, the other on the wall (Fig 1). The analogue image signals were transmitted on coaxial cables to an external control room (Fig 2), where the image mixing and digitising were performed. The interventional suite was equipped for combined radiological and surgical procedures, and also the image from the X-ray equipment was available at the control room permanently by analogue transmission of the monitor signals. The other image sources (video images from the laparoscope, gastroscope or ultrasound scanner) had to be connected to a wall-mounted panel for each instance of use. Two microphones were installed in the ceiling above the table, as well as a loudspeaker, and the audio signals were transmitted on XLR audio cables[6].[XLR is a plug type for audio signals that offers balanced transmission of the signal] For better quality images, we used the YC-video (also called S-video) outlet on the imaging equipment instead of the composite video format. In order to transmit YC-video on coaxial cables, special adapter cables (splitters and mergers) were made for separate transmission of the chrominance and luminance components. In the control room, the audio and video signals were digitised before transmission on the ATM (or other) networks.

The technology introduced some disturbances into the operating theatre. In some instances unplanned noise was transmitted to the loudspeaker, cables were lying on the floor (from the imaging equipment to the wall panel), and the microphone position might have to be adjusted in the middle of a procedure. Such disturbances, of course, should be avoided or minimised. A continuous problem was the sound quality, which was related to the microphones in the operating theatre. Adjustment of position to ensure satisfactory sound quality was needed in the beginning of each transmission. A clip-on or head mounted microphone gave better sound quality, but the wire was a problem if the surgeon moved around. Wireless microphones may be preferable, but were not used in this project. If they are to be used they will have to be specially designed for operating theatres (for example, to be robust against electromagnetic interference as from diathermy equipment, and to comply with the appropriate regulations). When it comes to a loudspeaker, it is probably preferable to use a loudspeaker (as in our setup) instead of earphones worn by the surgeon only. This allows the whole surgical team to be aware of the dialogue. An audio mixer in the control room provided the necessary possibility to adjust sound to and from different sources individually. This for example allowed the technicians in the control room to deliver short messages to the surgeon without this being transmitted onto the network. Using the technology necessitated a considerable amount of “backstage” support work (see below).

Introducing the cameras and microphones into the operating room created concerns about surveillance. Anybody present in the external room could watch and listen to the activities in the operating theatre, and this was not acceptable to the team in the operating room. A red warning light and a control key were therefore installed in the operating theatre. The video transmission lines had to be activated (through turning this key) by somebody in the operating theatre, and could not be turned on from the external control room. When active, the red lamp was lit (see Fig 1).

Challenges related to the technology-mediated nature of communication

The technology that was introduced “between” the surgeon and the audience necessitated that all relevant information was available as electronic signals. This may be seen as a “narrower” communication channel, and one of the challenges was to provide rich enough information for specific purposes. The available image and sound sources were usually sufficient and the following limitations were discovered.

In some procedures the surgeons also used analogue (film-based) X-ray images, and no permanent solution was available for transmissions of these. An *ad hoc* solution was to film them hanging on the light board with an additional mobile video camera.

Furthermore, when recording the work by the nurses, an additional camera also had to be used, as the nurses' work was more distributed across the room than the surgeon's work.

Some procedures involve frequent and dynamic shifting between several image sources. For example an ERCP (endoscopic retrograde choleangiopancreatiography) sometimes combined gastroscopy with X-ray fluoroscopy and in some cases also a laparoscopy image. When students are present in the room, they can detect the surgeon's changing focus on the different image sources from small bodily or verbal cues (e.g. direction of gaze). Those viewing at the other site could only see one image source from the operating room, and the technical/production personnel (who had access to all of the images in the control room) did not know the procedures in detail or did not follow the interaction closely. Consequently, on several occasions the viewers did not get all the relevant information. Either the surgeon had to mention explicitly which image he was looking at, or the technicians had to follow the procedure more closely than usual and detect where the activity seemed to be happening. In some instances the viewers would ask for some particular image. During one particular session a students' facilitator was present in the operating room, assisting the surgeon and taking care of some of the verbal explanations. When problems were discovered he started to comment on the surgeon's use of images more explicitly, which assisted the technical personnel's switching task. The presence of an additional person in the role of a "medical producer" allowed the surgeon to concentrate on the patient and the technical personnel to switch images following explicit commands instead of having to guess. It is possible in future that the image switching will automatically follow the surgeon's gaze, or perhaps the viewers will have access to all image sources simultaneously.

The narrower communication channel also introduced new demands on the surgeon's handling of the teaching session, and required conscious attention to how the information came across. For example, in order to show instrument positioning, the surgeon had to ask for a camera overview of the operation field, instead of the students seeing it for themselves if present in the room. The surgeon had to remember to relate to the microphone and to use the correct voice level. In order to simulate eye contact with the audience, the surgeon had to look at the currently active camera, which required conscious effort, as the natural impulse is to look at the image of the viewers when talking to them. In order for the surgeon to do this with ease, he or she needed a certain amount of feedback about what the viewers could see, for example information on which image was transmitted from the operating theatre and which one of the overview cameras was active.

The virtual presence of the viewers also necessitated new ways to provide reciprocity or mutual visibility. In the early phases of the project the viewers tended to come and go according to their duties at the hospitals, and the team in the operating theatre would not know which individuals were present at any given time. To obtain better control over the communication, the team was then provided with an image from the viewers' site, using an extra monitor inside the operating theatre. This image could also have been included on the laparoscopy monitor in a picture-in-picture mode. Although this would produce a smaller image, the surgeon would then avoid changing view direction in order to see the viewers.

The specific need for reciprocity and feedback was seen to differ with respect to at least two different “genres” of transmissions. In largely one-way demonstrations to large audiences (e.g. symposiums or conferences) the need to see the actual viewers was not acute. It was more important to be able to control the self-presentation, e.g. by looking at the currently active camera, or knowing which image the viewers saw. In other words feedback was more valued than reciprocity (or mutual visibility). Then the outgoing image (the one that was transmitted to the other side) was displayed on the extra monitor in the operating theatre instead of the image of the viewers. In small-scale interactive settings, the “performance” aspect was not that strong, but an image of the actual viewers (mutual visibility) facilitated dynamic interaction.

Challenges related to the increased distance to viewers and reduced local control
The increased distance to the viewers contributed to a change of the procedure towards a “performance”. This increased the pressure on the surgeon, as the session became more of a happening than it would be with viewers present locally. This was mainly felt to increase alertness with improved performance, but it is possible that it may work otherwise as well. The rest of the team in the operation room also became influenced by the tenser atmosphere, the additional workload and stress to ensure optimum transmission.

The increased distance to the viewers entailed that managing the patient’s “role” in this “performing situation” became more important. This was related to preserving anonymity as removing patient data on images and by not focusing on facial features. Routines in controlling the video camera were implemented to secure patient privacy. In most cases, the surgeon informed the patient in the pre-operative talk about the production and verified the patient's consent.

The ownership of the production and the right to use the recorded material afterwards was an issue addressed in the project. It would be possible for the viewers to videotape the material, and use it for purposes not intended. We investigated the possibility of identifying the original source of production by labelling (overlaying) the analogue video with the hospital’s logo. This was not carried out in practice because it reduced the image quality somewhat. “Watermarking” of the digital video (the MPEG stream) would be another possibility.

Increased distance entails an increased challenge in coordination. This is related to telemedicine being a network technology more than a single, self-standing system. The different participants have their own work duties and pre-fixed schedules to relate to. The improvisation and juggling of these demands may be tackled relatively easily in a local context or between two parties, but is increasingly difficult when the persons involved are distributed in several institutions. This may eventually require common/shared systems for scheduling of transmission, reservation of resources (rooms, equipment, support personnel) at all sites.

Overcoming distance in space is only one of the potential benefits of telemedicine. The possibility of providing information and communication across distance in time is at least as revolutionary. Video productions of surgical procedures can be made and stored in digital databases. This will increase the possible access enormously, compared to real-time transmission of surgical procedures. Such a production of videos will also require an "operating studio", where images can be obtained from the diverse image sources. In addition video editing hardware and software is necessary, as well as personnel with adequate skills. A production organisation (internal or external) is necessary, since it is a time-consuming task to ensure that the presentation is of high quality (clinical, pedagogical and technical). The same organisation would be responsible for the database, access, quality assurance, editorial responsibility and updates. In principle, the database could be made for multiple use (e.g. by novice surgeons, expert surgeons, operating theatre nurses or patients) and this requires flexibility in the structuring of the material.

Challenges to the local organisation of work

The most striking effect of introducing the technology was the need for a new personnel group to provide technical support. Their tasks included planning and preparation of transmissions, as well as work during and after transmissions. Several of the work tasks were very similar to television production work, and we may learn from how the production work is organised there[7].

Locally, there also arose a need to create shared awareness in the team or department about planned transmissions, for general information of when a transmission takes place, and to whom. This information was given at the weekly meetings of the whole department, and on the weekly work schedule listing all the planned operations. Routines for preparation of a transmission were established, as well as routines for how to treat and protect the patient.

Discussion

The introduction of telemedicine turns operating theatres into operating studios where visualising the performance is a new object of the procedure. Thus, metaphors from the theatre as "front stage" and "back stage" can be adopted to analyse the findings and experiences. The front stage is the surgical procedure itself and here the intent is to make it visible and easily accessible for the viewers (the audience). To optimise the content and its display, much backstage work is required. The need to pre-plan and rehearse transmissions is a further indicator of this performance aspect.

The important thing to realise here is that both parts of the work are equally necessary to produce a high quality performance. Often in telemedicine the focus is only on the front stage work, and the equally important backstage work is neglected. It is also important to realise that this backstage production work is not only done by the technical personnel and the operating theatre nurses. The surgeons also have to do some of the production work, for example through being more verbally explicit, relating to the active camera, and constantly thinking about what the viewers see. Therefore, designers of telemedicine systems should provide a means for facilitating easy production of a high quality performance by providing the surgeon and the operating team as a whole the required feedback to be able to manage how they present themselves and the procedure. The necessary mutual visibility between the interacting parties facilitates easy communication, and should also be provided. Also technology support for the technical personnel should be included, for example through provision of adequate image and sound mixers that allow them to control each image or sound input and output individually. Also a separate audio network for the support personnel may be helpful, as it allows them to communicate and coordinate without interfering with the "front stage" activities. There is also a need for a concurrent design or redesign or the organisation into where this technology is implemented as well. Some changes to the organisations of work and the routines will be necessary.

To conclude, we have indicated some of the issues and potential problems that may arise when telemedicine is introduced into operating theatres, and we have described some solutions or strategies to meet them. The changes and challenges when operating theatres are turned into operating studios are not trivial and will influence practical, clinical and organisational issues.

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References

1. Hanseth O (ed.), Buanes T, Eide K, Hustad R, Johansen M, Røtnes JS *et al.* DIMedS – Development of Interactive Medical Services: Distant Learning in Surgery and Radiology using Broadband Networks. Final report, Pilot Regular Teaching, Telia, 1999
2. Galliers R. Choosing information systems research approaches. In: Galliers R, (ed.) *Information Systems Research: Issues, methods and practical guidelines.* Oxford, Blackwell Scientific,1992:144-162
3. Walsham, G. The Emergence of Interpretivism in Information Systems Research. *Information Systems Research* 1995;**6**:376-394
4. Aanestad, M. Work Practice and Technology: Investigating the Dynamics of Technical Agency. *Proceedings of the 23rd Information Systems Research Seminar in Scandinavia* (IRIS23). University of Trollhättan/Uddevalla, Sweden, August 12-15, 2000. (ISSN 0359-8470) Available at: http://iris23.htu.se/proceedings/PDF/74final.PDF

5. Fosse E; Lærum F, Røtnes JS. The Interventional Centre - 31 months experience with a department merging surgical and image-guided intervention. *Minimally Invasive Therapy and Allied Technologies* 1999;**8**:361-369
6. Røtnes JS, Aanestad M, Buanes T. "Organizing multimedia technology for real-time transmission of image guided surgery". Presented at High Care 2000 (Second International Congress, February 25th to 27th, 2000, Ruhr University, Bochum, Germany. Abstract: "How to organize telemedicine equipment", available at http://www.highcare.de/abstracts/HTM0046.htm
7. Johansen M, Hanseth O, Buanes T, Røtnes JS. Supporting Computer Supported Cooperative Work: a case from telemedicine. In Käkölä, Timo (ed.): *Proceedings of the 22nd Information Systems Research Seminar in Scandinavia (IRIS22): Enterprise Architectures for Virtual Organisations* (ISBN 951-39-0512-8). Keuruu, Finland, 1999;163-176

Figure legends

Fig 1 **–** An operating theatre with two remote-controlled overview cameras. One camera is mounted in the ceiling above the operation table covered by a black glass dome. The other camera was mounted on one of the walls together with a red warning light indicating active sound and video transmission.

Fig 2 **–** A control room that was equipped to record all activity in the operating suites for the production of videos or transmission of “live” procedures. Analogous video signals (Y/C or composite) from the operating suites that are together with other received image sources displayed on 16 small monitors. The video of interest with corresponding sound is patched to lecture rooms.