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Rediscovering radiology: New technologies and remedial action at the worksite

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Abstract
This study contributes to social studies of imaging and visualization practices within scientific and medical settings. The focus is on practices in radiology, which are bound up with visual records known as radiographs. The study addresses work following the introduction of a new imaging technology, tomosynthesis. Since it was a novel technology, there was limited knowledge of how to correctly analyse tomosynthesis images. To address this problem, a collective review session was arranged. The purpose of the present study was to uncover the practical work that took place during that session and to show how, and on what basis, new methods, interpretations and understandings were being generated. The analysis displays how the diagnostic work on patients' bodies was grounded in two sets of technologically produced renderings. This shows how expertise is not simply a matter of providing correct explanations, but also involves discovery work in which visual renderings are made transparent. Furthermore, the results point to how the disciplinary knowledge is intertwined with timely actions, which in turn, partly rely on established practices of manipulating and comparing images. The embodied and situated reasoning that enabled radiologists to discern objects in the images thus display expertise as inherently practical and domain-specific.

Keywords
computed tomography, ethnomethodology, medical imaging, professional vision, radiology, workplace studies

Introduction

With its focus on the use of images as hubs for knowledge production within scientific and medical settings, this study contributes to a growing body of social studies of scientific imaging and visualization practices (Burri and Dumit, 2008). We focus on work carried out within radiology, a practice bound up with the visual records known as radiographs. This highly specialized domain of expertise has figured in a number of social studies, and the resulting picture is that of a field with a variegated history and with ramifications far beyond the clinical setting. To give a very quick overview: x-ray imaging was invented in 1895, the same year as cinematography, and in the early days media industries, scientific performers and entrepreneurial showmen launched both technologies as something new and magical (Jülich, 2008). In a description of the developments between 1896 and 1928, Hessenbruch (2000) discusses how x-ray workers initially comprised local cultures that gradually developed methods for calibration and established themselves as a permanent work force within medical practice. Still, this introduction of radiology challenged the established legal theories and practices of illustration and proof maintained by the medical and the legal professions (Golan, 2004). More recently, much attention has been paid to the emergence of novel forms of imaging technologies. For instance, the introduction of digital visualization technologies in medicine after the 1970s challenged the position of radiologists as experts within the medical field (Burri and Dumit, 2008) and thereby altered organizational structures (Barley, 1986). While Prasad (2007) addresses the controversy surrounding the invention of magnetic resonance imaging (MRI), Joyce (2005) examines popular narratives used to discuss MRI examinations.

This large body of work, only hinted at through the few examples given above, includes bountiful discussions on technological advance, knowledge development and epistemic authority in relation to radiological practice. Less, however, has been written about how radiological work gets done through practical and ordinary actions. This condition is not unique for studies of radiology, but resonates with Garfinkel's suggestion that there is a 'gap' in the sociology of occupations and professions literature (Lynch, 1993). A series of empirical investigations, collected under the rubric of ethnomethodology's programme of studies of work (Garfinkel, 1986), followed in the wake of Garfinkel's proposal to study the 'missing what' of organized complexes of activity. As Button and Sharrock (2000: 46) summarize, this programme 'was itself developed as a corrective to the tendency of sociological studies titled as "studies of work" to attend almost everything that goes on in the workplace, except the work being done there'. Common to the analyses found in this tradition is their focus on lived activities in actual workplaces. Whereas current approaches to the study of work and organizations 'often examine large-scale organizational change, workplace studies turn the spotlight on the local production of work and organization' (Luff et al., 2000: 21). Great emphasis is put on aspects that are of topical relevance to the studied members. In other words, details of high technical specificity are often made central in the analyses, which in turn require greater competence of the analysts' vis-a-vis the studied domain.

In what follows, we will address the work that followed the introduction of a new imaging technology at a department of thoracic radiology. Here, the question of how professionals can make successful use of a novel technology before any practices have been established for the interpretation and application of that very technology is brought to the fore. This epistemological quandary will be analysed as a members' concern. In other words, the topics of technological advancement, knowledge development and epistemic authority do enter into our discussion as well, but they do so only by virtue of being matters identified and worked on by the studied practitioners.

The fundamental reliance on particular technological systems has direct consequences for the skills that radiologists develop, and it also shapes the conditions of competent action. This fact was discovered anew with the introduction of the novel medical imaging technology called chest tomosynthesis. The radiology department we studied was one of the first clinical practices to be given access to this technology together with a handful of other departments internationally. Tomosynthesis was immediately recognized to have considerable advantages over ordinary chest radiography. Within the first months of clinical use, it was shown that the detection of pulmonary nodules was significantly higher for tomosynthesis than for chest radiography when used by experienced thoracic radiologists (Vikgren et al., 2008). However, the fact that chest tomosynthesis has a limited depth resolution compared with computed tomography (CT) was considered a disadvantage for interpreting pathologies (Johnsson et al., 2010). In addition, because tomosynthesis was a new technology, knowledge of how to correctly analyse tomosynthesis images was limited. As a response to this new situation, a team of radiologists and medical physicists arranged a collective review session. During this session a batch of already assessed cases was discussed in order to highlight critical issues in the detection of pulmonary nodules, with the general aim of improving detection.

The purpose of this study, then, is to uncover the work that took place during the review session. By drawing on the members' methodic practices and reasoning, made publically available throughout this collective process, we aim to show how, and on what grounds, new methods, interpretations and understandings were being generated

Expertise, technology and practices of seeing

In much prior research, expertise is analytically approached as a capacity of the individual and also as a set of transferable problem-solving strategies (for an overview see Chi et al., 1988). In contradistinction to such approaches, this study draws on a notion of expertise as inherently practical and domain-specific. As Livingston (2006: 405) puts it, reasoning in domains of expertise 'belongs peculiarly to the practices from within which reasoning arises'. Furthermore, expertise is not seen as a mental activity residing exclusively in the individual mind, but as distributed among staff members and artefacts (Goodwin, 1994). This suggests that the new imaging technologies for representing human anatomy should be analysed as integral to the practices through which they are used (Goodwin, 1995).

In adopting this approach, we concur with a number of studies that show how professional seeing is locally organized and tied to the particular concerns of the practitioners. Outside medicine, such investigations have been carried out on in the domains of chemistry (Goodwin, 1997), law (Kashimura, 2005; Suchman, 2000), oceanographic research (Goodwin, 1995), architecture (Murphy, 2004), traffic control (Heath and Luff, 2000), TV production (Broth, 2009) and computer gaming (Reeves et al., 2009).

The analytical focus is thus placed on the practical and situationally contingent methods members develop and employ to highlight details in their immediate environment as relevant objects in work (with a focus on items such as documents, monitors or drawings). As Lynch (1985, 1988) shows, specific practices of organizing the perceptual field are required to discriminate instances of the phenomena under scrutiny (for instance, cellular organelles viewed with an electron microscope) from artefacts or other irrelevant or misleading features. This task of defining and disambiguating temporarily uncertain structures and fitting them into adequate (member-relevant) categories has been shown to be an intrinsic part of much scientific and diagnostic work.

The interpretative work needed to transform something unknown into something known is demonstrated in the groundbreaking study by Garfinkel, Lynch and Livingston (1981) on the discovery of an optical pulsar. The study follows the process in which the observation of a phenomenon with uncertain status, which Garfinkel et al. discuss in terms of an 'evidently vague IT' ('IT' is not an acronym, but the pronoun 'it', highlighted for analytical purposes), is reshaped into a shared object with relatively definite meaning and properties:

> [S]omehow it was 'evolved' from an evidently-vague IT which was an object-of-sorts with neither demonstrable sense nor reference, to a 'relatively finished object'. Some-how an evidently-vague IT became another object, 'the relatively finished work of the optically discovered pulsar'. (Garfinkel et al., 1981: 135, emphasis in original)

As argued by Koschmann and Zemel (2009), such processes of defining the 'evidently-vague IT' concern how practitioners are able to talk about and elaborate upon conceptions of things they still do not know exist, while those things are being discovered. This is of fundamental interest to our study, since it is through the very 'discovery-in-progress' (Koschmann and Zemel, 2009: 213) that reasoning in the domain of expertise becomes visible and accessible for novices and analysts alike. In the context of surgery, Hirschauer (1991) foregrounds how such processes of discovery involve comparisons between the available visual field, as enhanced through the surgeons' stepwise dissection, and mastery of decontextualized versions of the body as displayed in anatomical pictures. By identifying and classifying objects in the generalized body, the 'normal anatomy' of corresponding structures serves as a kind of reference guide. In this way, the classification work involves both performing the surgical dissection itself and, simultaneously, embodying 'the properties of anatomical pictures' (Hirschauer, 1991: 279). The visualization of something (yet) unknown is thus dependent on two levels of visibility, the physical body as visualized through the surgeons' dissection layer by layer, and the abstract version as represented in the discipline of anatomy.

In a similar vein, Koschmann et al. (2011) show how the practical work of surgeons involves continuous (discovery) processes of identifying discrete structures and their relations. They show, in line with Hirschauer (1991), how surgeons gradually increase the visibility of anatomical details and how such highlighting is aided by the memory of idealized anatomical representations (also see Koschmann et al., 2007). The identification of the cystic artery, for instance, relies on stepwise actions by the surgeons, enhancing the visibility of an anatomical feature called the triangle of Calot. This is enabled by surgeons switching their attention between the triangle of Calot, as it is unpacked step-by-step through surgical procedures, and as an abstraction. This, however, does not mean that there is only one reference point for identification. Instead the identification of the singular object, as an instance of a certain kind, emerges through a procedure in which the body at hand and the abstract versions of it mutually define each other. From this it follows that the accomplishment of identifying something that is as yet unknown, in the case of surgery both involves the practical work of successively describing the present body and the work of classifying it. Or as Hirschauer (1991: 300) puts it: 'Dissection, which is the precision work of making objects visible, is at the same time classification work.' As a consequence, he argues, skills and knowledge are tied to each other in the work of rendering details visible in terms of specific categories.

Similarly, identification and classification procedures in radiology involve a kind of dissection in which certain structures of the human anatomy are rendered visible, layer by layer. A crucial difference is that the manipulation of the human body itself is not possible. Instead, practices of enhancing the visibility of anatomical structures are employed through systematic manipulations and comparisons of medical images to highlight and compare objects (Alač, 2008; Büscher and Jensen, 2006; Prentice, 2005; Slack et al., 2007). Slack et al. (2007), for instance, show how the practical work of interpreting mammograms involves specific arrangements of x-ray images so that suspected structures are rendered both recognizable and accountable. By regularly putting lateral and frontal projections of mammograms beside each other, interpretations are both contested and confirmed among radiologists. In doing this, crucial distinctions are made between pathological and non-pathological objects–between, for example, what is to be regarded as a tumour or as a harmless lesion. Since radiologists operate on representations of the body, and not on the organs themselves as in surgery, they also have to judge if the mammograms are to be regarded as factual or artefactual. This is an added complexity, where the phenomena under scrutiny are to be judged as adequately represented or as merely occasioned by the technology itself (also see Lynch, 1985). The significance of enhancing visibility of objects, by juxtaposing different representations of the same structure, has also been found to be a central practice in interpreting magnetic resonance images in neurological research (Alač, 2008). Alač's study shows how processes of 'purification' of images were displayed to newcomers in the field by comparing and manipulating functional and structural images of the brain (known as fMRI and MRI respectively). This was systematically carried out by shearing, rotating and switching between the images. In line with the research of surgery and radiology practices referred to above, Alač shows how stepwise manipulations are also inherent parts of the interpretation process itself to make the targeted structures visible, and possibly to fit into professionally relevant categories.

Similarly, Prasad (2005) argues that diagnostic work in radiology involves practices of enhancing the visibility of pathologies and, simultaneously, imposing pictorial representations of the human anatomy on the visual field. By referring to such juxtapositions of the immediate and idealized versions of the body, he argues that a kind of bifocal vision is employed, in which the memory aid of anatomical atlases serves as a means for visualizing the entire body.

Differential viewing allows radiologists to visually extract only those anatomic details that are useful for 'zeroing in' on the pathology. Nonetheless, zeroing in is possible not only because of differential viewing but also because this gaze is bifocal. Visual learning of anatomic atlases by radiologists, which work as mnemonics when the radiologists are trying to fix pathology, provides them with an encompassing visual picture of the whole body (Prasad, 2005: 309).

In all, the studies of scientific and medical representational practices referred to above show how the organization of perceptual fields builds on both spatial arrangements of artefacts, manipulation of representations and specific practices for seeing. These are practices for making phenomena visible, publicly available and accountable, which can be seen as well established methods regularly employed in both scientific and medical work.

Of central interest, and as a shared point of departure in the research tradition referred to above, is that scientific and medical images cannot be conceived as producing neutral representations of 'natural' phenomena themselves. Consequently, from an analytical point of view, there is no pre-given correspondence between a naturalistic phenomenon and its representation. Different technologies highlight different aspects, which all rely on specific interpretative skills by their users for drawing conclusions on what is actually shown. Making visual judgments, when novel technologies for imaging are introduced, thus involves additional challenges in efforts to come to agreement on the relevant characteristics of phenomena at hand. In other words, both scientists and professionals in clinical medicine are forced by the practical circumstances to develop shared ways of seeing. Regularly, uncertainties have to be transformed into congruent ways of understanding and classifying objects. Koschmann et al. (2011: 521) suggest that such discovery processes can ultimately be understood as concerning 'a simple matter of trust', which concurs with the research interest in this study: how members of a professional practice trust each other to see the same things when a new imaging technology is introduced.

The present paper is an investigation of how participants in a session, aimed at overcoming diagnostic difficulties, contend with changing representations exhibited by a novel imaging technology, chest tomosynthesis. Of central interest is how they manage to correct erroneous judgments and to define the objects that actually caused these mistakes as they go along. Analytically, this is based on an interest in how indefinite structures in the scrutinized materials are transformed into objects with certain meanings and relevancies for the profession. A related issue explored here is how the participants' disciplinary knowledge and experiences from other, more established, imaging technologies enter into their interpretative work.

Tomosynthesis in clinical practice

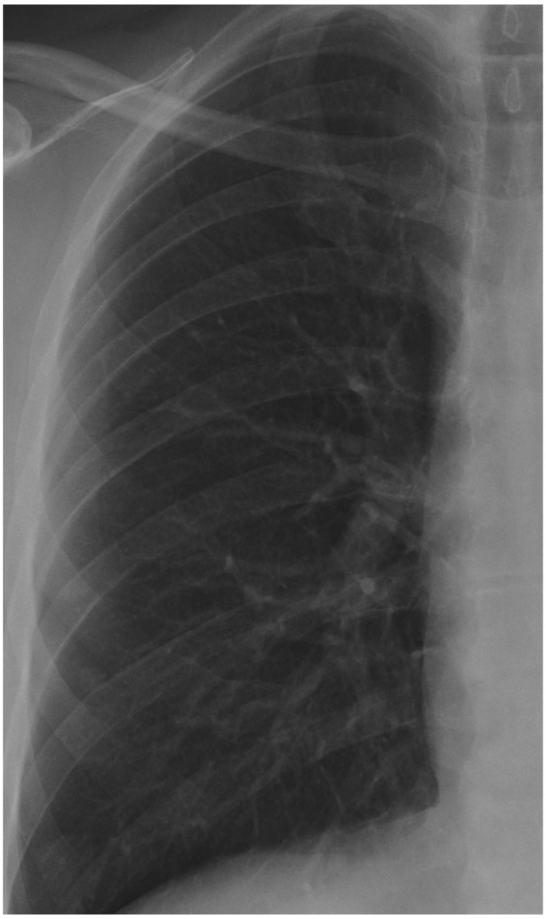
The clinical advantage of chest tomosynthesis over chest radiography is its potential to improve the detection of pulmonary diseases. Although more expensive than ordinary x-ray scans, it is far less expensive than CT, which is currently the only available alternative (Vikgren et al., 2008). Moreover, the amount of exposure to radiation for patients examined with tomosynthesis is only approximately 1/50 of a CT scan (Båth et al., 2010). In comparison to ordinary chest radiography tomosynthesis allows for the reconstruction of an arbitrary number of section images of the chest. This is possible by combining images from different angles produced by a moving x-ray tube. While the ordinary chest radiography examination results in projection images of the chest, a tomosynthesis examination results in section images, which are reconstructed with algorithms from projection images collected at different angles. In contrast to CT, it is not possible to call up sequences of section images in different orientations (coronal, transverse or sagittal). Instead only one of these orientations must be chosen in advance of the examination. Tomosynthesis thus provides a set of section images in one orientation, almost exclusively in the coronal (frontal) plane. Normally section images are reconstructed at 5 mm intervals. This generates approximately 60 images covering the entire chest. As with CT, one can move through the set of images in order to get a sense of the three-dimensional nature of the depicted anatomical structures.

One of the arguments for using tomosynthesis is its potential to depict pulmonary nodules with less interference from overlapping anatomy, such as ribs and other skeletal structures. Nodules are of specific interest in clinical diagnosis, because they can be a form of early-stage cancer. A nodule is often defined as a single lesion in the lung with a diameter less than 3 cm. Moreover, to be classified as a nodule, it should not be associated with pneumonia, lung collapse (atelectasis) or swollen lymph nodes. It is notable, especially for the purposes of the present study, that to meet the criteria for being a nodule the lesion should be completely surrounded by lung tissue. This means that abnormalities that emanate from the pleura (the layer covering the lung and its lobes) are not to be defined as nodules. Figure 1 shows an example of how nodules, which are very difficult to see with ordinary chest radiography, can be detected by tomosynthesis.

A crucial feature of tomosynthesis images is that they render structures in one section plane in sharp focus, while structures in adjacent sections are still visible but more blurred. This arises from the fact that the x-ray tube moves only 30º (the so-called limited angle tomography). The restricted angle implies that any reconstructed structure representing a single point in the three-dimensional chest cavity will contain information from other sections as well. The higher the attenuation of the x-ray beam in a structure (the term used to describe the absorption of x-rays), the more of that structure will be visible in other section images. A metal button on the thoracic wall, for instance, may be visible in all section images, from the front all the way to the rear. It means that highly attenuated structures such as the ribs, the vertebral column, calcifications, and so forth, are visualized not only in the section in which they are found, but also in several of the adjacent section images. In comparison, CT images are constructed on the basis of information collected from at least 180º. Consequently, they do not present such blurring effects. As a result of the incomplete scanning of the object, tomosynthesis images have poorer depth resolution than CT images. Tomosynthesis images thus represent anatomy differently from previous technologies and require changes in methods and judgmental criteria (Johnsson et al., 2010). The introduction of tomosynthesis is a typical example of how technological shifts place new demands on interpretative skills (Ivarsson and Säljö, 2005).

Arranging for visibility

Already, after a few months of clinical use, tomosynthesis had proved to be better for detecting pulmonary nodules than ordinary chest radiography (Vikgren et al., 2008). However, the perfor-



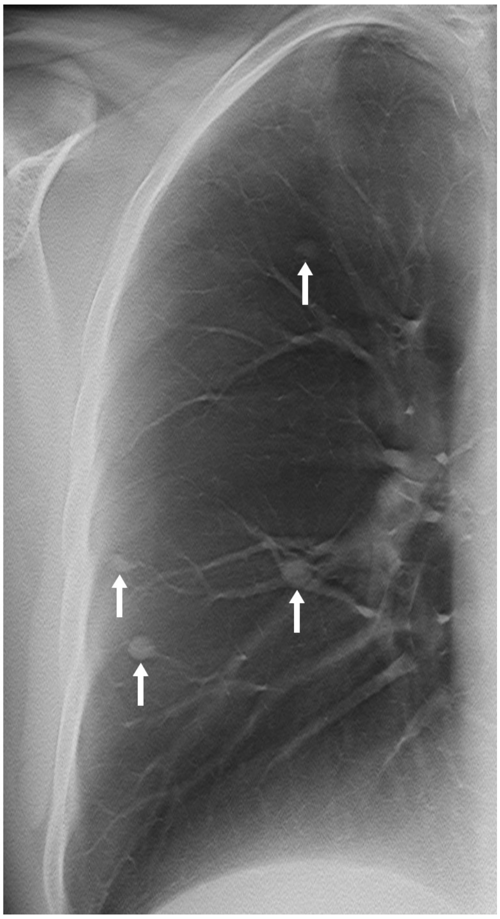


Figure 1. Two images from the same patient. The picture to the left shows a projection image from ordinary chest radiography and the right shows one of the section images from the tomosynthesis examination. Whereas several nodules are clearly visible in the right image, the same nodules are very difficult to discern in the left image. The arrows are inserted by the authors.

mance in nodule detection did not improve after additional clinical experience (Zachrisson et al., 2009). This occasioned the realization of a collective review session, internally termed an 'active learning session'. The authors of the present paper were involved in distinct ways. A research group at the departments of radiation physics (Asplund and Båth) and radiology (Allansdotter Johnsson) at the university hospital took the initiative to plan this session, and it was further designed in cooperation with researchers in the learning sciences (Rystedt and Ivarsson). The design of the review session was premised on the assumption that more deliberate and systematic methods for explicating the criteria for making judgments would improve diagnostic accuracy.

The basic material for the review session consisted of a collection of assessments of tomosynthesis scans of 25 patients who had also been examined with CT. In a first step, the assessments were made on an individual basis by seven reviewers. Their objective was to mark all suspected nodules in the tomosynthesis materials and to rate them on a four-grade confidence scale. On this scale '4' indicated a strong and '1' a weak probability that 'it' corresponded to a 'real' nodule. The reviewers were instructed to disregard all forms of lesion other than nodules.

In a second step, an experienced radiologist, using the CT scans for comparison, decided on which markings were to be considered true and false indications of a nodule. Since CT and tomosynthesis do not have compatible coordinate systems, the judgment relied on the radiologist's ability to discern the 'same' structures, despite the different methods of display with the two imaging technologies. In the review session, these judgments were contested in only a few cases. Then, all markings, their ratings and their originators were engrafted upon the material, and this information could later be accessed and displayed during the review session. If someone had not marked an instance of a true positive or had not marked an instance that someone else had marked, it was shown as a '0' (see Table 1). In total, 112 marked cases of real nodules and false positives were established, and these were displayed in the section image in which they had been entered. All 60 section images for each patient were available during the review session.

The review session included a third step. In addition to the seven reviewers, it included three active participants: the radiologist who had judged the markings, the project leader and a doctoral student in medical physics. It is important to note that out of the seven reviewers, only four were experienced thoracic radiologists regularly working at the department. Two of the remaining reviewers were physicians who had minor experience with thoracic radiology. The last one was a doctoral student in medical physics who had no experience with performing clinical diagnosis. There were several reasons for including these non-specialists into the process. One was to enable comparisons of the effect of the review session on experts versus non-experts in a follow up study (Asplund et al., 2011). A second reason for including non-specialists was to promote richer discussions on difficulties and problems in diagnosing pulmonary nodules. By installing an epistemic asymmetry in the relations between the expert and less experienced staff, it was expected that the methods and professional modes of reasoning for making critical distinctions would be further elaborated and demonstrated by the experts for the benefit of the novices (cf. Goodwin, 2000). As expected, there were many instances in the review session in which the experienced radiologists turned to the less experienced raters to answer questions or to elaborate on their explanations. This, however, is not the topic of the present study, which focuses on the experienced radiologists' accounts (in forthcoming work, we intend to address how they instructed the less experienced raters).

During the session both the tomosynthesis and corresponding CT slides for each patient were displayed simultaneously on two side-by-side projection screens at the front of the room. One display was monitored by the radiologist, who also had made the assessments of the CT scans, and the other by a doctoral student in medical physics who had inserted markings on the tomosynthesis slides and entered the results on the rating scale. When starting the review session, the project leader and the doctoral student explained the setup and how it was supposed to proceed. As a researcher in medical physics, the project leader was the one to whom the other participants turned to for explanations of the functionality of the technology. Moreover, he had the role of summing up diagnostic problems and criteria, and placing them in a protocol. The radiologist responsible for the reference method was monitoring the CT slides while the doctoral student showed, one at a time, the slides with markings of suspected nodules. Although she regularly changed slides, zoomed in, and so forth, when asked by the others, she was also the one who took the most initiative to move on to the next marking. The thoracic radiologists and the non-experts who had assessed the tomosynthesis slides were sitting in the middle. All participants had laser pointers, which they were requested to use for pointing at the images projected on the screen.

The review session under scrutiny has some similarities to rounds and other meetings in clinical settings in which problematic cases are presented and discussed. In such meetings, different technologies and methods of visualization are deliberately made use of, but in the present session the intention was to design a learning environment in which diagnostic problems could be both identified and resolved. We return to this reflexive relation between the session and the everyday practice of thoracic radiology in the final section.

The remedial work: First time through

In this section we present, in detail, that remedial work undertaken in order to collaboratively revise one of the 112 identified cases. This work starts with the identification and establishment of what is characterized as a false positive and ends with something that functions as a simultaneous explanation/description/categorization. In other words, in retrospect it is possible to see how this sequence works at the settlement of the false positive. However, we want to stress that this outcome was not available to the participating members during the process.

The presented sequence occurs approximately 1 hour and 20 minutes into the session, which eventually lasted for about 6 hours. Up until then, the group had been reviewing 16 cases of suspected nodules (divided between four different patients) and they now move on to case 17.

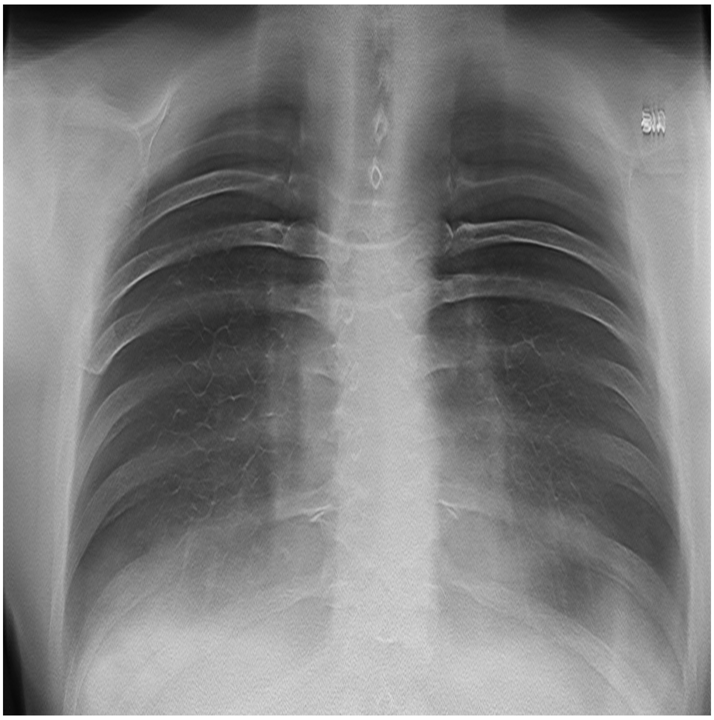


Figure 2. The chest tomosynthesis section image pertaining to case 17.

This transition is initiated when Pam asks, 'Should I take the next marking?' She then receives multiple confirming responses. Pam then changes the display of the tomosynthesis projector so that the section image with the annotations for case 17 is shown.

What becomes visible is the image illustrated in Figure 2 (with a close-up in Figure 3), along with the textual information from the individual reviews (see Table 1). The table first shows that this particular marking should not be considered a nodule. Mia, who is an experienced radiologist, had made this assessment based on the additional information provided by CT scans from the same patient. In addition, the table shows that Eve has marked this region with a '2' and that Ann has marked it with a '1'.

Mia, who is in charge of browsing through the CT images, takes it upon herself to localize the corresponding structure (Excerpt 1, line 100) and comments on her panning actions when

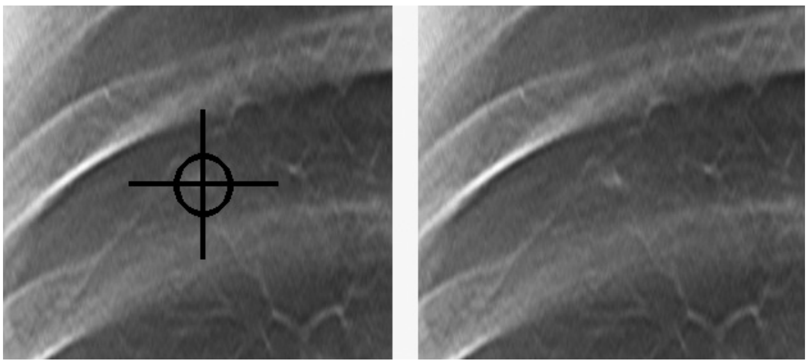


Figure 3. The same false positive marked with crosshair (left) and without annotation (right).

she centres the view on the left lung (line 102). The CT view is displayed through the transversal (horizontal) plane, and Mia begins by stepping upwards (towards the head) through the section images. She then stops and asks for confirmation on which direction she should take. Upon proposing that they should be looking further down (105) Mia receives a confirmation by Ann, who then adds that it should be 'pretty far back', referring to the locale in relation to a forward/backward direction in the thoracic cavity (108).

The work of providing directions is central to the activity. In line with Hanks' (1990) discussion of referential practices among the Maya, we can make a parallel observation here: radiological deixis is related to distinctly different orientational systems. One of these systems is the anatomical language that offers a nomenclature for describing areas of the body, and furthermore, distinct terms for orientations which are specifically employed to avoid ambiguities. Alongside this system, and as seen in Excerpt 1, the radiologists also make use of the referential terms of their mother tongue (for example, 'up', 'down', 'back').

While Mia continues to step through the different section images, Ann introduces her own previous actions as a topic for the talk. In line 110, Ann refers to the fact that she is one of the persons responsible for this marking. She continues (112) with a retrospective account matching her past 'thought', with the general description of nodules as 'something rounded'. The marking of something as a nodule when it is later discovered that it is not (that is, it is a false positive) is, not surprisingly, treated as problematic. In this setting it is positioned as an 'accountable action', in the sense that Sacks (1989: 37) describes as an act that calls for an explanation and correction. The introduction of case 17, and the lines up until the pause in 113, could thus be heard as setting the stage for remedial work that has to be undertaken.

In 114, Ann furnishes a counter to her previous mistake. By doing so, she does not simply dismiss the marking as mistake – a marking of nothing, as it were – rather, she treats it as marking something factual; a structure that can be localized and described.

Is the marking a nodule? Yes $\boxed{\text{No}}$

Eve	0	1	$\boxed{2}$	3	4
Mae	$\boxed{0}$	1	2	3	4
Sue	$\boxed{0}$	1	2	3	4
Ann	0	$\boxed{1}$	2	3	4
Lyn	$\boxed{0}$	1	2	3	4
Ada	$\boxed{0}$	1	2	3	4
Amy	$\boxed{0}$	1	2	3	4

Table 1. The individual markings made for Case 17. Eve, Mae, Sue, Ann are experienced radiologists, working in the department, whilst Lyn, Ada and Amy have less or no experience in the field. The scoring of a '0' as displayed in this table indicates that the reviewer either had missed a structure entirely or deemed it not a nodule. '1' indicates a weak and '4' a strong probability that it corresponds to a nodule.

In line 114, Ann begins to formulate what this structure could be. She provides an alternate, but still incomplete, description of the false positive as 'an interlobar fissure'. This term refers to the normal anatomy of the lung, where the lungs are divided into different lobes by folds of the visceral pleura called interlobar fissures (see Figure 4). The prosodic features of line 114 display a certain degree of tentativeness or uncertainty. Sue (116) aligns with Ann's proposition and adds that the fissure 'is folding itself somewhat'.

The conversation then returns to Mia's continued search for structure in the set of transversal CT images. Her comments on orientation and location ('up' in line 120, and 'down' in line 122) are heard as referring to the cranial and the caudal orientations respectively. After some 25 seconds, during which the others guide her in the search, Mia changes from section image 29 to 28. In this section, a structure is identified and tentatively proposed as a match for the marking (see Figure 5).

```
100 Mia: °e:::(h). let's have a look°
101      (0.7)
102 Mia: the other side
103      (2.3)
104 Sue: far [back
105 Mia:     [somewhat further down right=
106 Ann: =m:
107      (0.8)
108 Ann: pretty far back
109      (3.0)
110 Ann:→eh::m or is this on me
111      (0.6)
112 Ann: thought that there was someting rounded
113      (1.3)
114 Ann:→but is it not an interloba:r f:issure that
115      is somewhat
116 Sue: °yes° that is folding itself somewhat
117 Ann: eh- so I think that I [eh-
118 Pam:                       [there are two that
119      have mark[ed it
120 Mia:          [it has to be higher up
121      (0.3)
122 Mia: now I think I'm too far down in the CT image
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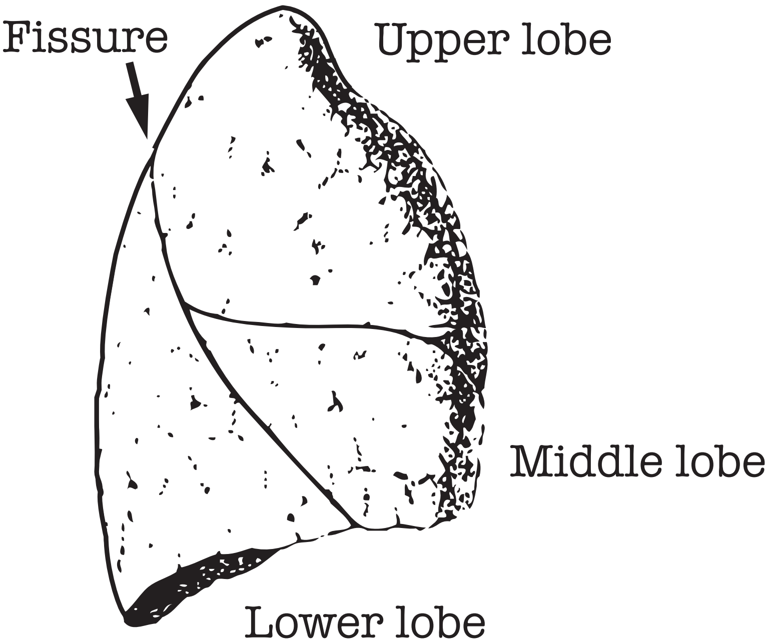

Figure 4. Schematic illustration of the right lung showing lobes and fissures.

Having seen the structure that is made visible in transversal section image 28, and commented on the possibility that it matches the marking in the tomosynthesis image, the participants quickly quit this particular view. Ann asks Mia to change the CT from the transversal into the coronal plane (the vertical back-to-front view) and a second round of searching is thereby initiated. While Mia begins to locate the structure, Ann returns to the previous topic: the account of her past actions (see Excerpt 2).

The conversation then returns to Mia's continued search for structure in the set of transversal CT images. Her comments on orientation and location ('up' in line 120, and 'down' in line 122) are heard as referring to the cranial and the caudal orientations respectively. After some 25

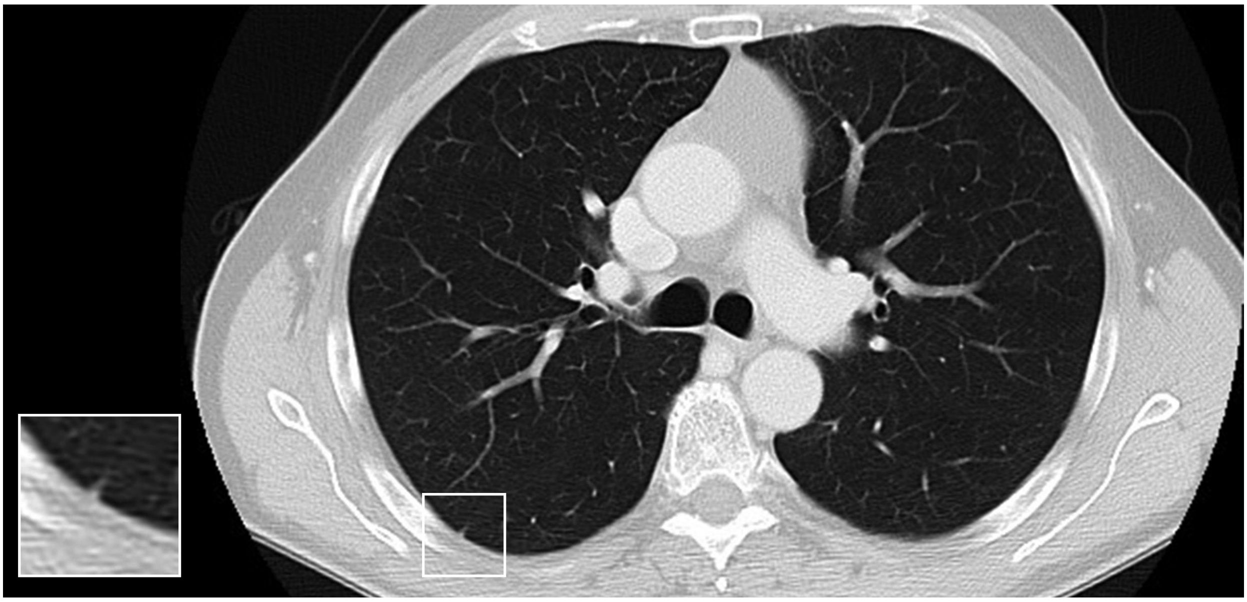

Figure 5. Transversal CT section image 28: The observable features of the false positive as depicted by the transversal CT.

```
200 Ann:→cause here- well e: I >thought in any
201      case that< that is probably a f-focal
202      thickening of a:n interlobar
203 Sue: m:
204 Ann: <fi:ssure> but it is very ha:rd even
205      on the CT sometimes to see if it is
206      a nodule or not
```

seconds, during which the others guide her in the search, Mia changes from section image 29 to 28. In this section, a structure is identified and tentatively proposed as a match for the marking (see Figure 5).

Having seen the structure that is made visible in transversal section image 28, and commented on the possibility that it matches the marking in the tomosynthesis image, the participants quickly quit this particular view. Ann asks Mia to change the CT from the transversal into the coronal plane (the vertical back-to-front view) and a second round of searching is thereby initiated. While Mia begins to locate the structure, Ann returns to the previous topic: the account of her past actions (see Excerpt 2).

In line 200, Ann reiterates her comment about thinking of this as an interlobar fissure. This time, though, she adds the notion of a 'focal thickening', though she prefaces this with an emphatic qualifier, 'probably'. In this way, the previously mentioned normal anatomical structure becomes further specified and positioned as a possible deviant case.

The work of locating the structure in the coronal plane turns out to be more difficult than it was in the transversal plane. For more than a minute, Mia browses through the set of images, and with the aid of the other participants, she tries to find the corresponding spot.

In line 300, Ann makes a request for images further back in the patient's anatomy. This request is supported by the claim that they are 'still on hilum level', which means that they are seeing information from the central parts of the lungs (Latin hilum pulmonis). Throughout lines 300 to 318 Mia continuously steps backwards and offers a few comments pertaining to their current localization. The different place formulations offered here ('on hilum level' and 'close to the rib bones') could be heard as conflicting, as they define separate localities. However, it should be noted that the two independent screens (with views that are not necessarily mutually coordinated) offer separate referential grounds on to which such deictic expressions can be tied. Ann's

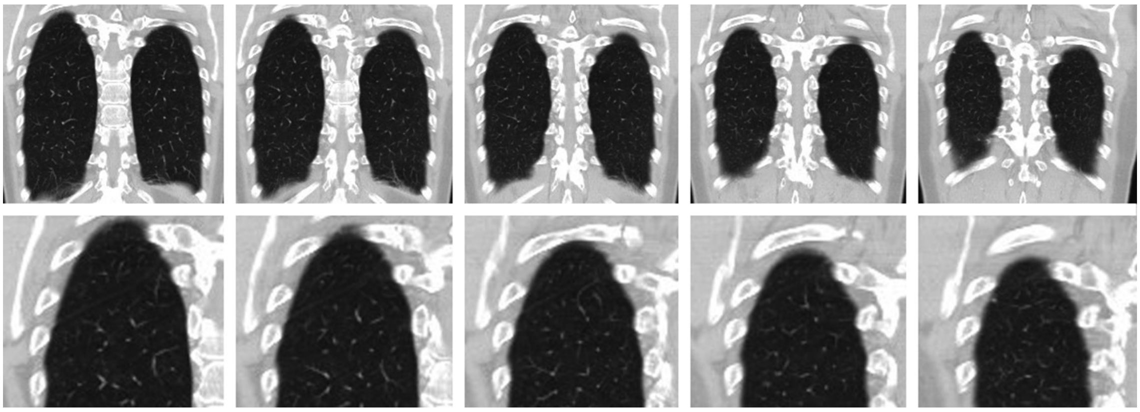

Figure 6. Coronal CT section images 75 to 79, with enlargements of the top of the right lung shown below. The shift to each image is indicated in Excerpt 3 by #75, #76 and so on.

specification 'on the CT' (line 301) makes it clear that she is talking about what is visible in the left image at this very instant. In contrast, the following comments are less explicit about where the talk belongs. Sue, and subsequently Mae, both re-use materials that are provided from the prior talk ('we are'), a conversational practice described as 'format tying' (Goodwin, 1990). One feature of this practice is that by 'maintaining the shape of the prior utterance the new elements of the utterance are rendered salient; they stand out in opposition to the prior move's compo-

```
300 Ann: >below then< further back we're still on
301      hilum: level right on the CT
302      (0.4)
303 Sue: we're very close to the rib[bones
304 Mae:                             [very close to
305      the rib bones yes
306      (2.1)
307 Ada: okay
308      (0.6)
309 Ann: stop eh somewhat further back still (0.2)
310      °I believe we can come°
311 Mae: there
312      (0.2)#(0.3)
313 ct         #75
314 Ann: °that #it is°
315 ct          #76
316      (0.3)#(0.4)
317 ct         #77
318 Ann:→this #is the f#i:ssures' >THERE<
319 ct         #78      #79
320 Eve: (m) [there inside (has-)
321 Mae:     [th[ere yes
322 Ann:        [>there it is<=
323 Eve: =there is [a dot right=
324                [((encircles a structure
325                [  with the laser pointer))
326 Pam:           [m:
327 Mae: =°.(h)y[e:s°
328 Ann:→       [kind of [that focal thickening of the
329                      [((brings in her laser
330                          pointer to the same area
331                          as shown by Eve))
332      interlobar fissure where it [sta::rts:
333 Eve:                             [you can see
334      precisely how it goes down in that dip there
```

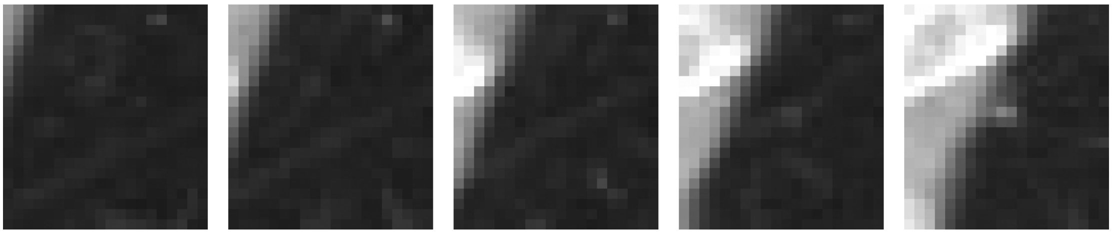

Figure 7. Enlargements of the same area of coronal CT section images 75 to 79 where the final frame shows the identified structure.

nents because the rest of the utterance maintains the same' (Goodwin, 2006: 12). But rather than offering an opposing description to Ann's account, Sue's move implies a form of perspective-switching (Ochs et al., 1996). Her comment is perfectly understandable as a reference to the point shown by the right screen (tomosynthesis). This place also happens to be the target for the searching activity, with the CT and the second place formulation possibly seen as an elaboration of Ann's request that also provides additional directions to Mia.

In line 318, there is a clear turn of events. The precise timing of these events is interesting, as it reveals something about the participants' professional attunement to the task at hand. Ann begins an utterance that refers to the interlobar fissure ('this is the fissure's'). During this stretch of talk, two new section images are displayed. Image 78 is shown for 0.4 seconds and then replaced with image 79. Image 79 is displayed right after Ann has started to produce the word 'fissure's'. This word is finished but the completion of the projected turn construction unit is aborted. Instead Ann calls out a distinct and loud 'there!'. Figure 7 gives a better indication of the level of detail that is furnished by the CT images. As can be seen in the last frame, the visual information pertaining to the sought-for structure is but a few pixels across. Despite this, it takes only 0.3 seconds from the appearance of image 79 until Ann begins to verbalize her observation. Furthermore, she almost instantaneously receives multiple confirmations from other participants. However, the only participants who display their understanding here are the experienced radiologists. It is also noticeable that their responses are not provoked by any form of prior gesture. Not until line 324 does Eve supplement her comment with an encircling gesture with the laser pointer, thereby making the first move to instruct everyone where to look. From this we take it that the radiologists in the group already have focused their attention on the relevant area. The exchanges between lines 318 to 323 thus provide a vivid demonstration of professional competence in action.

In 328–332 Ann delivers what becomes the final description of the visible structure and, in effect, the resolution of the troublesome false positive ('kind of that focal thickening of the interlobar fissure where it starts'). In comparison to previous versions (114, 201–204), the description this time is produced without any form of hedge. Furthermore, the description is now unequivocally tied to the visible structure through the deictic 'that'. In addition to the deviation ('focal thickening') from normal anatomy ('interlobar fissure'), Ann also specifies a precise location for the structure ('where it starts'). Although this finding itself leads into further discussion about the future possibilities or impossibilities of avoiding similar mistakes, the description becomes, for all practical purposes, a settlement of the matter of the unknown structure.

Case 17 recovered: The work of finding IT

In the previous section, we could observe the treatment of the false positive as a factual, albeit unknown, structure and the ensuing transformation of this unknown entity into a finished object, with a specific meaning and relevance for the profession. In this section, we aim to reiterate the same story, but recast somewhat differently, and specifically in terms of work done on a 'Sacksian IT', a pronominal reference that has not yet secured a nominal referent.

To begin with, the very establishment of this 'IT' emerges from the individual ratings previously made by the participants. As these were displayed side-by-side, any incongruities between earlier judgments were effectively exhibited. The CT-informed judgment stating whether the displayed marking should be regarded a nodule or not was also tied to this array. On the basis of this configuration of information, the participants with divergent judgments were regularly the ones who initiated the sequence of remedial actions, and they did so through the provision of some form of account. A general characteristic of these accounts was that they were 'answerable to the distinctive interests of the group' (Goodwin, 1994: 606). In this case, the account-givers performed the work of connecting the underspecified markings with professionally relevant categorizations, however provisional at that point (for example, 'something rounded' alluded to the definition of nodules). The accounts would then pave the way for discussions that topicalized the expert's reasons for making the incorrect judgments. These discussions were concerned with structures that could have caused the errors, and procedures through which similar mistakes could be avoided. We regard the framing of the situation in this way as a way to make the event instructional.

The first step undertaken to enhance the definitiveness of the 'IT' in question, was the search for the corresponding structure in the CT slice showing the transversal plane (this occurs throughout Excerpt 1). At this point, 'first time through' (Garfinkel et al., 1981), the evidently vague IT called for further investigation. It was not yet known if what could be discerned visually was caused by some pathology, by a structure corresponding to the normal anatomy, or, by a non-pathological variation from normal anatomy. Some, but not all, of these possibilities were subsequently ruled out when the IT was attributed to the, still vague and hypothetical, status as an 'interlobar fissure'. In an interjected confirmatory response, Sue also suggested that it 'is folding itself somewhat' (Excerpt 1, line 116). For an experienced radiologist, this remark is hearable as noting a deviation from an expected linear shape of the fissure.

The subsequently achieved localization of a possible corresponding structure in the transverse plane (see Figure 5) did not rebut the proposal on the floor, but it also did not conclude the business-at-hand. At this point, the definitiveness of the IT became further qualified when Ann suggested that it was 'probably a focal thickening' of an interlobar fissure (Excerpt 2, line 201). This comment could be heard as an extension of Sue's previous remark on the folding fissure. In the daily diagnostic work of the radiologists, the notion of 'focal thickenings' is regarded as an imprecise description and is used as a pointer to presumed benign but concentrated variations. In the case of possible malignant structures, such suspicions will be communicated through the use of other designations, which are considered to be more indicative of the pathology.

The group then turned to the coronal (frontal) plane of the CT to again find the corresponding structure. The localization work in this singular case shows that anatomy was used as a 'topographical language' (Mol, 2002: 48), or a 'map of the terrain' (Lesgold et al., 1988: 321), for finding the requested structure. Although IT had already been localized in the transversal plane (of the CT) it was far from self-evident in what section IT would be situated in the coronal plane. In this collaborative searching activity, descriptions such as 'the hilum level' and 'close to the rib bones' were used as guiding topographic landmarks. Eventually, so too was the fissure itself. In the coronal plane, the fissure, as it extends throughout the volume of the lung, became an observable and traceable object, visible in a series of adjacent section images. We can also note that the participants displayed their orientations to this elongated structure ('this is the fissure's' in Excerpt 3, line 318) immediately before the final identification ('there!').

In the final part of the examined sequence, the developingly objective character of IT reached its apex, through the almost simultaneous confirmations from all of the experienced radiologists (Excerpt 3, Lines 318–327). On this occasion, the IT was also attributed additional characteristics affirming its status as an instance of a focal thickening of an interlobar fissure: first, by the statement that it is located where the fissure 'starts', and second by 'it goes down in that dip there'. The precise location of the no-longer-so-vague IT, vis-a-vis other visible structures, was treated as decisive for how to perform the description. The achieved definitiveness of IT was thus not given by the last image (Figure 7). On the contrary, the sequence illustrates the kind of situated work that was required in order to transform the evidently vague IT into the '"performatively" objective' (Garfinkel et al., 1981: 137) focal-thickening-of-an-interlobar-fissure.

These situated inquiries relied on a whole sequence of actions; that is, sequentially developed and technically detailed professional ways of acting. Although both our analysis, and that of the practitioners themselves, can offer only retrospective descriptions of these practices, it also is necessary to acknowledge their relation to concrete practices. As Garfinkel et al. (1981: 140) assert, such practices are 'done in detail; they are real worldly, and they consists of all that detail can be in technical, material contents'.

The grounds for revising practice

One question that arises for us is: What kinds of resources did the experts rely upon in their work? First, as touched upon above, anatomy (as a discipline) could be viewed as providing a language and a map, both for orienting to the patient's body and for categorizing the structures rendered visible. The perennial problem with the discipline of anatomy is that it presents standardized and idealized versions of the human body. Inevitably, the anatomy of any single individual always deviates more or less from these standards. Reaching for a definition of an unknown structure in a set of medical images will, in the first instance, involve a decision about whether this structure is abnormal or not. As discussed above, a deviation need not be classified as a pathological one, because it can as easily be understood in terms of a local variation, deviating from idealized versions of the normal anatomy (Hirschauer, 1991; Prasad, 2005). For a practitioner to relevantly categorize an unknown structure in a set of images as pathological, it is necessary not only to know what constitutes pathological deviations, but also to know what variations of human anatomy can count as non-pathological.

A second part of an answer to our question is intertwined with the whatness discussed in the above paragraph, and pertains to the whereness of the structure in question. Since each image, as a stand-alone object, provided limited information (see Figure 7), the location of the structure under scrutiny was decisive for judgments on what it represented. Many decisions about whether the recognized structures were nodules or not were based on their observed connections to pleura (the tissues surrounding the lungs). By reference to the working definition of nodules, any scrutinized structure that could be deemed part of the pleura would be removed from the list of suspected nodules. Case 17, analysed above, provides an instance of this point, since the observed feature in the transversal CT image (Figure 5) is visibly connected to the layer covering the outer surface of the lungs. However, if it had been surrounded by parenchyma it would still remain suspect. Regularly, however, the participants did not stop there, but instead worked out a more precise judgment in terms of clinical categories. In the sequence analysed, the terminal decision that IT was 'a focal thickening of the interlobar fissure' required a very precise localization. This was accomplished by tracing the fissure through several section images of the lung to the point where it folded in between two lobes. Since the interlobar fissure is also a part of the pleura, the structure is not a nodule, by definition. Arriving at statements such as this is at the heart of diagnostic work. For the purposes of the arranged review session, the achieved definitiveness of IT additionally served as a satisfactory explanation and display of the reasons for the initial erroneous interpretation.

The professional revisions imposed by novel technologies necessarily have to contend with changes from the older technologies. However, in light of our observations, there also seem to be continuities that offer stability through such technological shifts. Apparently, a new difficulty was introduced by tomosynthesis, because of the ways in which highly attenuated structures were smeared out to adjacent section images. This resulted because the localization of structures in tomosynthesis was represented in an entirely different manner than with CT, a fact that contributed to many erroneous judgments (Asplund et al., 2011). A CT scan would depict a structure as a part of the pleura (as exemplified in Figure 5), but tomosynthesis often produced the illusion that structures were situated in the lung parenchyma. In spite of this, the appearance of deviant structures had clear similarities with other x-ray technologies in which discernment of contrast differences are basic. In addition, an established method employed in diagnosing CT scans was transferred for use in tomosynthesis – to scrutinize sequences of section images and to compare each section of particular interest with adjacent sections. This practice of systematically comparing different section images could therefore be seen as bridging the technologies.

Conclusion

Our analysis showed how diagnostic work was grounded in the presumed natural accountability of the examined patients' bodies and the two sets of technologically produced renderings. In addition, the very set-up of the review session provided enabling conditions for what was accomplished: two separate projector screens allowed for side-by-side comparisons of CT and tomosynthesis data; historical records of all individual markings effectively displayed any incongruities with earlier judgments. The use of large screens enabled constant comparisons and the public organization of a perceptual field (Lynch, 1985, 1988), which in turn allowed for transformations of uncertainties into congruent ways of understanding and classifying objects. This shows how expertise is not simply about providing correct explanations, but also involves discovery work in which competent seeing is made transparent. Furthermore, the results point to how the disciplinary knowledge is intertwined with timely actions, which in turn partly rely on established practices of manipulating and comparing images. The embodied and situated reasoning that led up to the definitions of objects in the radiological image thus display expertise as inherently practical and domain-specific (see Livingston, 2006).

Finally, we want to locate the studied practice of radiology in relation to Garfinkel and his colleagues' (1981) discussion of the natural sciences as discovering sciences. On the one hand, it can easily be recognized that the practical actions of finding or discerning pathologies that are otherwise veiled from plain view by layers of living tissue, are at the very heart of this profession. On the other hand, the present study, through its focus on the reflexive and collaborative activity in the review session, is also about how the members of the discipline must find their way in an expanded technological milieu. In order to preserve the outcome of the ordinary day's work, the staff found the need to calibrate their methods, interpretations and understandings with respect to a novel technology. As already noted, much research in the field of science and technology studies shows how technological advances in radiology challenge both the positions of experts and existing organizational structures (Barley, 1986; Burri and Dumit, 2008; Dussauge, 2008; Prasad, 2007). Our study extends this discussion by providing an example of how such changes are dealt with in situ. In this case, they did so by articulating criteria aimed at improving diagnostic accuracy. Our study focused on practical diagnostic reasoning in anatomy, but we also examined the workings of the technologies and the radiologists' methods for making their work accountable. Our close analysis of the endogenous activity in the review session thus brought into view some of the remedial actions that enabled the reflexive rediscovery of radiology. In this sense, the study points to the general dilemma of changed conditions that leave the practitioners without precedents. In their struggle to overcome such challenges, posed for instance by technological advances, the members had to converge on new methods and interpretations. In this specific case, this was turned into an activity in and of itself. However, we also hold that under ordinary conditions this management of professional accountability is an integral part of clinical practice, as fields of expertise are constantly being renegotiated from within.

Note

This study stems from an interdisciplinary collaboration organized through the Learning and Media Technology Studio (LETStudio), a strategic initiative for promoting interdisciplinary research in the area of the Learning Sciences at The University of Gothenburg. The present work involved researchers from the Department of Radiation Physics, the Department of Radiology, and the Department of Education, Communication and Learning. The study reported here could not have been accomplished without several sources of funding. It was supported by The Linnaeus Centre for Research on Learning, Interaction and Mediated Communication in Contemporary Society, The University of Gothenburg Learning and Media Technology Studio, The LearnMedImage project (The Academy of Finland, project 128766), The Swedish Research Council (projects 2005–3260, 2010–5105 and 2011–488), the Swedish Radiation Safety Authority, the King Gustav V Jubilee Clinic Cancer Research Foundation, the Health & Medical Care Committee of the Region Västra Götaland, and the Swedish Federal Government under the LUA/ALF agreement. Finally, we are deeply indebted to our anonymous reviewers for helping us to improve this paper and to make our arguments clearer.

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