Medical Image Quality as a Socio-technical Phenomenon

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Summary

Objectives: The study aims to interpret image quality in laparoscopic surgery not only as a technical parameter but also as the result of the situation of use.

Methods: Observational studies of laparoscopy in use, semi-structured and informal interviews with laparoscopists.

Results: When medical images are digitized to exploit novel technical possibilities, image quality becomes a paramount issue. Image quality is often discussed exclusively in technical terms, but the socio-technical study of image quality in surgical telemedicine presented in this paper showed that it is definitely more than a purely technical parameter.

Conclusions: While the resulting quality of the image was significantly shaped by the persons involved, the concept of “quality” itself was also relative and changing with the situation of use. A given technology does not determine image quality. Rather than focusing only on the technical quality, the attention of designers and decision makers should also be directed to the socio-technical network surrounding the image and its use.

Keywords
Laparoscopy, surgery, telemedicine, image quality, video quality


1. Digital Medical Images: Quest for Quality

The introduction of digital technologies in medical imaging has created new possibilities, among other things for digital transmissions of images across telemedicine networks. However, for practical and economic reasons, digitizing images usually means compression (i.e. reduction of the number of bits used to represent the image), which may affect the image quality. This is more pronounced for transmission of live video than for single (still) images, and the resulting image quality is highly related to the available bandwidth of the telemedicine link. Objective or quantitative quality measures to help define the level of ‘acceptable’ and ‘safe’ quality have been sought, but due to the limited correlation between objective measures and perceived quality [1-3], purely objective measures have proved difficult to establish. For all practical purposes, most image quality assessment methods in general are subjective [4, 5]. In medicine, at least within the diagnostic imaging disciplines (e.g. in radiology and pathology), quasi-objective methods, e.g. statistical analyses of large samples of individual evaluations or interpretations, are preferred [6-9].

In this paper we describe laparoscopic surgery (minimal-invasive or “keyhole” surgery in the abdomen), which relies on the video image as the only source for visual information. Consequently, sufficient image quality has been a paramount issue when discussing surgical telemedicine. The use of the video image in laparoscopy is more multifaceted and diverse than image use in the diagnostic disciplines, and doesn’t lend itself to rigorous testing in the same way. Thus, the image quality debates within laparoscopy are usually framed as discussions around acceptable bandwidth levels as a rough measure of quality. The commercially available six-channel ISDN videoconferencing solutions offer a transmission rate of 384 kbit/s and are most widely used in actual surgical telemedicine. However, video transmitted on these systems shows visible degradation of image quality (block effects, jerky motion and irregular updating of frames). Proponents of broadband technology often consider this video quality inadequate, and suggest a transmission rate of 1.25 Mbit/s [10] or “at least 6 Mbit/s” [11]. At the other extreme, a study (discussed in more detail below) conducted in Ecuador concluded that videoconferencing from mobile equipment at a transmission rate of 12 kbit/s may be used “… in the proper technical and clinical algorithms” [12]. By performing a socio-technical analysis of image use in surgical telemedicine, the aim of this paper is to look into possible explanations for how such different judgment may come about and to improve our understanding of this issue.

2. Studying Image Quality as a Socio-technical Phenomenon

We here attempt to demonstrate the validity and appropriateness of a socio-technical approach, which emphasizes the need to look at the interweaving of technical and non-technical factors [13]. The study belongs to an interpretivist tradition in information systems research [14-15] and has
thus mainly employed qualitative methods. The findings are based on the first author’s observations of laparoscopic surgical procedures, where some have been performed locally and other have been telemedically transmitted. This is combined with information from the second and third author, who are senior laparoscopic surgeons having substantial experience with telemedicine. Another data source is semi-structured interviews with two senior surgeons and one junior surgeon, as well as informal interviews and discussions with two operation nurses. The persons interviewed worked at two departments that both had experiences with surgical telemedicine. At the Interventional Center (IVC), at Rikshospitalet in Oslo, Norway, experience has been gained in broadcasting teaching sessions of laparoscopic surgery on a broadband network. The National Center for Advanced Laparoscopic Surgery (NCALS) at St. Olav Hospital has since 1996 offered training programs in laparoscopic surgery. The trained surgeons are offered telemedical follow-up and consultation across ISDN networks when they have returned to their own hospitals.

3. The Role of the Laparoscopic Video Image

The first section (“Achieving and Using a Laparoscopic Image”) describes image acquisition and use in general with a focus on factors that influence image quality. This section is based on a synthesis of observations, written and oral information. The second section focuses on surgical telemedicine, of which there are two main use areas:

- Demonstration and teaching of new techniques to remotely located students/surgeons.
- Assistance, advice or consultation during surgery (telementoring), where the expert surgeon is remotely located and is contacted to provide immediate advice and guidance to the surgeon performing the actual operation. (The section mainly discusses this second scenario).

3.1 Achieving and Using a Laparoscopic Image

Prior to the laparoscopic procedure the operation nurses prepare both the patient and the equipment. They check that the flexible light cable for the laparoscope doesn’t have broken fibers and they calibrate the black and white balance of the video camera. The nurses connect the screens and check the quality of the displayed image. When the actual operation starts, the laparoscope is entered through a trocar (port) in the first incision made by the surgeon. Before additional incisions are made, a gas hose (with CO₂ gas) is connected in order to expand the abdomen to facilitate the surgeon’s view and actions. When the instruments have been entered, the operation lamps above the table are switched off and the general lighting in the operation room is turned down. The window’s blinds are drawn and the monitor screens are positioned to prevent reflections.

After the instruments are entered, an assistant surgeon usually handles the camera. Thus the operating surgeon’s visual feedback is uncoupled from the actions performed: it does not follow the surgeon’s head movements, and he or she also has to look upwards at a monitor rather than at the hands. This uncoupling of action and vision may be difficult to handle and requires substantial training. Sub-optimal camera operation by the assisting surgeon may aggravate the difficulties, and the competence level of the assistant is thus an important factor for the surgeon’s perceived image quality. Adequate handling of the camera requires both technical skills and an ability to communicate well with the surgeon, and experience of working together may contribute to good cooperation.

During the surgical procedure the video image is used for navigation, for identification of organs or smaller structures (e.g. vessels and lumens), and for identification of pathological conditions. This implies a very dynamic use of the image information, and the verbal interaction between the operating and the assisting surgeon is characterized by frequent instructions to move the laparoscope closer towards the object or further away to give an overview, to change the rotation of the image, or to move to another trocar in order to give a view from a different angle.

The surgeon has to dissect through layers of tissue, identify anatomical structures and avoid cutting vessels inadvertently. To achieve this, the surgeon pushes the tissue with the surgical tools and watches how the different layers or planes of tissue move relative to each other. These actions introduce significant amounts of motion (of tissue and instruments) in the image, and thus the surgical actions themselves affect the resulting image quality.

If the laparoscope is removed from the body (e.g. to change trocar) it may cool down, so that on reinsertion the humidity inside the body cavity may condense and create fog on the lens. Injection of cold CO₂ gas also contributes to this problem, and heating the gas or minimizing any gas leakage through the trocars may help. To clear the fog, the assisting surgeon often removes the laparoscope and wipes off the fog on the lens with a sterile cloth or a finger. A common method to avoid unnecessary removal of the laparoscope is to wipe the fog off the lens by touching an organ surface with the tip.

Cauterizing or dissection by heat produce vapor that may appear as fog on the lens of the optics, or smoke from diathermy may fill the internal cavity and impair vision. The patient is immobilized and anaesthetized during surgery, but the patient’s body still interacts with the image: pulsation, respiration, and the peristaltic movements of the intestines introduce motion in the video images. The organs have different luminosity, the spleen and liver are dark and the omental fat is bright. Reflections from bright surfaces may impair visual quality, and conversely the dark organ surfaces or blood absorb light and reduce image quality. The surgeon’s technical skills are thus another contributing factor; a good surgeon may operate without unnecessary bleeding, which dramatically affects image quality.
3.2 Surgical Telemedicine: Challenges and Strategies

Having trust in the visual information received is crucial to surgical telemedicine, and the focus in the surgical community has been on what kind of compression technology and which bandwidths are sufficient and safe, but still cost-effective. It seems that the debate on whether ISDN videoconferencing technology is adequate has not reached a conclusion, and to introduce it we will commence with two apparently different opinions:

“In almost all cases one has a better than necessary image for judging the situation before you. I have never, because of the image, been in doubt about which advice to give… I can’t say that in any single instance the quality has not been adequate to make a judgment” (Surgeon A, NCALS, (using ISDN technology)).

“The image is alpha and omega, it is important. [...] I would of course prefer the highest image quality if it were available. [...] A simple problem can be solved, say, where to place the trocars – this can be guided from an image that needn’t be of high quality. Or where the operating surgeon wants to show some findings. Then you can also achieve quite good images on ISDN if you manage to keep the camera still. But in our project together with Ullevål, we discussed remote surgery instead of advice and training, and then it is absolutely necessary to see the finest details. When you work close to large vessels, it is absolutely crucial that you can see what you are doing. ISDN is not adequate for precision surgery, where the procedure is complex and you need a lot of movement of the camera” (Surgeon B, IVC).

Contrasted with the study of mobile telemedicine technology with a transmission rate of 12 kbit/s [12], the issue of adequate image quality appears to be a relative parameter. We will look into this issue and attempt to show how the trust in the transmitted image is established and maintained.

3.2.1 Requirements of Image Quality are Relative to Situation and Needs

Quality is always determined or measured in relation to something. Here we see that it is related to the need or problem at hand, and to the characteristics of the procedure (see also [16]). Prior to the first statement above, surgeon A stated that the need for advice seldom concerned questions on subtle anatomical details that would require high image quality. Most often the requested advice concerned suitable strategies for the problem at hand, the optimal sequence of actions, where to place the incisions for the trocars, which instruments to use, and in which trocar they should be entered to ensure the best working position. Surgeon B mentioned the criticality of the procedure (e.g. how close to large vessels), the complexity (the number and difficulty of separate steps), and the need for change of camera position. When commenting on the study using 12 kbit/s mobile technology, he also emphasized the characteristics of the surgical procedure:

“A cholecystectomy is a simple and standardized procedure with few steps. The placement of the trocars is standardized, the actions are few and straightforward, and everything happens within one small area so that the camera doesn’t need to be moved. [...] But for larger and more complex operations where there are several steps, such a low image quality is not suitable” (Surgeon B, IVC).

Both surgeons mentioned that their experience with particular surgical procedures also helped, as they were not too dependent on a high quality image when they knew the anatomy and the problem well. They also indicated that novices might need higher image quality when they were in a learning situation and needed to have all the details.

3.2.2 Strategies for Compensation and Augmentation

Movement of the camera is an issue commented on by surgeon B. For telemedicine transmissions, much motion in video that is digitized and transmitted drastically reduces image quality [17-19]. In telemedicine settings, several compensatory strategies are commonly used to counteract quality degradation caused by movement. Some technologies allow grabbing and transmission of a still image if detail is important, and this appeared to be a particularly appreciated detail. This feature was mentioned as a safeguard when using ISDN videoconferencing by the senior surgeon at NCALS. The study of mobile telemedical technology [12] also explicitly mentioned the ability of the equipment to transmit still images to the consultant surgeon when the video quality was poor. If this functionality is not present, it may be approximated by other means: the surgeon may stop the actions in order to show details [16, 18, 20], ask the assistant to zoom in with the camera, or employ a camera holder (e.g. a robotic arm) to eliminate tremor or unnecessary movements from the camera assistant [21-22]. Verbal interactive discussions are also important [23-24]. The “mobile telemedicine study” also emphasized the important role of the “whiteboard” functionality in Microsoft NetMeeting that allowed a digital image to be shared for simultaneous viewing and annotating [12]. Additional patient information, such as a verbal or textual description of a problem, X-ray images and so on may be provided.

3.3.3 Other Security Measures, Established Standards for Safety

The relationship between the surgeons appeared to be an important factor when it comes to determining sufficient image quality. In tele-assistance the expert surgeon who gave advice needed some knowledge of the skill level of the operating surgeon [24].

“Another issue that is very important is that you know how experienced the surgeon you are talking to, is. I myself do not want to assist a surgeon I don’t know. If you don’t know what experience he’s got from before and which qualities he’s got, it can be difficult… I know those who have worked here, or attended a course here, well enough to be sure that they can do it. But if it’s a surgeon
that I don’t know, I don’t want to ask him to do things that I’m not sure he can do, or where he even may do harm” (Surgeon A, NCALS).

A similar focus on the remote (operating) surgeon’s skills was strongly emphasized by the study using only 12 kbit/s technology for telementoring of laparoscopic surgery:

“At 12 kbps the video image is 2 x 2 inches with a 5-7 frames-per-second rate. The resolution and motion of the image are below standards traditionally used in previous telementoring projects. But an intense preprocedural preparatory program overcomes this handicap. Components include objective-based skill evaluation and development, computer-assisted cognitive and judgment maturation, and training in a telemedicine simulator. This program allows for maximal preparation of the remote surgeon with precise technique checkpoints and progression along with an established chain of command” [12, p. 402].

It was also mentioned who the remote operating surgeon was: one of the second-year surgical residents at the Yale University School of Medicine. The teleconsultation setting was thus highly influenced by institutional factors, and the above-mentioned “established chain of command” was visible in this excerpt:

“The ‘telementoring’ physician properly identified the cystic artery and cystic duct. These structures were not transected until the ‘telementoring’ physician instructed the remote (operating) surgeon to proceed” [12, p. 401].

The other senior surgeon interviewed also recognized the need for some kind of formal structure and requirements:

“When it comes to training and education it is important to have a structure, but I think that in an open consultation service you cannot assume that you’re familiar with the surgeon. [...] The surgeon should be able to convert and do the procedure openly; I think that’s a requirement1. But the surgeon on the other end may have started on things that he has judged himself able to do, and then run into trouble. I might not have recommended that approach in the first place. I’ve worked with surgeons in Russia and I know that this kind of cooperation may be difficult. Some do not know things and some think they know more than they do. [...] I would then feel safer with a higher image quality, as it provides you with a better overview and you can move the camera faster” (Surgeon B, IVC).

4. Image Quality is a Complex and Dynamic Socio-technical Phenomenon

The description in the previous sections is intended to show that medical image quality is created and sustained by a socio-technical network consisting of both technical and non-technical actors. Physical devices (equipment) and material entities (gas, fog, vapor, blood, organs) were important elements, but so were the human actions and skills (technical surgical skills, communication skills, the nurses’ work and so on). An image’s quality is a collective result, and the responsibility and the credit for high quality does not lie with one of the elements in this network alone. They are all interdependent, and all (or at least many) are necessary if a high-quality laparoscopic image should be generated and transmitted.

The phenomenon of adequate image quality was not only a complex one, where many factors contributed to the resulting image. More importantly, the assessment of what constitutes “adequate” or “sufficient” image quality was also dynamic and changing, as the situation of use impacted the demands on quality:

1. Laparoscopic surgical procedures can usually also be performed in the traditional way of open surgery. If serious problems arise (e.g. large bleedings), the laparoscopic equipment can be removed, the abdomen opened and the procedure continued with traditional surgical tools, which allows the surgeon increased control through direct, physical access to the organs. This is usually called to “convert” the procedure.

The concept of “sufficient image quality” is thus not a static and universal entity; rather it is relative to the situation of use. What was considered sufficient image quality was first of all related to the surgery itself (which problems were to be solved), but also to the configuration of the rest of the socio-technical network. Important aspects of this configuration were e.g. what additional support for the interaction was offered, or which institutional setting the session occurred in. It seems that the image quality was labeled “adequate” or “sufficient” when the information-related demands of the surgical practice were met, in part through the array of additional means described above. It is not that the image quality in itself in any objective or deterministic sense just “was” adequate or sufficient. The socio-technical network that surrounded and supported the image itself made its quality adequate. Trust was based on this total configuration and depended on the characteristics of each element, but also significantly on which, how many and how robust relationships that existed between these elements. The importance of these links and relations may explain why the emphasis was not on the technical...
image quality alone, and how a clearly sub-optimal image still could be considered safe and sufficient.

5. Conclusion and Implications

This paper argues that safe and sufficient image quality is achieved by the entire socio-technical network as a collective result, and that trust in the information received is not based solely in single elements (e.g. in the image itself) but also relates to the total configuration of the elements and the relations between them.

What are the practical implications of this? Certainly it should not be interpreted to say that individual elements don’t matter. A faulty element in this socio-technical network (e.g. a piece of equipment) or a missing link (e.g. no audio channel) can in some cases put a total stop to the planned telemedical surgery. However, in other cases it seems that faulty, missing or nonsatisfactory elements may be circumvented by parallel links (e.g. transmitting a still image to compensate for low video quality). Thus, the implication we want to emphasize is this: Securing high quality equipment in all parts of the chain and optimizing the network elements is all very well, but if for some practical, technical, or economic reason this is unattainable, there may be ways to compensate for this through providing additional relations and resources (technical or social). The technical solution strongly shapes, but doesn’t wholly determine the resulting use-related image quality.

Another implication of studying work practices as socio-technical networks concerns issues of technology design, development and use more generally. When new tools are introduced, the users not only need to learn about how to use the tool itself (e.g. how to operate the videoconferencing equipment). They simultaneously need to learn in a broader sense about how and when to use the tools, and when not to use them. As this paper describes for surgical telemedicine, any discipline that takes on new technologies needs to establish shared use practices, including discipline-specific standards for safe use. This has to be based on experience from use of the technology in real-life settings. Designers and decision-makers should therefore not only consider the technology as such, but should also plan for this kind of learning. Such a process may be stretched out in time, and a priori defined requirements, criteria, goals and milestones may turn out to be irrelevant or not applicable. Thus, managerial dedication may be required to support the learning process, which again requires recognition that technology implementation is in reality technology appropriation. Socio-technical analyses are well suited to provide such insights.

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