

Chapter 2

The Visual Touch Regime: Real-Time 3D Image-Guided Robotic Surgery and 4D and “5D” Scientific Illustration at Work

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Abstract Emerging multidimensional imaging technologies (3D/4D/“5D”) open new ground for exploring visual worlds and rendering new image-based knowledge, especially in areas related to medicine and science. 3D imaging is defined as three visual dimensions. 4D imaging is three visual dimensions plus time. 4D imaging can also be combined with functional transitions (i.e., following radioactive tracer isotope through the body in positron emission tomography). 4D imaging plus functionality is defined as “5D” imaging. We propose the idea of “visual touch”, a conceptual middle ground between touch and vision, as a basis for future explorations of contemporary institutional standards of image-based work. “Visual touch” is both the process of reconciling the senses (human and artificial) and the end result of this union of the senses. We conclude that while new multi-dimensional imaging technology emphasises vision, new forms of image-based work using visual materials cannot solely be classified as “visual”.

Keywords Display technology • Visual perception • In situ image guidance • Senses • Innovative knowledge • Scientific illustration • Image-guided robotic surgery

2.1 Bringing Vision and Visuality into Business and Management Studies

New work practices in the use of vision are emerging as the dominant workplace regimes in the institutional landscape. But business scholars still lack a theoretical language to describe and understand the present dynamics of modern

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practices of vision and of current production standards for image-guided goods and services.

Vision and visibility are emerging in many forms and ... [have] a central role in the functioning of organizations. Since human vision is to some extent always already present, it is somewhat paradoxically also what is somewhat taken for granted and overlooked (no pun intended); it is an “absent present” in organization theory. Always all-too-mundane to be noticed, yet largely theoretically unexplored, vision is what deserves a proper analysis and a proper theory. (Styhre 2010b, p. 19)

We live in an increasingly image-based professional world but vision has not been fully scrutinised in empirical field studies or explicitly developed in theoretical management studies. Imaging and visualization is an increasingly important area of investigation in science and technology studies (STS): images are shown to help professionals define theories (Nersessian 2008); relocate and share ideas (Galison 1997; Henderson 1999; Knorr Cetina 2001; Latour 1990); and communicate with disparate audiences (Burri and Dumit 2008; Landau et al. 2009). Images have become increasingly important in medicine (Engström and Selenger 2009), where diagnostic imagery is invaluable to diagnosing patients (Joyce 2005; Mol 2002) and conducting treatment.

The social studies of imaging technology and visualization raise important questions about how images come to be, and how images intersect with different forms of knowledge about ourselves and our world (Burri and Dumit 2008; Daston and Galison 2007). Human knowledge is deeply entrenched in “traditions of seeing”, which is reflected in various notions ranging from “professional vision” (Goodwin 1994), “visual knowledge” (Cohn 2007), and imaged knowledge (Beaulieu 2003).

In the field of management and business studies, Alexander Styhre, a scholar in organisation theory, explores regimes of visibility and provides theories about the requirement for skilled vision in certain practices by situating these practices in historical, cultural, and organisational settings (Styhre 2010a, b). For Styhre, vision is far from being a straightforward matter or a trivial phenomenon in organisational life. Styhre argues it is important to outline specific forms of vision(s) in the workplace, a view with which we concur. Our research attempts to fill some of the gaps in the understanding of vision and visibility and thereby shed new light on the concepts. Our conceptual analysis is empirically anchored on what anthropologist Geertz (1983) calls the “thick descriptions” of real-life practices of seeing. Our case demonstrates that in situ “multi-dimensional visual touch” is an emerging and distinctive form of visibility in the technology-mediated work environments of robotic surgery and scientific imaging.

Robotic technologies and advanced imaging technologies have redefined surgical work, resulting in a dilemma in current surgical practice as to how the use of human senses is being redefined. The purpose of this chapter is to introduce, explain, and empirically explore the reorganisation of interactions in medical practice in the use of visually guided robotic surgery. The process of introducing new technologies changes the priority of the senses and the knowledge that is lost and gained. The integration of various forms of advanced robotic and

imaging technologies into surgical practice involves a profound shift in focus for surgeons away from traditional manual surgery. (Wasen 2010) The transition involves a change from the use of physical sensation (i.e., tactile feedback) in traditional surgery to a dependence on visual feedback in robotic surgery. Although it promises increased precision, stability, and control, computer-integrated robotic surgery can be challenging because surgeons can no longer depend on their sense of touch. This change-induced dilemma represents a point of ‘organisational transformation’—the need to adjust standard human or professional practices in new and unexpected ways.

Our interest in robotic technology and 3D and 4D imaging¹ is based on how these influence surgical practice and professional visual expertise. We explore how the use of technology has been adjusted to fit certain surgical needs and how surgeons’ preferences have been addressed and continue to be addressed. By allowing the surgeons’ experiences and perspectives to guide our findings, we aim to contribute to discussions of visually guided robotic surgery and how it affects established professional embodied knowledge. Increasingly detailed and comprehensive images and videos are being produced, leading to enhanced visual attention and immersion. This transition is rendering the invisible visible and the unobservable observable. From our perspective, practices of observing and knowing in multi-sensorial worlds are coupled with the serendipitous findings in the medical and other scientific fields.

The chapter is structured into five sections. First, we justify the importance of examining the work performed by professionals. We draw on the scientific literature pertaining to organisational knowledge and innovation management. Second, we provide a brief historical overview of surgery and the introduction of robotic techniques and imaging to surgery. Third, we present prior research on individual established knowledge in professional work and on image-guided medicine. The fourth section introduces empirical cases of image-guided robotic surgery and the increasingly important shift in importance of the sense of touch in the transition from traditional to imaging practices. The description includes reactions from surgeons to this transition. In the discussion, we position multi-dimensional scientific imaging and image-guided robotic surgery as institutional standards for image-based work. We conclude that while new multi-dimensional imaging technology puts an emphasis on vision, new forms of image-based work with visual materials cannot solely be classified as “visual”.

We challenge the common perception regarding the distinction between vision and touch and propose that the line between the two is in fact blurred, given that touch in this context is defined as “touching with the eye” (i.e., a form of “tactile vision”) rather than limited to only the physical touch. “Touching with the eye”

¹ 3D imaging is defined as three visual dimensions. 4D imaging is three visual dimensions plus time. 4D imaging can also be combined with functional transitions (i.e., following radioactive tracer isotope through the body in positron emission tomography). 4D imaging plus functionality is defined by the OsirixX® DICOM Viewer as “5D” imaging.

should not be equated with the more general notion of “digital touch”, which is used for haptic technology (see, e.g., Paterson 2005). Therefore, the employment of advanced visual technology reconfigures and redefines the meaning and uses of vision and touch. We propose the concept of “visual touch”, a conceptual middle ground between touch and vision, as a basis for future explorations of contemporary institutional regimes of image-based work. “Visual touch” is both the process of reconciling the senses (human and artificial) and the end result of this sensorial union. Finally, consideration is given to the generalisability of our analysis when determining how other multi-sensorial work practices should be studied.

2.2 Organisational Knowledge

The knowledge creation process reflects the dynamic and emergent nature of organisational innovation. As Davenport and Prusak succinctly put it, “ALL HEALTHY organizations generate and use knowledge. As organisations interact with their environments, they absorb information, turn it into knowledge, and take action based on it in combination with their experiences, values, and internal rules. They sense and respond. Without knowledge, an organisation could not organize itself; it would be unable to maintain itself as a functioning enterprise.” (1998, s. 52) The organisational innovation view includes cultural heritage, social interaction, communication, and decision-making (Wejnert 2002; Rogers 2003; Kincaid 2004). Attention is also paid to the tangible and intangible dimensions of knowledge work as well as the work environment. This view is echoed by Tornatzky and Fleischer (1990, p.10) who maintain that the term “innovation” should be understood as “the situationally new development and introduction of knowledge-derived tools, artefacts, and devices by which people extend and interact with their environment”.

Barley and Kunda question the lack of focus on people’s day-to-day actions in management and organization studies. “The dearth of data on what people actually do—the skills, knowledge, and practices that comprise their routine work—leaves us with increasing anachronistic theories and outdated images of work and how it is organized.” (2001, p. 90). Barley and Kunda argue that it is not sufficient to interview practitioners as to their practices and that scholars must also observe how work is accomplished in the workplace. In a wider sense, innovations constitute new work methods, social and cultural practices and even new ideas or new ways of thinking and perceiving the world. The generation of new knowledge in surgical practices proves useful when it is adopted, augmented, applied and passed on in an organisational setting. As Nonaka and Takeuchi observed, “When organizations innovate, they do not simply process information, from the outside in, in order to solve existing problems and adapt to a changing environment. They actually create new knowledge and information, from the inside out, in order to re-define both problems and solutions and, in the process, to re-create their environment.” (1995, p. 56) Organisational innovation is unlike technological

innovation in that it focuses on changes in routine human activities rather than on the process of invention (Freeman 1994).²

Organisational innovations, as symbols and perceptions, may be viewed as the human endeavour to incorporate new technologies into specific professional, organisational and cultural environments. Technological change follows when an innovation is put into practice and replaces old habits with new routines. The use of imaging in health care is not only the use of a novel technology but also the cessation of existing work practices in favour of newer, more effective ones. Organisational innovation can also act as a form of path dependency; the decisions made in the past influence and limit the options for action in the present.

2.3 Surgery, the Early Use of Robotics, and Reinstating Binocular Vision

The evolution of medicine in general, and the art of surgery in particular, traces its history back to the ancient Greeks. Indeed, the making of surgical equipment and instruments has a long historical tradition of skilled craftsmanship (e.g., Göransson et al. 1987). These semi-specialised tools enhance the manipulative capacity of the surgeon's hands and represent extensions of the human body (cf. Mumford 1934, 1952). The era of modern surgical practice has commonly been referred to as either the period following the introduction of antiseptics/aseptics (Bynum and Porter 1993; Harding-Rains 1977) or the post-anaesthetics period (Cartwright 1967; Sullivan 1996). The subsequent post-modern era of surgical practice began with the adoption of complex remote manipulation technology (cf. Bicker et al. 2004), which included the use of robotics. For Bicker et al. (2004, p. 391) and colleagues, remote handling “has its roots in some of our most primitive tools... Blacksmiths tongs are a crude, but effective example of an early remote handling tool.” Being able to extend one's reach into a hostile environment is a valuable ability when one still wants to control the position and orientation of materials

² Hawkins and Verhoest (2002) discuss a considerable body of research showing that technological and organisational change are highly interconnected. The characteristics of innovation, as laid out in the OECD Analytical Report on Technology, Productivity and Job Creation (OECD 1996), clearly demonstrate that technological change “calls for and results from institutional and organisational change”. Hawkins and Verhoest's approach is consistent with the one presented by OECD (1994), but their approach more explicitly emphasises discovering how firms and organisations use technology in order to extend our knowledge. However, we do realize that there may be a limitation in the use of the term “organisational innovation” as it closely resembles the notion of the “social invention of the organisation” (Pedersen and Dobbin, 1997). Other related concepts, such as “social innovation” or “non-technological innovation”, are more or less consistent with the term “social invention”. These concepts are somewhat problematic as most advanced work settings assemble various technological devices and social practices, which tightly interweave the social, organisational, and technological.

while working (Vertut and Coiffet 1985). Telemanipulation extends the human operator's reach into remote environments while focusing on ease of manipulation and meeting the sense requirements for participating effectively. Manipulation involves manual dexterity, judgment and intelligence, which are governed by practice and the senses.

At the beginning of the 21st century, the innovative use of robotics enabled the exploration of remote places not previously accessible to humans. Space robots navigating the moon or at the bottom of the sea are well-known examples, but recently, robots have begun exploring new frontiers inside the human body. To be able to navigate in such remote areas, robots must be interlinked with sophisticated visualisation technologies.

Since the beginning of traditional invasive surgery, and even before the evolution of specially designed operating theatres, human touch has been a key feature in treating patients. Robotic technology has only recently entered the operating theatre, releasing surgeons from old constraints such as limited human vision and the lack of precise hand movements. At the same time, however, the technology has created new constraints, such as precluding the use of tactile information and stereoscopic vision during surgery. This highlights an increasingly important area in the study of imaging and visualisation as to how to replicate binocular vision and touch. The history medical and surgical imaging spans centuries of anatomical depiction (Oldfield and Landon 2006; Roberts and Tomlinson 1992; Tsafirir and Ohry 2001), artist/surgeon collaborations (Crosby and Cody 1991) and more recent bodily explorations with computed tomography (CT), magnetic resonance imaging (MRI), and positron emission tomography (PET) (Holtzmann-Kevles 1997; Marchessault and Sawchuk 2000). Imaging technologies transform the body into data, revealing what cannot be observed by unaided human senses, and providing information for an expanded understanding of imaging results. These technologies present an opportunity to discover new relationships that are "productive of new relations" (Beaulieu 2003). The current challenge with modern surgical technology is how to use imaging to improve upon the surgeon's finely honed abilities.

2.3.1 Depth and Presence Through Stereoscopic Imaging

The ability to perceive depth is the innate ability of binocular vision. The slightly different images captured by the eyes are reconciled by the brain to provide an illusion of depth (Fig. 2.1). Stereoscopic imaging in surgery is fundamentally different from the common understanding of 3D imaging, which is often only the 2D representation of a 3D object. Surgery and medicine have strived to attain quality stereoscopic representations since the late 1800s (Getty and Green 2007) and have successfully used stereopsis in training and in practice (Davidson 1916; Brodke and Randolph 2003; Held and Hui 2011; Hofmeister et al. 2001; Lee et al. 2010; Marescaux and Soler 2004; Oleynikov et al. 2005; Patel et al. 2008; Xing et al.

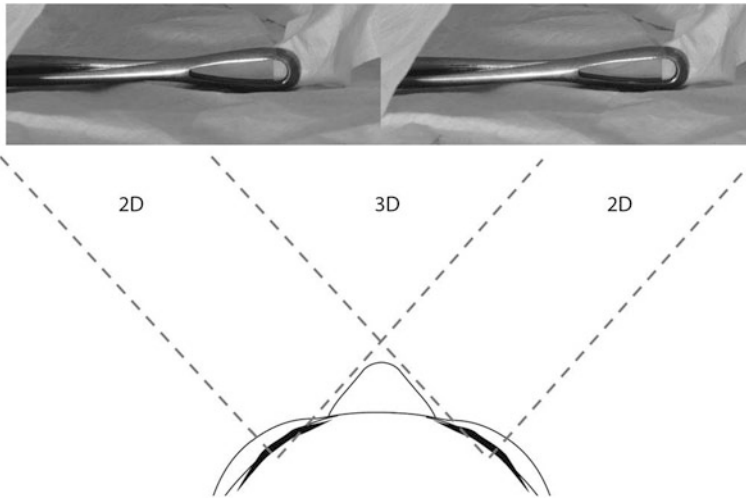


Fig. 2.1 Stereoscopic images are a result of binocular vision where eyes that are placed a distance apart are used together. Each eye sees a different image (2D), and the brain reconciles these images to produce a sense of depth and three dimensions (3D). © M. Brierley

2009; Morton 1989). These authors have attempted to achieve “enhanced shape perception in the absence of other visual cues, whether the application is diagnostics, trainings, or remote surgery” (Held and Hui 2011).

The need for stereoscopic imaging lies not only in improved imaging but also in improved navigation of a physical space by replicating the spatial understanding previously gained through touch.

The ability to precisely navigate 3D space is lost when binocular vision is not available and when the space under consideration cannot be touched. Stereoscopic approaches to surgery provide alternatives for both the loss of binocular vision and the loss of touch.

Images used to plan, guide, and review surgery take on an integral role in these procedures. Companies that create stereoscopic imaging technologies offer new sites for development of computer-mediated life sciences (Myers 2008) and changes in their practices. Professional practices change as stereoscopic imaging in robotic surgery become closely integrated with work of surgeons.

2.3.2 The Role of Visual Embodied Knowledge in Professional Work

Visual knowledge may depend on the specific competences required by specific technologies (Cohn 2007), or it can have an intangible quality, such as a pervasive personal element that cannot be observed or touched, that is embodied in

people, artefacts and actions (Bal 2003). Blackler (1995) argues that knowledge is linked to actions, indicating that its value lies in its use. Polanyi (1967/2009) introduced the term “tacit knowledge” to describe an experiential knowledge that cannot be written down. It is (1) embodied knowledge, such as the ability to hold a pencil or (2) contextual knowledge, for example, the way the laboratory setting gives knowledge its meaning (Knorr Cetina 2001). Thus, tacit knowledge is both somatic (a physical routine) and collective (a cultural practice) (Collins 2010).

The intangible skill of surgical practice is described as a skill developed through experience and maturity, a skill that some people call “intuition” (Cohn 2007, p. 93). Surgeons feel as much as see their way through surgical procedures.

2.3.3 *The Senses*

Part of the change dilemma in surgical practice today is how the senses are being redefined. In robotic surgery, touch is mediated through images and machines at a distance from the patient. Research has linked the senses to culture (Howes 2005; Classen 1993; Feld 2005), to memory (Bergson 1908/1988), and to the situated environment (Feld 2005). McLuhan pointed out that “[a]ny culture is an order of sensory preferences.”³ Others have examined lived experiences as involving shifts in sensory, multi-sensory or cross-sensory experiences (Feld 2005, pp. 180; Newell and Shams 2007; Shams et al. 2000) and considered how our experience over a lifetime decides our cultural understanding of the senses (Howes 2005). We know physical space through how our body exists in that space (Bourdieu 1977), which is also part of memory. Steven Feld highlights the work of Bergson (1908/1988) when he writes that memory is the “thousand details out of our past experience” (Feld 2005, p. 81).

Out of these explorations arises an important question about the senses and how they are attuned to taken-for-granted activities in professional worlds and between people. By recognizing changes in sense emphasis in a changing surgical environment (touch as mediated by image and robot, rather than direct surgeon-patient interaction), we can scrutinize the theoretical positions that guide our conceptions of senses and knowledge. As Rosenberger (2011) recently maintained, “Technologies provide mediation between our bodies and the world, changing our perceptual abilities ...how humans embody technology, and how technological embodiment transforms human experience” (Rosenberger 2011, p. 13). Furthermore, Myers (2008) reminds us of Merleau-Ponty’s (1962) phenomenology of perception where “sensation and movement are intimately tied to visual understandings of form” (Myers 2008, p. 166). The empirical part of this study pays particular attention to the practices of seeing and touching mediated through multi-dimensional imaging in the surgical domain. In the empirical context, where surgeons’ movements change with new technologies, so must their perceptual approaches and their embodied understandings of surgery itself.

³ The Playboy Interview: Marshall McLuhan”, Playboy Magazine, March 1969.

This chapter attempts to fill some of these gaps in our understanding by examining how change is understood from the point of view of practitioners; how an emerging technology influences user perspectives, knowledge, and practices; and how those in an established medical profession interpret and negotiate these changes.

Ethnography that focuses on the senses in particular accounts for how multi-sensoriality is “integral” to people’s daily work and lives (Pink 2009, pp. 1–2). This method examines how the senses work in gaining and navigating knowledge. Methodologically, our chapter contributes to these efforts by promoting the benefits of cross-disciplinary research in the realm of workplace studies.

2.4 The Case: From 2D Imaging to 3D Stereoscopic Cameras and 4D/5D Surgical Imaging In Vivo

The late 20th and early 21st centuries have seen a rapid proliferation of powerful robotic systems in healthcare, systems designed to exceed the surgeon’s limitations. While the human eye is an astonishing “depth-seeing apparatus” (Jastrow 1936), its field of vision is limited due to optical glare and other factors. The power of robotic systems also lies in their ability to become extensions of the human body and thereby allow operators to work remotely, thus enabling human expertise to be applied in physical spaces that were previously unreachable. Bicker noted, “.... although relatively complex mechanisms, when well maintained and used by skilled operatives, these devices can be used to undertake highly dexterous and extremely precise tasks” (Bicker et al. 2004, p. 394).

In the case of robotic surgery, for example, robotic arms can hold sophisticated camera systems steady. Even when the surgeon is working directly on a patient’s body through a robot, the risk of danger to internal organs is still present, and therefore, a “gentle human touch” during surgery is still necessary. If a surgeon is performing open surgery on a patient in a standard operating theatre, all members of the team can view the operation and see how it is proceeding. In traditional surgery, if an event occurs in the surgeon’s periphery, the event is still within the surgeon’s direct vision (see Fig. 2.2). These circumstances are representative of surgical procedures before two-dimensional (2D) imaging.

The transition from manual open surgery to manual laparoscopic surgery (i.e., keyhole surgery) marked a profound change to 2D imaging. This new imaging technique relied on a change in hand-eye coordination that often took surgeons years to acquire proficiency and expertise in handling to efficiently master the use of manual laparoscopic instruments. Moreover, working with 2D images in keyhole surgery was a challenge because most television screens did not have good contrast resolution. As Fig. 2.3 illustrates, the lead surgeon would often encounter visual noise on the mounted television screens and would lack a sense of depth when using laparoscopic surgery.

Non-invasive approaches, to which robot technology belongs, have dramatically altered the traditional methods surgeons have used to sterilise and use



Fig. 2.2 Traditional open-heart surgery requires that surgeons and assistants work on a patient in close proximity with one another. In a standard mitral valve operation, assistants interact directly with the head surgeon (far right). © K. Wasen



Fig. 2.3 Two non-stereoscopic 2-D images of the cameras in laparoscopic surgery. © K Wasen



Fig. 2.4 The robotic arms occupy the space around the patient where the head surgeon and surgical assistants would normally stand (see Fig. 2.2). In robotic mitral valve surgery, the head surgeon controls the robot remotely through a console. Although assisting staff members are more spread out in the operating theatre, they are still required to be in close proximity to the patient and the robotic arms. © K. Wasen

their instruments and the methods employed for operating on their patients. (see Figs. 2.4 and 2.5) A surgeon explained this new approach as follows: “As we become less invasive, we are not putting our hands inside the patients as much at all.” Thus, physical contact with the patient is lost with the new system. An obvious advantage motivating non-invasive approaches is the improved aseptic or sterile environment they provide. While the promises of technological mediation in robot surgery are increased precision, stability, and control, the transition from traditional open surgery to robotic surgery is challenging because surgeons can no longer use their tactile sensation. A urologist expressed a similar concern:

You cannot feel. It is easier to feel things; it is easier to operate if you can feel things. You can feel how thick the tissue is, you can dissect with your hands. When you are tying something or dissecting something, you can feel how much tension you are applying to the tissues. You get none of that with the robot; you do not get any tactile feedback from the robot. It almost feels the same; no matter how hard you are pushing, it feels the same on the robot.

For all of the interviewees, the direct loss of physical contact during an operation with the patient’s bodies in general, and patient’s internal organs in particular, has had several direct negative consequences. A thoracic surgeon found that non-invasive approaches in robotic surgery have made his work much harder in that “It is a big difference that you cannot feel, there is no tactile feedback.”

Fig. 2.5 The head surgeon works at the robotic console remotely from the patient and the surgical team. The *left* image presents the upper console interface where the surgeon views the 3-dimensional imagery and interacts with the hand controls. The *right* image presents the foot controls. The console is able to operate remotely and can be placed outside the operating theatre or even outside the hospital.
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This study demonstrates how surgical robot technology fundamentally alters the way physicians use their different senses when operating on and interacting with patients through technological mediation during surgical procedures. More specifically, robot surgery entails a profound shift in focus for surgeons in their traditional manual procedures, from a reliance on physical sensation (i.e., tactile feedback) in traditional open surgery to increased dependence on visual feedback.

2.4.1 Compensation with Superior Artificial Visualisation

Professional competences in the surgical domain integrate with the new and unfamiliar high-tech demands of robotic applications, and this may mean replacing an advanced understanding of touch with a developed comprehension of visual data.

First, surgeons must learn and adapt to a new task routine in the operating theatre. Second, the transition from manual hands-on surgery to remote robotics is not easy and requires a different type of hand-eye coordination skill. Third, the case of robotic surgery points to the fact that not everyone can benefit from this new technology. A large part of the success of the operation relies on professional knowledge to analyse and understand the detailed 3-dimensional images as well as the surgeon's ability to use the sophisticated 3-dimensional camera system in an optimal manner. For this reason, it is paramount that new surgical trainees are taught how to use robotic systems and learn the proper role of these systems in the contemporary operating theatre.

The transition from human to robotic touch and from human to 3D magnified vision alters the use and purpose of the senses in surgical practices. Robotic technology in a medical setting supports and extends a surgeon's visual capabilities, promotes a dependence on visual media, and requires surgeons to work more independently (human to robot rather than human to human). Just as humans have created an ability to touch and manipulate what could not previously be observed through robotic support, so has robotic technology changed our practices and our needs.

I think adjusting to using visual cues about the tension on tissues and things like that are very important. But, on the other hand, about technology, is that people insist "well, you know, my tactile sensation is better than your visual". I do not think that has been proven. I would argue that there are probably more benefits to magnification in many sorts of cases than there are to tactile feeling.

The above surgeon explicitly questioned the traditional reliance upon physical feedback as an important prerequisite to do a satisfactory job. For unskilled hands and for most inexperienced residents working in surgical clinics, such tactile sensations would be exceeding difficult to fully perceive. In contrast, experienced and knowledgeable physicians could easily discern the same anatomical details by touching them. The surgeon quoted above also maintained that enhanced human vision is far superior to any tactile ability.

I think that in many surgeons' hands, they overestimate the importance of their tactile feeling simply because they have never done without it. As technology advances, there will be new ways to look at things, such as looking at if you can use a probe to determine if an area is malignant or not. Is that not better than your fingers? So, why not?

Surgeons have noted that in conventional open procedures, they were able, at least to some extent, to have extraordinary magnification of the surgical area. As observed during video-documented conventional open procedures, surgeons commonly had loupes positioned on top of their heads (i.e., a pair of specially designed magnifying glasses attached in front of their eyes; see Fig. 2.2). When using these types of "sensory enhancing equipment" (McLuhan 1964), a surgeon's centre of attention still remained on a small part of the entire wound, an area that would be invisible to the naked eye. Hence, visual perception is gained either by using a pair of magnifying glasses or optical camera systems. As one urological surgeon noted, such visual magnification also renders some things

imperceptible because, as he explained, "... you are looking at a tunnel vision event where you see only a direct vision of what the camera is looking at. You do not see left and right, you see only a direct tunnel vision." This surgeon suggests that there is an increased reliance on selective non-direct visual images from the two cameras inside the patient. The visual selectiveness is experienced as positive because it actually enables the surgeon to focus on what is happening inside the patient's body. As the urological surgeon notes, "You are extraordinarily focused on this one spot [of the entirety of the wound] with the robot. There is no question about that. But I think that the amplification of it is so much greater because of the [three-dimensional] magnification, so you have to be cognizant of where everything is around you because you are only seeing a small area."

Surgeons who have had extensive experience operating under the old regime of manual procedure noticed initially that increased immersion also resulted in a narrower field of vision. In practice, a 3-dimensional view of the surgical field in robot surgery provides surgeons with the possibility of an even greater sense of screening their sensory awareness from other external inputs.

New imaging technology supports the surgeons' need for extraordinary focus in their job. In other words, the material configurations of the imaging technology render certain aspects perceptible and allow physicians to notice details that they had previously just assumed would be there. For example, various small nerves and blood vessels in the human body are almost invisible to the naked eye.

With robotic surgery, however, enhanced artificial magnification provides greater visual amplification than was provided by loupes in traditional open surgery. As one assistant thoracic surgeon described in reference to the vast difference between open and robotic surgery in terms of improved 3D visualisation, "The magnification, and your ability to discern structures, is almost microscopic in nature". Another surgeon described it this way:

So, in principle at least, the robot gives you a big advantage there because it actually gives you the opportunity to focus on exactly what you are doing and still get information in digital format or in audio format, visually on the screen or just from a microphone of what is going on around the room ... Of course, it is a different type of feeling, which may be a little bit scary for the surgeon in the beginning because he does not, for example, see the whole heart.

Despite the experience being "scary" at first, the above quoted surgeon repeatedly refers to the advantages of an increased ability to focus. This suggests that 3D imaging in surgical work demands focus, but this may be related to the technology employed. Bicker et al. (2004) observes that the use of tele-operated technology brings a dramatic increase in mental concentration. D'Aluisio and Menzel's (2000, p.175) documentation of a robot surgical practice at a hospital in Leipzig describes how the German surgeons have chosen to move the console out of the operating theatre to enable the surgeon's total immersion in the magnified image of the operating field, thus eliminating sources of distraction. Communication with the supplementary surgeon and other members in the team is mediated through

microphones. The Leipzig surgeon explained the initiative to distant himself from the patient and the other staff members as follows:

I'm happy that I don't hear them anymore. Because it's a new way of surgery and you want to be totally immersed in that image. Your brain can only process so much information. If you hear something—the brain has to process it. To concentrate, you try to shut off all those inputs you don't need, which leaves more space for the rest of the information. (2000, p. 175)

In this quotation, a practitioner who is working from the surgical console reflects on the ability to filter out “noise” from a remote location in the hospital. The surgeon wants to be completely immersed in the stereoscopic images provided from the robotic systems. The surgeon goes on to describe the intellectual challenge of adjusting to the multi-dimensional 3D visual tool, a tool that also filters out unnecessary negative stimulus from the operating theatre environment. As Murphy notes, “... focusing on a single signal entails a learned inattention to other noise. Perception always involves disengaging from a broader field of possibilities for the sake of focusing on, isolating, and rendering intelligible a more narrowly delineated set of qualities.” (2006, pp. 24–25). Through years of day-to-day practice and experience, physicians become trained at filtering important information from the unimportant, and this involves developing the skill to effectively differentiate the “normal” from the “peculiar” and identify certain patterns in the anatomy during surgery. The surgeons' perception is manifested in the ability to direct their attention to particular details while ignoring others.

2.4.2 *Surgical Imaging In Vivo*

Thus far we have illustrated how new modes of surgical knowing, visual attention and immersion are situated in surgical practices that are changing from using the apparently restricted 2-dimensional images to more detailed images in 3D stereoscopic robotic surgery. In the final part of the empirical case description, we want to turn to another category of health care professionals in surgery, namely medical illustrators. The connection between touch and vision can also be found in illustrators' facility with new emerging imaging technology. The biggest transition in the knowledge about the body has been the development of imaging in vivo, which takes place in a living organism as opposed to the study of cadavers. When one medical illustrator explained how her clients responded to her work, she highlighted how images can help doctors form the mental models they already have in their heads, based on their years of experience understanding the human body:

So when they see something illustrated in full-colour in a really nice style, to them that's just, that's just the cat's pajamas. And they always say, and I can't tell you how many doctors that have said, 'that's exactly what it looks like.' But it's not exactly what it looks

like. What I figure it is, I must be hitting on, it's exactly like the image that they've formed in their head 'cause they've done the same thing in their head that I've done graphically, which is remove all the extraneous that's not important, focus in on what is important,

For skilled medical illustrators who have worked with surgical illustrations for many years, newly generated 4D images may create both new practical and theoretical knowledge (see Fig. 2.6a, b). One of the interviewed medical illustrators showed a beating heart in a 4D OsiriX reconstruction⁴ to one of his colleagues who had worked in the profession for many years; this colleague, who was astonished, commented "... 'the heart doesn't do that' [to which the medical illustrator responded] ... well that may be, but this heart did this and here's a movie of it doing it. You think you know what the inside of the beating heart looks like, there's no way to know that". As the quotation suggests, such a transition to visual 4D and displays including functionality, in effect, makes certain unobservable details observable, and thus renders the invisible visible. Mediated multi-dimensional images seem to expand the practitioner's faculty of perceiving in real-time by focusing their attention on hitherto unnoticed aspects.

...you can do all the dissections you want. But you're seeing in death. ... I have a movie of the beating heart where I make everything translucent except for the bolus of blood inside the left ventricle. And you get to see this thing beat ..., and ... you see a tremendous difference, in which you learn, ... that the internal volume of the heart changes much more than the external volume of [the] heart, much more, it's not even close. And you'd never know that from books.

As expressed by the medical illustrators, images previously based on normalized cadaver-based anatomy are now individually rendered in life, and put to work within the surgical theatre. Surgeons themselves discuss the benefits of visualizing hidden anatomy through new imaging modalities, in part reducing risks to patients (Brodke and Randolph 2003). Surgeons use image data to locate the areas of concern prior to surgery as well as use the same images to navigate to the areas of concern during surgery. Figure 2.7a, b features an example of this imaging integration during a focal laser ablation surgery of a tumour of the prostate.

Examples from prostate cancer treatment demonstrate the real-time use of magnetic resonance sequences to create an image of the prostate in a 3D space. As described by health professionals working at Princess Margaret Hospital:

This 3D image of the prostate and surrounding structures will remain available while the probe of a miniature surgical robot is manipulated percutaneously into the cancer. The miniature surgical robot is strategically placed adjacent to the perineum with the patient in the bore of the magnet. This probe uses image information from the MR machine as a guide for the precise elimination of cancerous cells. The location of the probe is guided with computer software, ensuring precision in the destruction of the area of concern.

The work of the surgeon in these cases is pre-planned and then conducted through the visual environment. These examples of surgical imaging in practice

⁴ OsiriX® is one of many medical image viewers available for Digital Imaging and Communications in Medicine (DICOM) file types.

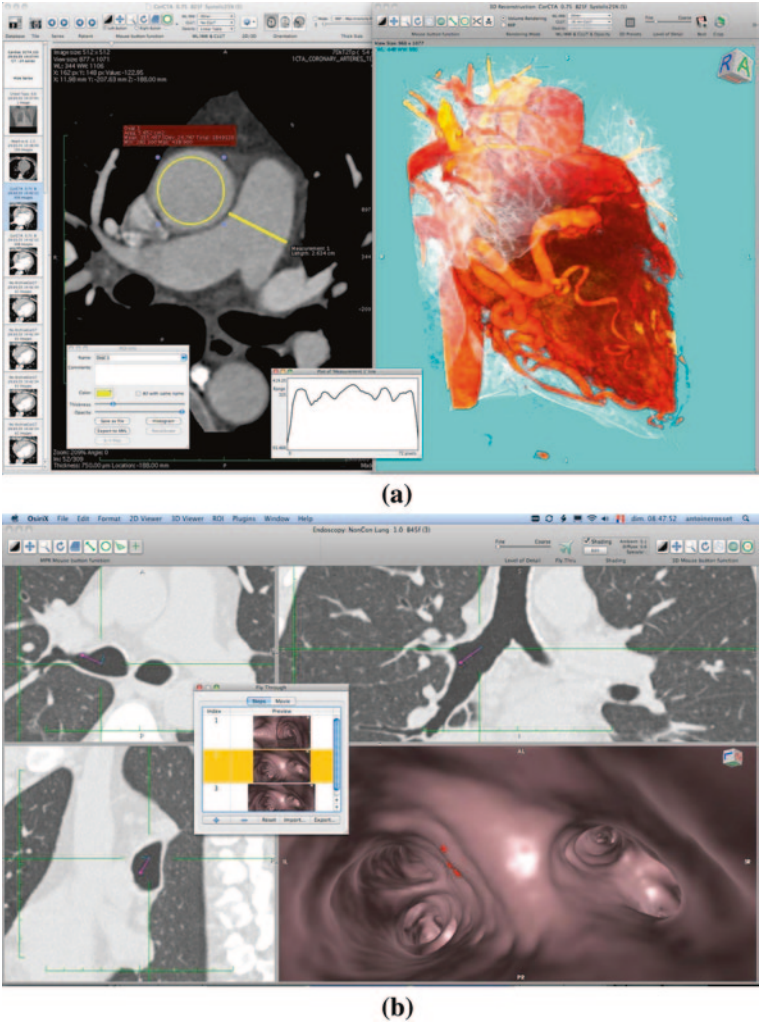


Fig. 2.6 **a** 3D virtual reality of the human heart. A volume renderer such as the OsiriX® software featured here provides a means of working with information based on data captured in the live human body. The 4D and “5D options” (three dimensions, time and functionality) offered by OsiriX® are particularly helpful when examining anatomical relationships over time. Previously “untouchable” activities of the human body, such as the heart beating, can now be explored in life and multiple dimensions. Human vision and image manipulation take the place of touch. © A Rosset, OsiriX **b** The in vivo non-stereoscopic 3-D result of the OsiriX® endoscopy viewer of the human lung. © Antoine Rosset, OsiriX

highlight both the information provided in vivo and the precision provided by the visual. Anatomy that was once hidden to knowledge is newly available to surgical work as it is being done.

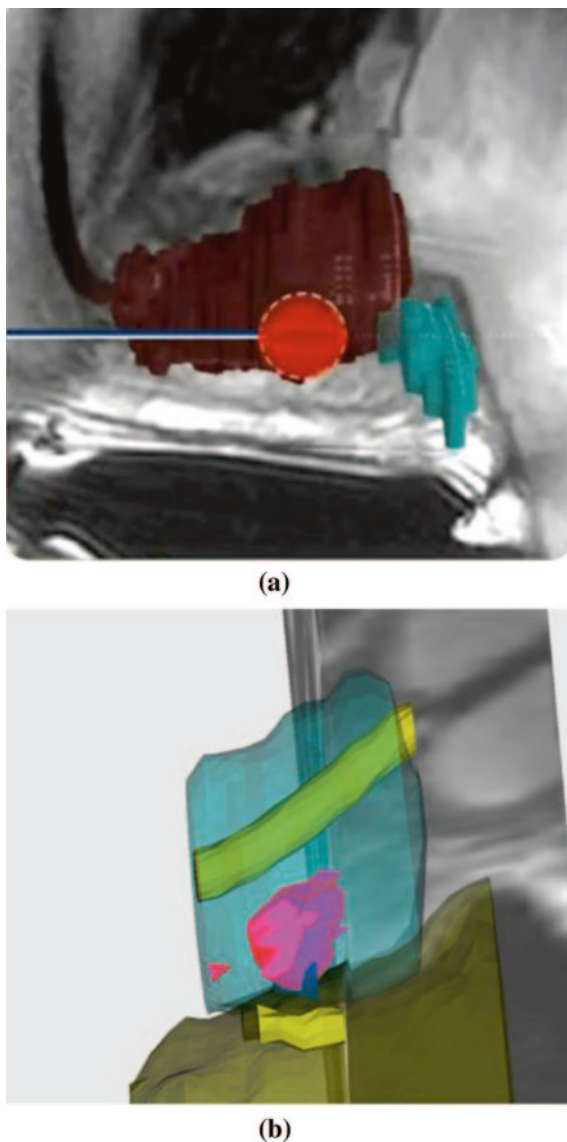


Fig. 2.7 a, b Two frames from animated and live footage videos demonstrating focal laser ablation (FLA) therapy procedures of the prostate. Laser heat is used to raise the temperature of the area of concern to a point where the tumour can no longer survive **a** The first frame is a screen capture from an animation which gives a general overview of each of the steps in the FLA procedure. As described by the Prostate Cancer Centre: “... [During the step] when the probe is activated, the cancer and a small margin of surrounding tissue are destroyed. The volume of destruction is visualized in real time and consequently, the margins, or the area around the cancer, are minimized. Blood vessels, nerves and other vital structures are untouched and remain healthy.” **b** The second frame is a screen capture from a video that shows MRI image data. The prostate is green-blue, the tumour is blue, the urethra and nerves are yellow, and the area receiving heat from the laser is pink. © The Prostate Centre, Princess Margaret Hospital, University Health Network, Toronto Ontario <http://focalprostatecancertherapy.com>

2.4.3 *Transition in Sensory Focus and Professional Expertise*

In robotic surgery, the loss of touch is balanced by remote visual information from the patients. The increased dependency on vision is compensated by the high magnifications possible with new imaging technologies, or to use Ideh's (Ihde 1995) notion 'perception enhancing technologies', which results in surgical precision at scales that surgery based on touch has not able to achieve. These aspects demand special attention to the experience, perception, and embodied knowledge required for in vivo image-mediated surgical procedures.

Based on the rich empirical data from their use, it is clear that emerging visual technologies, either in the form of three-dimensional (3D) stereoscopic images from high-resolution (HD) cameras or four-dimensional (4D) images, such as those generated by the OsiriX® system, can help focus attention on very small details. By enlarging and enhancing the surgeon's visual capacity, this sophisticated technology makes numerous things perceptible but renders other things imperceptible. Surgeons can push a button on the console and pan the 3D camera to view the periphery, which provides them with a curved view (a so called "curved arcing view"). This image is a representation, or an indirect mediated view. During surgery, surgeons need to be able to evaluate the situation in the periphery outside the narrow working area. Most of today's vision systems do not provide surgeons with the entire peripheral view, which is available in traditional surgery, thus limiting their ability to observe the field from an angle other than a direct one. This limitation is especially salient in laparoscopic two-dimensional (2D) vision systems because this type of surgery does not generate a curved view but instead creates a flat view. Based on the detailed accounts of surgeons, however, the advantage gained by the new enhanced three-dimensional vision and heightened perception clearly outweighs any of the drawbacks of imperceptibility that may be related to the tunnel vision inherent in this indirect vision.

It is important to note that the surgeon's work still relies heavily on expertise and tacit knowledge; however, human experience and vision *per se* may not be enough for the surgeon to see and discern all the important and relevant anatomical structures needed to treat a patient successfully. Therefore, knowledge and mediated vision go hand in hand. The human actor is given new visual capabilities in the enactment with a series of assemblages that pertain to certain material qualities. We introduce the concept of "sensory awareness" (McLuhan 1964) to further discuss the fundamental transition involved in the interaction between technology and surgeons from a traditional unaided vision to a "multi-dimensional visual touch".

The theory of "sensory awareness" is central to McLuhan's (1964) philosophy, which portrays human existence in an increasingly technological world. This study considers the experiences from medical practices employing sophisticated visualisation technology. The concept of "sensory awareness" in this study explicitly emphasises the mutually enhancing and complementary characteristics of surgeons and their tools (both physical and mental) that assist in accomplishing tasks and activities. That is to say, robot technology applied in a medical setting supports and extends a surgeon's capabilities and sensory feedback. McLuhan (1964) maintains that the positive effect of putting a new medium or

technology to use is that it generally expands people's inherent senses. This, in turn, enables new ways of experiencing the world. Paradoxically, the negative effect is that any artificial extension of one sense simultaneously moves another sense to the background (i.e., an "amputation", in McLuhan's terminology). This dual effect is a common characteristic of most modern technologies, and it disproportionately unbalances our senses. Hence, innovative robot technology in surgery, for example, liberates former constraints, such as the limited human vision and lack of precise hand movements. At the same time, new robotic procedures create new constraints; they exclude abilities such as the sense of touch through the surgeon's fingers (often called force or haptic feedback) as well as temperature, viscosity and other characteristics that provide the surgeon with significant information.

"Sensing is believing" is the articulation of a theory that may help explain why most surgeons in this study exhibit frustration regarding the loss of physical sensation. Physical feedback for surgeons is a "situational feedback" mechanism or a reflective practice in action in which surgeons continuously "let the situation talk back" (Schön 1983). According to Donald Schön, practitioners may take the role of the artist in the "situational backtalk" and enter into a "reflective conversation with the materials of the situation". By physically experiencing the procedure and interacting with the patient in traditional open surgery (for example, by touching the internal structures and feeling the resistance), surgeons are actually engaged in a physical form of dialogue with the patient's body and organs (Hannaford 1996). Daston (2008) describes how insight and learned experience among individuals is developed in a type of "disciplination of the gaze" by focusing on what is important, which is an ability that is acquired through years of long-term training and day-to-day work in the OR (see also Goodwin (1994) seminal work on "professional vision").

Grasseni (2007) offers the related concept of "skilled visions" where multi-sensoriality, skilled movement, and changes in points of view are important for accomplishing objectives (see also Pink 2009, p. 13). Clearly, the surgeon's vision (or "the surgical gaze") involves the ability to inspect a multitude of visual representations of the anatomy that are captured and enhanced by the technologies described above.

2.5 Regimes of Visual Attention: Perceptibility and Imperceptibility

Perceptibility and imperceptibility are concepts that have been extensively discussed and empirically scrutinised in various management science settings (also known as business studies or business administration), particularly in studies drawing on related work in psychology (Bruner 1957; Tversky 1972) and in the field commonly known as organisation theory (Beyer et al. 1997; Louise and Sutton 1991). In this line of research, Dearborn and Simon's (1958) work on

managers' information management and decision-making is especially significant. More recently, Beyer et al. (1997) re-examined Dearborn and Simon's work on "selective perception" and found that cognitive labour can also direct attention away from certain information aggregates. Beyer et al. (1997) describe how professionals apply what they call "selective imperceptions", referring to people's occasional failure to perceive certain information.

Perceptibility and imperceptibility, however, are not two isolated dimensions of intellectual work and information handling capacity confined merely to intellectual (mentalistic) phenomena. Some organisational theorists have extended these terms beyond the mentalistic level towards human awareness and their connection to the senses. For example, Tsoukas and Chia (2002, p. 571) draw on Bergson's work *The Creative Mind* (published in 1946) to show that a key to making sense of the emergence of change (flux) and complexity in contemporary social and organisational settings is not necessarily an intellectual understanding (reflection), but rather the result of engaging with the sensory world. Thus, they argue "... turn toward sensation; bring yourself in touch with reality through intuition; get to know it from within or, to use Wittgenstein's (1958) famous aphorism, "don't think, but look" (para. 66). Only a direct perception of reality will enable one to get a glimpse of its most salient characteristics".

Following Tsoukas and Chai (2002, p. 571), human understanding and perception are closely linked to the use of the senses and are unfolding processes (what they refer to as movements) in which not necessarily reflection-based knowledge but rather "direct knowledge" of the constantly changing state of affairs is gained.

Clearly, new visual technologies are changing what can and cannot be detected by the senses in the new work regimes we describe. For example, one practitioner described how he literally could put his finger on the edge of a beating heart, which was displayed on a 4D image projection. By seeing the heart's movements, he was also able to observe previously unknown variations in a patient's anatomy, in this case, the internal volume of a beating heart ("the left lateral margin"), which the 4D OsiriX® reconstruction rendered visible. However, Tsoukas and Chai note that human perception is inherently limited because there will always be small variations that the sensory apparatus cannot detect. This fact is also true for visual technologies. Therefore, it becomes important to reflect on what reveals the imperceptible in the use of image-guided technologies. This observation is consonant with Murphy's point that "Seeing necessitates the designation of the unseeable, knowing the unknowable" (2006, p. 9).

More recent research shows that perceptibility and imperceptibility are both tightly interwoven with social practices, material cultures and complex technological infrastructures situated in wider socio-cultural environments. Along these lines and in Murphy's (2006, p. 24) terms, perception is thus distinguished

.... by historically specific modes of paying attention, which always necessitate strategic suspensions of perception. Perception involves historically produced disengagements from a broader field of bombardments for the sake of concentrating on and rendering intelligible a more narrowly differentiated set of phenomena.

Haraway (1991) here reminds us that there are no ahistorical and neutral images and no impartial photographs in scientific imaging practices, only specific viewpoints, or what she calls “visual possibilities”.

The ‘eyes’ made available in modern technological sciences shatter any idea of passive vision; these prosthetic devices show us that all eyes, including our own organic ones, are active perceptual systems, building in translations and specific ways of seeing, that is, ways of life. There is no unmediated photograph or passive camera obscura in scientific accounts of bodies and machines; there are only highly specific visual possibilities, each with a wonderfully detailed, active, partial way of organizing worlds (1991, p. 175).

Some scholars attempt to disentangle and historicise dominant domains of perceptibility. Murphy (2006) introduced the concept of “regimes of perceptibility and imperceptibility”, which is

... the regular and sedimented contours of perception and imperceptions produced within a disciplinary or epistemological tradition. Regimes of perceptibility are about more than just what we can see. As regimes, they were often understood by the historical actors employing them as natural or inevitable outcomes of social and technical arrangements. Produced by assemblages that are anchored in material culture, regimes of perceptibility establish what phenomena become perceptible and thus what phenomena come into being for us, giving objects boundaries and imbuing them with qualities. Regimes of perceptibility populate our world with some objects and not others, and they allow certain actions to be performed on those objects. (Murphy 2006, pp. 24–25)

Although this elaboration of “regimes of perceptibility” concerns ontological matters, also relevant is how regimes are embedded in the competing material, technological, and institutional cultures that affect epistemic practices. Regimes of perceptibility and imperceptibility are always situated in certain space–time segments and are therefore limited to particular materialities and physical settings.⁵ The forms of such regimes make certain socio-political, institutional and historical circumstances possible, Murphy argues. If we want to understand what is actually happening in image-guided medicine, we need to understand the dominant social ontology in epistemic practices. We also need to include the wider historical and material conditions in which dominant social ontologies of medical work are entrenched. Our initial premise was that

⁵ Murphy’s (2006) study accounts for how office personnel were exposed to dangerous chemicals in their work environments. She describes how there were simultaneous notions of “sickness” and “wellness” in the history of the ontology of chemical exposure. At a certain moment in time, what was considered imperceptible in a sick building later became re-defined and eventually known as “sick building syndrome”. This ontological shift occurred because a new expertise of a different type, with a new set of apparatuses, entered the scene and managed to capture “sickness” in the realm of the perceptible. In this line of reasoning, what constitutes a certain ontology regime is bound to local conditions and situates knowledge at a micro- or meso-level (such as in the context of buildings and surgical interfaces) but is at the same time also bound to wider historical and material conditions. The attractiveness of the phrase “regimes of perceptibility and imperceptibility” is that it appreciates the tension between the seeable and invisible, the knowable and unknowable, and the “existent” and “nonexistent” in certain historical and material conditions.

where surgeons' movements and the uses of senses change with new imaging technologies, so must their perceptual approaches and their embodied understandings of surgery itself.

2.5.1 Vision is Not An Isolated Given

Vision interacts with the other senses as part of the community of practice to which surgeons belong. This line of analysis has two important implications. First, images do not speak for themselves. Styhre (2010b) maintains that professional vision is never isolated but is rather manifested in shared professional norms and certain ways of thought in an organisational setting. Therefore, professional vision is always under the influence of these norms, as "... this gaze is never wholly self-enclosed but is instead always under the threat of disintegrating or falling apart. That is why specific thought collectives must maintain their authority and jurisdiction over certain 'ways of seeing'" (Styhre 2010b, pp. 72–73).

The production, analysis, and use of medical images are situated in a cultural context in what Foucault (1973) has described as "regimes of truth", which temporarily stabilise and institutionalise the borders between what is thinkable and unthinkable and what is reasonable and unreasonable in a medical setting. What is considered seeable or unseeable within a community of professionals, such as a community of physicians is, according to Foucault's line of reasoning, tightly coupled to power and authority.

While images produced in medicine (and in science) might appear objective and universal, only certain viewpoints are honoured, while others are overlooked. (Joyce 2005) Timmermans discusses (2008, p.170), on the one hand, a form of "disciplinary objectivity" in professional activities, but on the other hand is, of course, a "less disciplined objectivity". In professional practices, there are always openings for deviances, anomalies and differences in interpreting images. In the quest to divert from the tight disciplinary power of the thinkable and reasonable, new insights may arise and new knowledge and embodied knowing developed.

2.6 Touching New Visual Worlds: Discovering New Knowledge

There are times in life when the question of knowing if one can think differently than one thinks, and perceive differently than one sees, is absolutely necessary if one is to go on looking and reflecting at all. Michel Foucault, *The Use of Pleasure*

The distinction between "medicine as art" and "medicine as science" is still very much alive today. Our argument, however, is that the differences between the two may soon abate and that the two notions of medicine in fact are inseparable

and increasingly interlinked with technology. Hence, robotic surgery is a practice in which science, technology and art are combined. The experience and maturity, which some call artistic “intuition” (Cohn 2007, p. 93) of surgery are maintained in parallel with technological confidence and scientific certainty.

Knowledge is dependent on and embodied in the individual and, as von Krogh et al. suggest, “Where you stand or what you know determines what you see or what you choose to be relevant” (1994, p. 58). “Visual knowledge” (Cohn 2007) and “observation” thus become closely related. Haraway (2000, p. 160) argues, “[S]cientific knowledge is about witnessing. That is what the experimental method is about, the fact of being there”. In the intensified blending of science, medicine, and technology, multi-dimensional imaging instruments function partly as ordering devices. The shift in several scientific visual regimes is actually beginning to reshape medical practices as well as other domains in the natural sciences. This shift becomes especially salient in how multi-dimensional images *per se* become perceptible as scientific facts, as a result of new modes of organising and ordering of new data, information, and knowledge. While some aspects are made visible by the new forms of multi-dimensional representations, equally important is to question the limits of new image-based knowledge. As Murphy (2006, p. 91) notes, “To create knowledge means to create a tunnel where other things are not chosen”. Following Murphy, this means to ask what falls outside of the knowledge being produced under the present circumstances, which highlights the limits of regimes of perceptibility and their boundaries to the imperceptible.

It is important to study this shift in epistemic practices because imaging in the making also changes everyday conceptions of scientific enterprises. These new imaging practices represent a new form of art and science in modern medicine, and to use Nonaka and Takeuchi’s (1995) notion, robotic surgery “re-creates the professional environment”. It is still an art because image-guided robotic surgery and scientific imaging involve professional problem solving, expertise and social creativity because every patient or case is unique. It is still a science-based practice because it relies on the proper use of medical knowledge, which is based on application of best practices in the treatment of patients and which adds value to the health care system.

The particular shift we have discussed focuses on the replacement of human touch by 3-dimensional visual touch. Remote handling technologies are able to facilitate such an artificial metallic touch. Working through 3-dimensional images changes the type of surgical work carried out and the sensory relationships required and understood as knowledge. The shift in authority from touch to visual sensation in modern surgery is one we find increasingly predominant in contemporary culture and society in general. Interestingly, we see that scholars working in several scientific domains recently have begun to use 3D as well as 4D and 5D visualisation as a powerful instrument for innovative knowledge production.

Knowledge production is found in the way scientists interact with new tools. In an ethnographic study of human encounters with imaging technology, Morana Alac (2008) studied lab technicians’ interactions with functional magnetic resonance imaging (fMRI) data. Alac demonstrates how seeing digital images

“involves the hands as well as the eyes” (p. 505). Alac watches neuroscientists use gestures as an interface between their bodies and the technologies representing fMRI, manipulating digital displays and gesturing to make sense of their experimental data. In acknowledging the embodied process of ‘seeing’ fMRI, Alac demonstrates that “reading digital images enables them [neuroscientists] to re-enter a world of culturally meaningful embodied actions” (p. 504). These “gestural engagements” meet at the junction between the digital world and the world of embodied action (p. 484).

When images become tools, they also include their own “gestural engagements.” Daston and Galison (2007), write that “Images become tools like other tools, part of the apparatus—more like the computer screen that shows the workings of a distantly controlled robotic manipulation in remote surgery...” (p. 414). These practices meet at the junction between the digital world and the world of embodied action. Surgical instrumentation participates in adjusting how the surgeon navigates his or her material world, requiring a variety of gestures and directing surgical practices to stabilise human worlds. People’s actions might just as well be based on relationships with objects in the world as routine social activity (Schatzki et al. 2001, p. 19).

When images mediate the connection between the surgeon and a patient’s body, these actions necessarily change the way the body is understood (Beaulieu 2000; Waldby 2000). Understanding the world is accomplished through explicit and tacit knowledge, and part of this tacit knowledge must involve changes in sensorial focus and understandings that are a result of this focus. The surgeons interviewed in this study confirmed the challenges and triumphs of dealing with new imaging technologies as a change in their habitual understandings.

Interestingly, if applied appropriately, the very same complex imaging technology also leads to new forms of professional knowledge production. What we refer to as “multi-dimensional visual touch” currently serves as a key component in the development of professional surgical expertise. This chapter advances the idea that robotics and imaging devices in surgery are not only technological breakthroughs but also enable professionals to acquire new knowledge based on detailed 3D, 4D and 5D images. As Nancy Nersessian explains in “Creating Scientific Concepts”, “contrary to the popular image of science, ... conceptual innovation ... emerges from lengthy, organic processes and requires a combination of inherited and environmental conditions” (2008, p. ix). The imaging changes that occur in surgical practice are part of a larger context.

Addressing the initial distinction between “medicine as art” and “medicine as science”, it is useful to keep in mind that 3D technology does not result in creativity, innovation and new knowledge *per se* if it simply maintains the old ways of doing things. If 3D images merely reproduce known facts and representations of the world, just as artists from time to time reproduce and duplicate paintings and other forms of art, there is no real genuine incentive for change and innovation. However, if 3D, 4D and 5D images reveal something new and change the way people see the world, there is a foundation on which to develop new knowledge and understanding. The shift to either 3D, 4D or 5D visual technology still has professional

expertise at the centre of attention and relates to Webber's point that, "In the end, the location of the new economy is not in the technology or in the microchip or the global telecommunications network. It is in the human mind." (Webber 1993, p. 27).

In the case of 3D technology assisting surgeons in image-guided robotic surgery, 3D visual feedback is a sophisticated tool that incorporates certain skills in the configuration and distribution of image data to the surgeon. Our findings prove the fact that images must be processed and endowed with purpose, as well as a relevance that is ordered, interpreted, and analysed by professional surgeons. While a robot has the ability to collect and store data, it cannot analyse, interpret or act on the raw data generated from 3D imaging systems. The surgical robot in this case is not an "innovator" or a creative entity; it is a sophisticated tool. The knowledge eventually attained is embodied in a medical expert, and knowledge creation is characterised according to its relative tacitness and social embeddedness. As the nature of surgery changes, so will the demands for usable surgical expertise in the future. Our research suggests that the role of the surgeon has changed and will continue to change over the coming decades by scientific and technological breakthroughs in medical care. In light of the progression of modern high-tech health care, robotics is regarded both as a threat and an opportunity for contemporary professionals.

Based on an in-depth investigation of robotic surgery, we suggest that the phenomenon of 3D imaging technology affects how professionals experience the world and the capacity for 3D technology to guide human perception and action. While we focus on a limited case study of how vision is mediated by 3D technology in surgery, we also generalise this observation to the entire scientific domain because 3D, 4D and 5D imaging technology is changing the way science is conducted.

Multi-dimensional visual interaction implies a new method to perform work tasks. A wide variety of applications emerging from 3D imaging are starting to make a significant impact on key scientific progress in anthropology, archaeology, and medicine. The social motivation to innovate and adapt 3D image technology in science is related to the desire to improve social well-being as well as to advance knowledge. Anthropologists are now using high-resolution 3D videos as a conservation technique of artefacts (Scopigno et al. 2011) as well as for reconstructing ancient tombs and landscapes (Bruno 2010). Three-dimensional scanning data also provide scholars with a novel opportunity to store long-term digital archives of important cultural artefacts for future generations. For example, archaeologists have created a digitised 3D model in colour of Michelangelo's 5-metre statue of David. (Levoy et al. 2000) An article in *Science* recently reported that scholars have started using high-speed 3D video microscopy in medical experiments to better understand the underlying processes involved in viral transfer events, resulting in new knowledge that may help to develop future vaccines (Hübner et al. 2009). While the most recent usage of 3D image devices promise to revolutionise scientific practice in certain domains, much of the current knowledge about the emerging 3D applications remains based on computational modelling and 3D models of virtual places. The concept of 3D imaging in real-life may be moving from a potentially disruptive technology in science to crucial practice in other societal domains, such as entertainment, advertising, and education. This presents an area for future research.

We describe how the ability to see in depth in the real 3D world may also have a significant impact on other sectors and businesses in society. In endeavouring to attain the knowledge attributed to images, in combination with the precision images afford, gestural worlds shift and new possibilities arise.

2.7 Conclusion: Seeing and Knowing in Multi-Sensorial Worlds

As the surgeons' movements and use of senses are changed by the new imaging technologies, so must the surgeon's perceptual approaches and embodied understandings and knowledge of surgery change. Exploring the expansion of vision therefore contributes to an epistemological and ontological reconsideration.

Transitions in surgical practice provide an intimate view of the reconciliation of vision and touch. We propose the notion "visual touch", a conceptual middle ground between touch and vision, as a basis for future research in exploring contemporary institutional regimes of image-based work. "Visual touch" is both the process of reconciling the senses (human and artificial) and the end result of this sensorial union. In the words of the surgeons and the illustrators interviewed, there is a longing for what is yet to be known and done.

In our view, practices of seeing and knowing in multi-sensorial worlds are coupled to creative processes of serendipity in medical and scientific knowledge. When individuals are touching new visual worlds in real-time 3D, 4D or "5D" imaging, they are also able to discover unexpected knowledge and gain new insight. Changes in work practices sometimes make it impossible to return to previous times. It is a form of path dependency, where the decisions made in the past influence what we do in the present. Yet in the move to an image-mediated surgical experience, the multisensorial remains a topic of conversation—will surgeons continue to demand a more focused visual experience and deny the need for human touch and audio feedback, which some surgeons appear to appreciate doing without?

Another question that arises is whether it is possible for the surgical community to return to practices that do not emphasise vision. Indeed, it is possible to envision a different path where in the future, robotic technology will provide multisensory representations of the surroundings.

Institutional innovations consist of gradual adjustments to how we live in the world and may result in unplanned consequences (Pantzar and Shove 2010). Scholars who study organisational innovation see it as a continuous process of creation and evolution in what people do and consider acceptable behaviour. The transitioning sensory requirements of surgeons are part of a changing professional knowledge-based practice that is path-dependent. To obtain a more balanced picture of the future implications of multi-dimensional imaging technologies in robotic surgery and in other medical and scientific practices, these applications should be continually and thoroughly evaluated. This evaluation is not only to scientifically confirm the promised benefits of surgical processes but also to understand what is taken for granted in the world and how new and unexpected knowledge is discovered.

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