# Philosophical Issues in Medical Imaging

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## Abstract

This chapter aims to shed light on the normative questions raised by medical imaging (MI), paving the way for interdisciplinary dialogue and further philosophical exploration. MI comprises noninvasive techniques aimed at visualizing internal human body structures to aid in explanation, diagnosis, and monitoring of health conditions. MI requires interpretation by specialized professionals, and is routinely employed across medical disciplines. It is entrenched in clinical guidelines and therapeutic interventions. Moreover, it is a dynamic research field, witnessing ongoing technological advancements. After surveying philosophical issues arising from MI, which are relatively unexplored, the chapter focuses on the epistemology of diagnostic imaging. Specifically, it delves into what constitutes an image as evidence and how radiological procedures generate knowledge. The discussion dissects three facets of the radiological process: image interpretation, radiological reporting, and semantic analysis. Each facet carries distinct epistemic implications, as errors can manifest in various ways, affecting the acquisition of patient-relevant knowledge.

**Keywords**

medical imaging, radiology, epistemology, medical error, oncology, diagnosis

## Introduction: What is medical imaging

Medical imaging (MI) is a set of noninvasive procedures for creating images of the inner parts of the human body, with the main aim of explaining, diagnosing, and monitoring health-relevant conditions. The most widely used imaging modalities at the time of writing include X-rays (conventional radiology), computed tomography (CT), positron emission tomography (PET), magnetic resonance imaging (MRI), ultrasound (US) or sonography, and hybrid modalities, such as PET-CT. What they all have in common is that the information provided is presented in the form of an image, which needs to be interpreted or “read” by a specialized professional—most frequently, a radiologist.

Medical imaging is an essential part of health care today. Imaging diagnostic tests are routinely employed in emergency departments, in oncology, cardiology, and gynecology—to mention just a few medical fields where their use is pervasive. Imaging tests are included in official clinical guidelines for many conditions, from cancer to healthy pregnancy, and they are increasingly requested by patients and doctors alike. Imaging procedures are also employed in therapeutic interventions, either for guiding the intervention (such as fluoroscopy in orthopedics) and for directly performing it (such as in coronary catheter implantation). Medical imaging has a role in prevention as well; screening for breast cancer, for example, involves mammography, a kind of X-ray procedure. Medical imaging, however, also plays an essential part in the rising cost of health care. Depending on their novelty and technological complexity, imaging procedures may be very expensive for health-care systems, or for patients if they pay out-of-pocket. For this reason, their diffusion is not uniform, both geographically and socially; moreover, they are a resource not to be wasted.

Medical imaging is a research field in medicine, and a rapidly evolving one. New imaging techniques, combinations of existing ones, and specific applications are introduced every year. Within diagnostic imaging, as a new test becomes available, imaging specialists—often specialists in clinical fields, such as cardiologists or oncologists—investigate whether it fares better than the current best method (gold standard) with a specific clinical question (diagnostic studies). The impact on patient management, its cost-effectiveness, and the appropriate use of procedures is also assessed.

Beside diagnostics, imaging is central to most medical research fields; for example, imaging data are relevant to drug development, both in the preclinical and in the clinical phases, and to epidemiology and the classification of diseases. Most recent research fields involving imaging are radiomics and theranostics, both with applications in oncology. Radiomics combines a big data approach with artificial intelligence, and consists of the mathematical analysis of large datasets of images (for now, mostly from cancer diagnosis), with the promise (not yet fulfilled at the time of writing) of extracting information with predictive and clinical value (Lee et al. 2017; Guiot et al. 2022). Theranostics (therapy and diagnostics) is the use of the same agent both for diagnosing and for intervening in a condition (Chen and Wong 2014).

## A selection of questions for philosophers of medicine

All the above-mentioned aspects of medical imaging—the set of technologies, importance in health care and research—present questions that fall within the scope of the philosophy of medicine, intended as an empirically informed and possibly interdisciplinary normative discipline, which studies medical knowledge and medical concepts. Such questions include the nature of evidence that images provide, the epistemology of diagnostic imaging, and the limits of evidence-based medicine (EBM) when applied to imaging research. Other issues raised by the role of medical imaging tests in health care, such as whether they are overused (used too much, when they are not needed) lay at the intersection between philosophy of medicine and bioethics, for they involve our concepts of health-care fairness and diagnostic justice (Hofmann 2010; Kennedy and Cwik 2021). There are also specific questions debated within the medical imaging scientific community that are conceptual in nature, and therefore call for philosophical expertise; for example, how to define the gold standard (the epistemic benchmark) for diagnostic studies (Claassen 2005), whether theranostics is really a new approach or just a new name (Simon 2021; Wiesing 2019), and the notion of medical error in the specific case of image reading (see section 4.1). It is therefore likely, and arguably desirable, that the philosophy of medicine in the future will pay more attention to medical imaging than it has done so far, with a few exceptions (see also Lalumera and Fanti 2020 for an overview). This would also be in line with a general tendency towards specialized and applied philosophies of medicine (Stegenga et al. 2016).

The main goal of this chapter is to present a narrow selection of questions that may be important for present and future developments in the philosophy of medical imaging, out of the many possible topics that may be of interest to philosophers of medicine. The proposed selection is perspectival in that it privileges the epistemology of diagnostic imaging (or the epistemology of radiology, in a broad sense of the letter term). The guiding idea is that diagnostic imaging raises normative epistemic questions at different levels. These normative questions are parallel with the empirical questions that the medical community is confronted with—and this counts as a further point in favor of choosing questions, from the point of view adopted here, that prefer an interdisciplinary approach to the philosophy of medicine. Let us introduce these questions with an example.

Anna, an otherwise healthy woman in her forties, has been suffering from moderate lower back pain for a couple of months. Her family doctor requests a CT scan for her at the local hospital, to see what the cause of the pain might be. The radiologist from the hospital reports to the doctor that the CT scan shows a herniated disk. The doctor tells her that this is probably the cause of her pain. An epistemic assessment of this item of medical knowledge (in a non-factive sense of the term) includes different steps. By virtue of the CT image, what is the evidence regarding the inner features of Anna’s body? What is needed for the radiologist’s report to be correct? How do we know whether the CT scan test is a good test for the clinical question posed by Anna’s symptoms? Moreover, was the doctor right in referring Anna to a clinical radiologist?

Indirect proof that these questions tap into different aspects comes from considering the different ways in which something can go wrong in Anna’s scenario. It can be the case that CT scan provides a good enough image of Anna’s spine, but the radiological report is not correct. Or it can be that the radiological report is correct, but a lower back CT scan shouldn’t have been done for Anna, because other imaging tests are more accurate. Finally, there is the possibility that the CT scan test is the best imaging test Anna could get, but it is not appropriate, because any imaging test at this stage will likely fail to have a positive impact on her condition; this is, in fact, the current medical consensus on moderate lower back pain (Chou et al. 2007; Oliveira et al. 2018). To sum up, these are normative questions in the epistemology of medical imaging: How do images provide evidence? What is correct for radiological practices? What is the standard for choosing the best imaging test (diagnostic accuracy studies)? Finally, what counts as appropriateness when it comes to diagnostic imaging?

This chapter concentrates on the first two questions—what do images provide as evidence, and what is required for the whole radiological procedure to be in epistemic good standing. As for the other two, the epistemology of diagnostic accuracy studies is an unexplored field for philosophers, though it has been recently addressed in a few interdisciplinary works (Lalumera and Fanti 2019; Pomykala et al. 2022), whereas what counts as appropriateness regarding imaging tests has received relatively more attention by philosophers of medicine (Lysdahl and Hofmann 2020; Hofmann, Andersen, and Kjelle 2021). Both are promising avenues for further philosophical research.

Other philosophical issues about medical imaging will not be addressed in this chapter, because they are examined in other areas of philosophy, outside of the philosophy of medicine. The first is the epistemology of neuroimaging. The epistemic credentials of studies aimed at mapping cognitive tasks to brain regions or activation patterns, mainly with functional MRI (fMRI) and later with PET, catalyzed the attention of both philosophers and scientists in the early 2000s (Bogen 2002; Poldrack 2008). The philosophy of neuroscience is now a thriving field, intersecting with the philosophy of psychiatry (Bickle, Mandik, and Landreth 2019; Broome and Bortolotti 2009). Other issues that arise within radiology, such as the ethical problems posed by the radiation risk associated with some imaging modalities (Cho 2016), fall within the domains of bioethics and medical communication ethics. The relatively recent question of whether human imaging readers can in principle be replaced by artificial intelligence readers is debated within the philosophy of artificial intelligence (Alvarado 2022). Finally, this chapter also does not review the fascinating research on how the introduction of medical imaging techniques changed the medical profession, the “medical gaze,” and our conceptions of bodies and diseases, which lies at the intersection of history of science and technology, sociology, and cultural studies (Van Dijck 2011; Daston and Galison 2021; (Joyce 2005, 2010).

After a short description of the main kinds of medical imaging modalities, we will tackle the normative questions proposed above, starting with the problem of what evidence is provided by medical images. We will then move to considering the complex issue of the epistemology of radiological procedures.

## Main kinds of medical imaging modalities[[1]](#footnote-1)

As mentioned above, there are different modalities of medical imaging. Readers interested in physics and bioengineering can browse through the fascinating accounts of their differences, and of how their development is tied to groundbreaking discoveries in the structure of matter that took place in the last century, involving two Nobel prizes and possibly—though very indirectly—The Beatles (Van Dijck 2011; Myers and Wagner 1974; Kevles 1997; Maier et al. 2018; Goodman 2010). Here, only a sketchy description will be provided. The reason is twofold. First, technology in medicine, as elsewhere, progresses rapidly, and though the underlying physical bases of imaging modalities remain constant, the procedures, component phases, and parts of imaging machines have changed over time, and will change in the future. A detailed description of the present state of the art of imaging modalities is therefore likely to be of limited utility. Moreover, for philosophers interested in medical epistemology, the difference between a CT scan as it was manufactured in 1990 and a contemporary one is not obviously relevant. Neither is it whether X-rays, sound waves, or decaying isotopes (we’ll see these below) are what the image is constructed from. What is relevant is to individuate whether and how images of this complexity contribute to medical knowledge in a distinctive way, and what can be said about the normative requirements for such a contribution.

Imaging technologies can be based on the physical properties of X-rays, radioactive substances, sound waves, or magnetic fields. In conventional radiology, CT, and fluoroscopy, an X-ray beam is passed through the body, where the X-rays are either attenuated or scattered by the internal structures, and the remaining X-ray pattern is detected and turned into an image. Attenuation depends on the atomic number of the elements a tissue is composed of, so generally X-ray imaging is good for visualizing tissue composed of elements of a higher atomic number than its surrounding tissue, such as bone and calcifications. Plain X-ray represents the oldest technique of medical imaging, having been introduced at the end of the nineteenth century (Kevles 1997; Mould 1998). It is still widely used, for example, to study the lungs (chest X-ray) and to diagnose bone fractures. The main limitation of X-rays imaging is that it is bidimensional, i.e., it does not provide images of inner body parts as solids.

CT, introduced in 1971, essentially represents the tridimensional application of X-rays, enabled by computer processing of radiograph attenuation data (Goodman 2010). Its visualizing power can be enhanced by means of contrast media, i.e., substances that are opaque to X-rays and therefore enhance the visibility of target organs or tissues. Just like X-ray, CT has applications in all medical specialties, and it is probably the most widely used form of medical imaging for diagnostic purposes worldwide. The main limitation of CT is that does not provide functional information (what is happening within the person’s body); information can only be derived from anatomical features (what is there). The general problem of all techniques based on X-rays is that they expose both doctors and patients to a small increase in cancer risk due to radiation. The debate on how to quantify this risk and how to balance it with the health benefits in terms of lifesaving diagnoses that X-rays can provide is intricate and philosophically interesting in itself; it involves, among other factors, an evaluation of the quality of evidence for radiation-induced cancer risk (Schmidt 2012).

In nuclear medicine technologies, like PET and SPECT, what is detected and turned into an image is radiation emitted from within the patient’s body. Radiation arises from a radiotracer, a chemical compound that contains a decaying isotope; before the scan, the radiotracer is administered to the patient; as it spreads through the body, it concentrates differently in the presence of specific physio-pathological processes, such as metabolism or blood flow. The image produced shows radiotracer uptake, therefore providing functional information about what happens within the patient’s body. PET is mainly used in oncology, especially for monitoring the growth of tumors (staging), response to treatment, and recurrence. The basic idea is that tumor cells have peculiar metabolic processes that take up specific radiotracers; for example, some varieties of thyroid cancers are “avid” (technical term) for 18-fluoro-2-deoxyglucose (FDG). In differentiating cancer lesions from other abnormalities, such as infections, a PET scan can be more accurate than a CT scan, but it is rarely if ever recommended as the first diagnostic imaging test, i.e., for primary detection when a problem is suspected. At the moment of writing, a PET scan is very expensive—an aspect that we will consider below, in discussing the role of imaging in health care. A further shortcoming is that, like X-ray based techniques, nuclear medicine imaging involves a small radiation risk. As for history, though its physical bases are older, nuclear medical imaging procedures were gradually introduced into medical research and practice only in the 1990s (in Europe and the United States); it is the youngest of medical imaging modalities we will be considering (Carlson 1995; Wagner 2006).

Sonography is an imaging modality based on the reflection properties of ultrasound waves. These are transmitted through the body, where they are reflected differently by different parts and structures. An image is then composed from the reflection times and amplitude of sound signals. Ultrasound imaging can show motion inside the person’s body in real time, for example, heart contractions (echocardiography) or fetal movements during pregnancy. Ultrasound prenatal diagnosis, one of the main applications of sonography, started in the 1970s (Campbell 2013). It revolutionized the way we see pregnancy—both metaphorically, and almost literally. The main advantage of ultrasound imaging is the absence of radiation risk; the limitation is related to the difficulty of sound waves in reaching structures deeply located within the body.

Finally, in MRI, a temporary magnetic field is created in the person’s body, and an image is generated from of the signals of radio waves interacting with fat or water molecules in organs. During a scan, different temporal sequences of data are obtained and then composed; they are used to study different organs and pathological processes. The main applications of MRI are in oncology, orthopedics, cardiology, and neurology. One advantage of MRI is the lack of radiation exposure; the disadvantages are the limited applicability to some organs, such as the lung and bowel, and the discomfort experienced by the patient for the duration of the scan, which can take up to 90 minutes. Magnetic resonance images came into clinical use in the 1980s, whereas the first functional MRI (fMRI) of the brain, based on the known correlation between changes in blood flow and neural activity, was performed in 1991 (Belliveau et al. 1991).

The medical imaging modalities presented so far as different methods can also be (and increasingly are) combined in hybrid formats, such as PET-CT, PET-MR, and ultrasound and CT. Combining modalities means obtaining more informative images; for example, a PET-CT contains both functional and anatomical information, such as a spreading an infection and a 3D rendering of the lungs, thereby overcoming the limitations of each of the two component modalities (Israel et al. 2001; Padmanabhan et al. 2017).

Let us leave technology aside and go back to the role of the philosophy of medicine with respect to medical imaging. With a view to assessing their epistemic contributions, there are two features that the kind of imaging modalities described so far have in common. First, they consist of reconstructing images (as the verb “to image” expresses) out of data regarding various non-visible properties. For example, a PET image is generated via mathematical procedures called reconstruction algorithms out of measures of the decay of isotopes contained in the radiotracer—which, in turn, conveys information about a biochemical process going on in the person’s body, i.e., the metabolism of glucose by the cells of a tissue. Medical imaging modalities just “present data in the form of images” (Delehanty 2005), as we will discuss below. If we are interested in the epistemology of imaging—how imaging contributes to the making of medical knowledge, broadly construed—the first question to ask is: What do these very complex things—medical images—provide as good evidence?

The second common feature of MI is that images convey medically useful information only when interpreted or, as in the common usage in medical literature, “read.” For example, an irregular increased gray area in a specific quadrant of a lower back CT scan means a herniated disk only to a radiologist who knows how to read it, who then fills in a radiological report, which is an official document containing data as well as a communicative act directed to the referring doctor and to the patient herself. All this adds additional levels of evaluation and assessment. The epistemic questions raised by imaging (constructing images) and radiological practices will be the topics of the next two sections.

## Medical images as evidence

One way to tackle the question of whether a medical image, i.e., a PET scan of a person’s lung is good evidence for an inner body condition—for example, that there is cancerous lesion in the lung tissue—is to ask: is medical imaging like seeing? Or, to paraphrase the title of an article by Ian Hacking (1981), do we see through a CT scan, or a PET scan, or any of the other MI devices? If medical imaging were just like seeing through a person’s body, we would have a straight answer to the question of what makes a medical image good evidence for a person’s condition. In empiricist epistemologies, seeing has always had an epistemic privilege, and so has observing in the philosophy of science. To put is simply, *ceteris paribus,* visual experience is a good way to knowledge, and if one sees that something is the case, then one has good reasons for believing that something is the case (skeptical worries apart, as we always keep them when reflecting on scientific knowledge).[[2]](#footnote-2) Likewise, traditionally, observing phenomena is epistemically safer than inferring about phenomena.

Whether we see through a person’s body with MI or not, unsurprisingly, depends on what counts as seeing. This latter issue is a classical theme in the philosophy of science. According to Bas Van Fraassen’s strict empiricist criterion for seeing (Van Fraassen 1980), we see a tree through a telescope because if we were sufficiently close, we would be able to see the tree without the instrument, but we do not see through a microscope, because there is no condition in which we could be able to see, for example, the actin filaments of a cell without the instrument. Let us apply this criterion to common examples of what medical imaging give information about. A breathing fetus or a beating heart are things we could be able to see with the naked eyes, in specific conditions; so is a liver, a liver tumor, a shinbone, and a broken shinbone. Anatomopathologists who perform autopsies (examinations of dead bodies) are specialized in this kind of observation, and so are surgeons. A breathing fetus and a (big enough) tumor are observable entities, in this restricted technical sense. But inflammation, very early-stage cancers, and most metabolic processes are not. It would turn out that, according to Van Fraassen’s criterion, medical imaging could be a kind of seeing only in some cases, and that in those cases (but those only) it could therefore inherit the epistemic privilege attributed to seeing.

However, as Hacking commented on Van Fraassen, it is contingent that the human visual system has the limitations it has, and it is not clear why these limitations should have any epistemic value. He therefore proposes a different concept of seeing, unbound by the characteristics of the human eye:

How far could one push the concept of seeing? Suppose I take an electronic paint brush and paint on a television screen, an accurate picture (I) of a cell that I have previously studied, say, by using a digitized and reconstituted image (II). Even if I am “looking at the cell” in case (II), in (I) I am only looking at a drawing of the cell. What is the difference? The important feature is that in (II) there is a direct interaction between a wave source, an object, and a series of physical events that end up in an image of the object. (Hacking 1981, 150–151)

According to Hacking, direct interaction between the source (or the phenomenon) and the image is the key criterion for seeing. He also adds that images that count as seeing in an epistemically relevant sense should provide a good map of what they represent, i.e., they should preserve all the relevant spatial relations that hold in the phenomenon represented.

In simple terms, we can think of “direct interaction” in this view as tied to causality. When we talk about something being observed directly, we mean that the cause-and-effect relationship between the observed object and our perception of it is relatively straightforward. In the example, if you see an image of a cell on a TV screen that was painted or pasted, the causal connection between the cell and the image involves a more indirect path. The cell caused an image, which then went through various steps like being stored in the experimenter's memory and reproduced. (Incidentally, this notion of directness is the same in the so-called direct reference theory in the philosophy of language, defended by authors such as Saul Kripke and Hilary Putnam in the Seventies of last century.) According to this simplified reconstruction of Hacking’s view, selecting the most direct or shortest causal chain becomes one criterion for determining whether we are genuinely seeing something or if we are reconstructing it through inference and the use of instruments, the other being the map criterion.

A philosopher who recently addressed the question “do we see through the instrument?” specifically to the case of PET and CT is Megan Delehanty (2005). She holds that the “seeing” discourse is more misleading than useful in our case. Her main point is that medical imaging technologies reconstruct images out of data that could be displayed otherwise—and are displayed otherwise, for example data from PET and SPECT scans are often stored as sinograms, two-dimensional graphs that do not bear any resemblance to body parts (Maier et al. 2018). The image format, where the image resembles a body part and spatial relations of organs and tissues are preserved, is just one of the possible ones in which the same data could be displayed—albeit the cognitively and rhetorically more efficient one. In the same vein, a textbook for radiologists defines a medical image as “a pictorial representation of a measurement of an object or function of the body” (Dance et al. 2014). In fact, this is the principle on which radiomics is based (Gillies, Kinahan, and Hricak 2016). If the data that imaging modalities provide are measurements, then they do not give us observational evidence of inner body conditions.

Moreover, as Delehanty illustrates for the specific case of PET, reconstruction algorithms are needed to transform the initial data about the radiotracer’s decay into something that can be displayed as an image; these algorithms correct the data, rather than just converting them (Delehanty 2005, chapter 2). The same point can be found, in more general terms, in an image science textbook: direct imaging is any method where the initial data set is a recognizable image, whereas in indirect imaging, a data-processing or reconstruction step is required to obtain the image. Direct imaging includes, among others, the human visual system, photographic and electronic cameras, and confocal scanning microscopes; most of the medical imaging modalities we have considered, such as X-ray CT, SPECT, PET, and MRI count as indirect (Barrett and Myers 2013, xv). In all these cases, Hacking’s idea of a direct interaction with the imaged phenomenon loses any grip, and his broadly empiricist account of seeing through cannot explain how medical imaging can provide good evidence.

A promising strategy at this point is to bite the bullet and abandon the idea that from an epistemic point of view medical imaging is a kind of seeing through a person’s body. Delehanty’s proposal is a form of process reliabilism, in the jargon of epistemology (Delehanty 2005, chapter 3). Process reliabilism can be described in this context as the view that good evidence is evidence produced by a method whose errors have acceptably low frequency, given a finite specified sample size. The key feature of process reliabilism is that it does not give any direct epistemic role to the fact that medical images look like inner body parts. On this account, medical images (a CT scan of the lower back, a PET-CT scan of the chest and abdomen) provide good evidence for clinically relevant conditions (a herniated disk, a lung cancer) insofar as they are output of relatively error-free processes.

The question now becomes, what are these processes and what is for them to be error-free? The first process is the one we have focused on so far, that is, imaging proper, or the construction of an image by a technological device. The philosophical question here intersects with scientific research. In image science (a branch of Physics), the key construct is image quality, intended as a measure of how accurately an image portrays its object, where images and objects are mathematical models. Image quality is quantified by measuring contrast, unsharpness (blurring), and noise; each of these constructs is defined by mathematical equations and, intuitively, it corresponds to a kind of error that the imaging process can make (Dance et al. 2014). Image quality measurement can be used to evaluate images within a specific modality and also across modalities; as various imaging tasks require differing levels of image quality, an image may be of sufficiently good for one task, but inadequate for another (Barrett and Myers 2013; Maier et al. 2018).

Measuring image quality for different imaging modalities and tasks involves complex mathematical and statistical operations. In fact, it is not something that medical doctors such as radiologists or nuclear medicine physicians routinely do, neither it is something that they know about in details, generally—physicists are the specialized professionals for this. This fact fits with accepting an externalist account of knowledge and justification, such as reliabilism, according to which a knowledge procedure can be epistemically good, even if subjects who employ it cannot articulate the reasons why it is good. Very shortly, externalism in epistemology asserts that one can have knowledge even without providing reasons or explanations, as knowledge fundamentally relies on appropriate connections to the world (Littlejohn 2023). Reliabilist accounts, a subset of externalism, center around the idea that knowledge results from dependable methods, typically judged by their historical truth-record and current counterfactual reliability. The latter implies that if the circumstances were different, the output of the method would have aligned with them—a condition often referred to as the tracking condition (Goldman 1979; Goldman and Beddor 2021; Lipton 2000). In the context of image quality and imaging, good evidence for a reliabilist is that which is produced by such reliable methods. Applying this to the question of when a medical image serves as good evidence for an inner body condition, the reliabilist answer is therefore “when it is a high-quality image.”

Incidentally, an early and seminal discussion on medical images as evidence in the philosophy of science, focused on fMRI of the brain for research purposes, rejected reliabilism because of the alleged impossibility to individuate what counts as an error—a contingent fact that had to do with the special case of fMRI for brain correlates of behavioral tasks, with the technological limitations at that time, and ultimately with the neglect of image science (Bogen 2002). This is not to say that the image quality solution to the problem of images as evidence is objection-proof; future work in the philosophy of science might investigate the epistemology of image science models in detail, for example by assessing the validity of the constructs employed or discussing the assumptions about probability (frequentist or Bayesian) that they incorporate.

## The epistemology of radiological procedures[[3]](#footnote-3)

### Image reading

The guiding idea of this chapter is that there are questions at different levels that need to be addressed if we are after a philosophical understanding of diagnostic medical imaging. So, in the terminology of reliabilism, there are other processes to consider, in addition to image construction. The second process or series of processes is social and cognitive, and its output is a radiological report, possibly including a diagnosis; for example, a suspected cancerous lesion in the person’s lung, or a herniated disk. Let us call it the radiological procedure. As mentioned above, radiological procedures are ubiquitous in contemporary patient management. Studies in the social epistemology of clinical decision making emphasize the essential contribution of medical imaging tests and reports (Van Baalen et al. 2017). Work that focuses the epistemology of radiological procedures per se, however, is scarce; therefore, what follows will not be a synthesis of the state of the art, but rather an indication of areas that can be explored.

Our proposal is that the good epistemic standing of radiological procedures is in its turn epistemically complex, as it involves three levels of normative assessment. First, it depends on rules and conventions about how to read images (the “semantics” of imaging); second, on how these rules and conventions are applied by the individual radiologist in the specific case (usually called “reading”); and third, on how the reading is conveyed in a written report (“reporting”). That imaging involves conventions may appear controversial (there is an element of arbitrariness in conventions, and what could be arbitrary in the fact that a grey area in a radiological image of a shinbone should be read as broken bone?). Let us consider reading and reporting first, which are comparatively more familiar.

Since AI-based systems for image analysis are not ready for use, medical images need to be read by a specialized physician. Reading a medical image can be described as a conversion of visual information into clinically relevant information (the term “conversion” is intentionally vague at this stage). For example, in the lower back CT scan of our fictional Anna, the radiologist reads that the spinal cord (the white central shape in the image) is being compressed (dark area) by a herniated (slipped towards the right) intervertebral disc (one of the blocks in the lower left) between the fourth and fifth lumbar (lower) vertebra. Which general conditions should the radiologist’s reading satisfy in order to count as good evidence for Anna’s condition—on the assumption that the CT scan has good image quality? A possible option again is to adopt process reliabilism as an epistemic framework and explore the view that image reading is knowledge-conducive (it makes good evidence), when it is the output of a reliable process, that is, a process that it is relatively error-free.

Unfortunately enough, or interestingly, radiological reading and reporting are far from being error-free. Radiological errors are a huge problem in contemporary medicine. Recent studies quantify them at up to 30% of reported findings, with variations depending on imaging modality, task, and location (Bruno, Walker, and Abujudeh 2015). Though we are considering just the reading stage at this point of our discussion (or the so-called pre-reporting errors), the data are still impressive. Not all radiological errors affect have an impact on patient management—on their final diagnosis, intervention or absence of, and eventually on their health outcomes—but some do. Medical error, across medical specialties and interventions, is a leading cause of death (Makary and Daniel 2016). Moreover, radiologists are increasingly held responsible for misdiagnoses and negative outcomes, and are sued for malpractice (Cannavale et al. 2013). These are plausibly strong motivations behind the abundance of studies and guidelines dedicated to classifying radiological errors, individuating their causes, and above all, proposing operative solutions to minimize them.

It is worth placing a reminder here that the epistemology of image reading is not primarily concerned with finding solutions to avoid errors—just like the epistemology of testimony (for one) is not primarily focused on how not to be fooled by liars, impostors, or fake news. What counts as error, though, is a conceptual question worth addressing, together with what the different kinds of errors are, and which competencies or skills they count as failures of. On the first question, defining a medical error, there is an ongoing discussion in the scientific literature (Grober and Bohnen 2005; Havens and Boroughs 2000). Here are some of the requirements and difficulties that have been presented. Errors should be distinguished from malpractices, that is, cases in which blame can be attributed to the agent. There should also be a difference in principle between errors and variations in interpretation, but the possibility of operationalizing this difference depends on whether there is a consensus of experts on interpretation issues, which is not always the case; according to an influential opinion article, this is the “Achilles heel” of radiology (Robinson 1997). Moreover, if something counts as a medical error only if impacts on clinically relevant outcomes, we are trumping the epistemic goal of medicine (knowing and explaining diseases) in favor of the practical goals (curing and caring) (Taylor 2017). On the other hand, in many cases—and in most cases in radiology and diagnostic medicine in general—errors are epistemically accessible and quantifiable only from their clinical effects. There is room for suggesting that the definition of error in medicine is a genuinely philosophical problem, that is, one of those cases in which no additional amount of evidence can settle the issue.

Arguably, so is the problem of the classification of errors. At the most general level, radiological errors in reading can be of two kinds, not detecting an anomaly when there is one (false negative finding) and detecting an anomaly when there is none (false positive finding). In addition to these so-called detection errors, a further distinction that can be found within the medical literature is between interpretation errors, which concern how the anomaly is categorized (for example, compression and not fracture), and threshold errors (as when a too faintly colored area, or a too small colored area, is interpreted as cancer in a PET scan). This classification of errors reflects a view of what are the components of the process of image reading, that is, perception (for detection), medical knowledge of normal structures and functions (for detection and interpretation), and knowledge of the specific imaging modality and its semantics (for threshold setting). The same epistemic components are indicated as competence requirements in a recent guideline of the European Society for Radiology (ESR 2011). Other authors propose different subclassifications of errors, for example a distinction among different kinds of perceptual errors in image reading based on their cause (fatigue, cognitive biases such as inattentional blindness, and satisfaction for search, etc.) (Taylor 2017). From a non-systematic recognition of the literature, it appears that that there is no agreed upon classification principle for errors—cause, etiology, and effect are equally employed and mixed up—and this indicates a possible area for philosophical inquiry.

In addition to the problem posed by the notion and varieties of errors, the reliabilist framework proposed so far for the epistemology of image reading is further complicated by what has come to be accepted as consensus in phenomenological and ethnocognitive studies of radiology, that is, that image reading is a kind of seeing-as, or Gestalt perception (Van Baalen et al. 2017; Briedis 2020). In seeing-as, what is seen emerges out of a specific but unconscious spatial organization of the parts of a scene—as when, suddenly, one sees a smiling face when looking at three dried leaves on the ground. Seeing-as is a holistic process, defined as perceiving more than the elements of the observed scene (that is, perceiving them also as organized in a meaningful way). Philosophers of perception and psychologists of vision have claimed that in some fields, including radiology, seeing-as correlates with expertise, and may even be taken as a defining feature of expertise (Landers 2021; Siegel 2011). The bottom line is that expert radiologists do not read images by recalling and applying conversion rules from visual to clinical information.

If reading images is a kind of seeing-as, it makes little sense to distinguish between perception, knowledge, and threshold errors in radiological reading, as one holistic competence is supposed to be in place. Therefore, it makes little sense to reflect on separate correctness conditions relative to those components, for a good epistemic standing of radiological reading. A recent discussion of seeing-as in reading images suggests that radiological seeing-as depends on the individual’s “horizon,” a sort of paradigm in Thomas Kuhn’s sense (Kuhn 1970) defined as the total experience a person has accumulated during his or hers lifetime, which includes personal social experience, education, rules and laws, family values, politics, religious standing, and professional expertise (Friis 2017; see also Friedrich 2010). The suggestion is that the horizons of different people can be incommensurable, that is, what they bring about cannot be meaningfully compared; this is the case when radiologists do not belong to the same group and thus do not share the same type of education, professional experiences, and culture (Friis 2017).

These considerations about the thesis that radiological reading is a kind of seeing-as point to a tension in the externalist approach to medical epistemology and the epistemology of medical imaging. Arguably, seeing-as is an epistemically opaque process, that is, a process such that we don’t really know how, and why, it works; with another metaphor, it is a black-box process, which can be assessed by its outputs only, but not by inspecting the methods, mechanisms, or rules that produce them. Even if we are externalist in our epistemic assumptions (we do not require that the knowing agents are reflective on their methods and aware of the validity of such methods), still there is the intuition that medical knowledge and medical evidence needs some kind of accountability—that it is not a really black box, but a box we can at least partially see through, or that someone can see through. This is the case of the complicated models for assessing image quality, or, in a different area, the complicated statistical rules for the meta-analyses of studies; image quality measurement and meta-analysis are not epistemically opaque processes, but they require complicated processes, knowledge of which is deferred to experts. This accountability requirement for processes involved in medical knowledge, as well as the epistemic opacity allegation, are also central to arguments against replacing human image readers (radiologists) with artificial intelligence software – the problem with AI reading software is that it can be blamed as epistemically opaque (Alvarado 2022).

Is the seeing-as account of image reading incompatible with an epistemology of radiology that preserves the intuition of the accountability of medical knowledge? There are some ways to support a negative answer. A first one may be that epistemic transparency versus opacity is an underspecified requirement, with fuzzy boundaries, as well as context-dependence. A further one could be that seeing-as is not opaque, but rather it is a perfectly well understood cognitive capacity, and the fact that it is not analyzable into discrete components, such as propositional knowledge and perception, is not relevant; in fact, there are well-known principles of Gestalt perception (Koontz and Gunderman 2008). In a different vein, it could be argued that seeing-as pertains to the psychology and phenomenology of reading images, and those are relatively irrelevant to the epistemology of reading images (just like, for example, it can be argued that the epistemology of logic can be kept separate from accounts of how people reason, or the psychology of reasoning). Finally, a radical externalist approach would consist of biting the bullet, abandoning the accountability requirement for the epistemology of radiological reading, and allowing for seeing-as (and AI) processes as providing good evidence, insofar as they are relatively error-free. Each of these strategies stands in need of further development and clarification; the sketchy list above is just meant to signal another area for work in the epistemology of radiological procedures.

### Radiological reporting

Let us go back to our initial vignette of a patient Anna who suffers from back pain. So far, we have seen that, to obtain good evidence for her condition, we need a good quality image from the CT scan and a relatively error-free reading by the radiologist. Let us now consider the radiological report. The importance of radiological reports lies in the fact that what the radiologist reads is not evidence that can be acted on (clinically relevant evidence), until it is communicated to the relevant stakeholders in the diagnostic process, that is, the referring physician or medical team, the patient, and her family. Reports are therefore part of what we have called the radiological procedure, and from this they earn their epistemic relevance. What makes a radiological report epistemically good? More precisely, in the case of a good quality image, and a good reading, what conditions does the reporting process add to the epistemology of radiology? Again, what follows will not be a summary of recent philosophical work, but rather an illustration of a possible topic to investigate.

As for the other stages of the radiological procedure considered in the previous sections, the medical literature on good radiological reporting is vast (Wallis and McCoubrie 2011). This is because there can be no clinically relevant evidence from medical imaging without reports—as said, they are as epistemically relevant as the images themselves to obtaining medical knowledge. Radiological reports are documents; as such, they are part of the electronic patient record, they are stored in databases, and can be accessed at any time. This brings us to the second reason why the medical literature on the topic is vast: fear of malpractice suits (Kwee and Kwee 2020). The most common cause of malpractice suits against radiologists is failure to diagnose, that is, an error in reading. Beyond these errors—that is, assuming a good quality image and a good reading—the second cause of malpractice suits is failure to communicate. In these cases, it is claimed that a defective (even if accurate) radiological report caused the diagnosis to be delayed (a typical example is mammography for breast cancer) (Berlin 2000). Failure to communicate brings into light a further dimension along which a radiological report can be assessed as good or bad.

The main theme that emerges from the literature is that a good radiological report is such that the one who reads it—the referring physician, a specialist, the family doctor, or the patient and family—knows what to do after reading it (Lee and Whitehead 2017). Good reporting is action-guiding reporting. Back in 1923, a leading expert criticized radiologists who “describe in detail all that the roentgenologist sees in the film or on the screen, but does not tell what he thinks about it, what conclusions he draws from it, and what it means to him” (Enfield 1923). In other words, a good report should include a diagnosis whenever possible, and a clearly understandable one. An expert opinion published in 2000 makes it explicit that “radiologists should minimize, if not eliminate altogether, the use of such phrases as ‘if clinically warranted,’ or ‘if clinically indicated may be of value,’ when assessing abnormal radiographic findings. Because radiologists are acknowledged to possess radiologic expertise derived from training and experience, they should not relinquish to nonradiology physicians the responsibility of evaluating the potential significance of a purely radiographic finding that is unexpected or unusual” (Berlin 2000).

For a radiological report to be good in the sense of adequate as a basis for action, it should also be readable for its intended target. Studies show that referring doctors do not understand abbreviations used by radiologists, and (more relevantly) they often assign meanings to terms conveying uncertainty (such as “suspicious for” and “consistent with”) that do not coincide with those intended by reporting radiologists (Khorasani et al. 2003). Readability is even more important, and difficult to achieve, as increasingly more often the patient, and not only the referring doctor, is a reader of the report, in a patient-centered model of care (Itri 2015). Easy accessibility of radiological reports by patients has been described as disruptive by imaging specialists, for it forces a radical change in a profession that traditionally did not include a direct relation with patients and caregivers (Bruno et al. 2014).

How radical should be the change in reporting? The threshold set by the requirements of clarity and simplicity is interesting to discuss. A study of the quantitative analysis of readability of radiological reports in the US concludes that fewer than 4% of all reports in the sample were at the eighth-grade reading level,[[4]](#footnote-4) which is what the average U.S. adult can read, and therefore they were classified as difficult to understand by patients and caregivers (Martin-Carreras, Cook, and Kahn 2019). The problem here is whether and how precision and accuracy of radiological data stored in reports, which are essential to patient care and to medical research, can be achieved without employing technical terms (or terms that are not understandable by an eighth grader). Would a simplification of language in medical imaging reporting bring about a loss of essential concepts, as in the Newspeak dystopia of George Orwell’s famous novel? (Gray and Gunderman 2019). It appears that a (philosophical) question about patient-centered radiology, or patient-centered care in general, needs to be addressed.

Discussion of what counts as good radiological reports have included the proposal of methods of standardization since the early days of medical imaging diagnosis. Standardization is proposed in the form of templates or lists of questions for the radiologist to fill in (structured reporting), and more recently in the form of software for reports. For example, a structured report of an abdominal CT contains subheadings that describe each of the anatomic areas examined, such as the liver, spleen, pancreas, and kidneys. Structured reporting could also be intended in a stronger sense, as including explicit rules for the use of terms (Nobel, Kok, and Robben 2020). Ideally, structured reporting should improve the completeness of information as well as readability; it is indicated as a goal by scientific societies, such as the European Society of Radiology (ESR 2018).

Difficulties in implementing structured reporting in radiology, however, appear to be prohibitive when compared to other medical specialties, such as pathology and surgery (Schwartz et al. 2011). Some resistance may come from a sort of professional pride of old-style radiologists, who see standardization as a threat to their authority in performing what they consider their main professional task (arguably, surgeons do not consider reporting as their main professional task) (Gray and Gunderman 2019). But economic factors are surely relevant. Studies have found that standardized reporting systems are costly in terms of money and time (productivity), especially for private practice radiologists. As a commentator writes in an academic radiology journal, “In the world outside of medicine, what would a manufacturer do when customers require a product that costs more to create? Corporate peculance would dictate one of two responses—decrease manufacturing cost or increase price. In medicine, we are constrained by third parties with downward pressure on any price adjustments” (Weiss and Langlotz 2008).

To sum up what may be of philosophical interest, the epistemic properties of radiological reports depend on features that account for their efficacy as communicative acts – apparently, a case where the pragmatics of communication ground epistemology. This might be contingent and temporary, as standardization tools may gradually take over. But at present, it is a relevant feature of contemporary medical practices. Moreover, discussions of readability thresholds stimulate reflections on patient-centered care, and the difficulty of implementing structured reporting touches the big issue of costs of health care.

### The semantics of medical images

Of the many processes that feature in an ideal analysis of radiological procedures as ways of knowing, assigning meanings to images is maybe the least obvious and the most neglected in philosophical discussions—the exception is Laura Perini’s work, focused on examples from microbiology (Perini 2012). Still, its epistemic relevance is central, since we have abandoned the naïve epistemological idea that medical imaging is a kind of seeing through, and images provide information because they look like phenomena. Let us go back to our initial vignette.

In Anna’s case, the CT scan produces a good quality image, the radiology correctly reads the grey area within the elongated white object as a compression of Anna’s spine and issues her report. Here, what the radiologist correctly read is that a slightly grey area in that location means a non-severe compression, which is a minor pathological finding. Our question is: What does this meaning relation stand on? That this is obvious, or quite unproblematic, in our fictional example should not lead us to forget that it nevertheless stands on some metaphysical (and epistemic) basis. First, the meaning relation depends on the properties of the imaging modality and on the properties of human tissues—in this specific case, simplifying, X-rays are attenuated in different ways by differently dense bone tissues. Second, the meaning relation depends on the threshold between compressed and normal spines, which, in this case, is also a threshold between a pathological and non-pathological finding. Let us call semantics the set of meaning relations for an imaging modality. The semantics is what makes the radiological reading correct. But, as soon as we acknowledge this, we should admit that it could occur that the radiologist reads the image correctly, but the meaning relation was problematic in the first place—that the meaning was incorrectly fixed.

That images of the kind we are considering have semantics that appear more clearly when we don’t know what they mean. In their ethnographic study on the first autoradiographs, Amann and Cetina (1988) concluded that a social process involving coordinated conventions between scientists was needed to assign meanings to images produced by these new devices, that is, to understand how the data can be converted into evidence. The conventional element in the semantics of imaging is also defended by Perini (2012), who calls it “semiotics.” She also explains that there is a difference between arbitrariness and conventionality in meaning assignments, in that the first is an unconstrained association between sign and meaning (as when I decide that the color purple for my computer desktop folders means “teaching”), which is still based on human agreement and decision, but also constrained in the logical multiplicity of alternatives.

Is there conventionality in the semiotics of medical imaging? This question allows for a quick affirmative answer: yes, insofar as the community of imaging specialists regularly issues recommendations and guidelines about how images should be read. This is necessary whenever a new imaging procedure is introduced and when the detecting capability (sensitivity) of an existing one increases. These recommendations and guidelines are often outputs of consensus conferences, in which experts of the field are called to judge on an issue after surveying the relevant existing evidence, and a final mediated judgment is collectively produced (Solomon 2016; Stegenga 2016). For example, as MRI for prostate cancers became more accurate by introduction of new methods (dedicated sequences), and smaller lesions became visible, a series of consensus conferences were held to fix the semantics of the new range of available findings (Weinreb et al. 2016). These recommendations and guidelines are often outputs of consensus conferences or procedures, in which experts of the field are called to judge on an issue after surveying the relevant existing evidence, and a final mediated judgment is collectively produced (Solomon 2016; Stegenga 2016). If the semantics of imaging is fixed by consensus, then it is at least partially conventional. If it is partially conventional, we can understand why it can be the case that sometimes meaning assignments are wrong.

A less straightforward way to defend the notion that the semantics of imaging is conventional is by arguing that, whenever there is a threshold to fix between pathology and non-pathology on a continuum of states, agreement on values is involved (Kingma 2014; Amoretti and Lalumera 2021). How big a red patch should be in order to count as cancer in a PET scan? Another case from diagnosis in prostate cancer may be cited here. There is an ongoing discussion among experts on whether low grade lesions should be still called “cancer” or not (Esserman et al. 2014; Epstein 2022). The main reason for changing their name is because they are harmless to the patient (a value criterion), in spite of their being cells of the cancerous type (factual criterion), and rather to overtreat them would be bad. That they are harmless to the patient, however, is itself agreed on by experts, rather than proved with conclusive evidence. The closer one could get to conclusive evidence in that case would require following a large number of patients with these low-grade lesions for a long time, and then evaluate postmortem if it the lesions have impacted on their life expectancy. Here, a further decision about values is involved, namely, that to wait for the results of such a study—if feasible from an ethical point of view—would be worse for the patients than taking the risk of an incorrect fix of the pathological threshold.

The general philosophical point here is that whenever there is a threshold to fix between pathology and non-pathology on a continuum, agreement on values is involved (Kingma 2014; Amoretti and Lalumera 2021; Lalumera forthcoming). Notice that the threshold problem does not disappear if we consider imaging modalities as providing numerical data about a measured quantity (as radiomics promises to do), and not just visual information to the reading expert—it can be just rephrased as what is the threshold value for that quantity for assigning a pathological meaning. Following this route, the conclusion is that the semantics of imaging is conventional in that it depends on values on which experts should agree on. A thorough discussion of this point, however, would bring us directly into the debate on the nature of medicine, of health and disease.

## Conclusion

After a survey of the main philosophical issues raised by medical imaging, this chapter focused on the epistemology of diagnostic imaging, in particular on the questions of what makes an image evidence, and by virtue of what a radiological procedure is knowledge-producing. We isolated for the sake of discussion three aspects of the radiological procedure, image reading, radiological reporting, and the semantics or assignment of meanings. Each of this can go wrong in different ways, that is, each of this makes a different epistemic contribution to the task of obtaining patient-relevant knowledge from a medical image. The resulting picture can be read as showing that medical imaging is a highly technological and rapidly changing part of contemporary medicine, but its contribution to medical knowledge involves processes that are not just technological, and whose reliability (or epistemic good standing) is worth focusing on.

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2. Note here that I am using “good evidence” and “good way to knowledge” as synonyms for the philosophical word “reliable” as much as possible to avoid confusion, because reliability in medical imaging, as elsewhere in medical research, is the degree to which a test or measurement yields the same result on different occasions (De Vet et al. 2011; Lalumera, Fanti, and Boniolo 2021). [↑](#footnote-ref-2)
3. Some of the content of this section is published in (Fanti and Lalumera 2023a) and (Fanti and Lalumera 2023b), which refer to a manuscript version of this chapter as their source. [↑](#footnote-ref-3)
4. An eight-grader in the US educational system is 13 or 14 years old. The scale used is the Fleish-Kinkaid readability test, (Kincaid et al. 1975). [↑](#footnote-ref-4)