The digital anatomy theater: scientific practices for representing the body

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Abstract

Contemporary scientific practices for representing the body are investigated ethnographically through a comparative analysis with the Renaissance anatomy theater, a practice used to understand the body in early modern science. First and foremost, I seek to analyze the manner through which visualizations of the inside of the body produce knowledge of its functioning. The conclusion is that, currently, the production of knowledge greatly privileges the validation of code and modeling of the biological processes in which one wishes to intervene. The objective is to unveil the meanings of the circulation of images, data and theories that bring together material bodies, visualization techniques and scientists, enabling the production of truth about the body in a biological sense.

Keywords: anatomy theater; scientific visualization; the body; ethnography; computational modeling.

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Curiosity regarding the human body, its functioning and its interior, invisible to the unaided eye, is an important part of both Western culture and scientific practices since their inception. Even before the emergence of that which we call modern science, practices investigating the internal structures of the human body had been prominent in the visual culture of the West, both in art and the sciences. I do not intend to speculate, here, on the origin of this immense curiosity. Rather, I just seek to interpret some of its connections with contemporary scientific practice in an attempt to investigate the development of distinct forms of producing knowledge of the human body. Additionally, interpretation of how these practices are related to broader sociocultural contexts is crucial to understanding the meaning of these practices.

One could say that the investigation of the distinct methods of visually representing the body may reveal a great deal about how a certain era and culture envisioned its world and constructed ways of understanding it. In this article, however, I wish to study not only images of the human body, but also the specific methods used to make it visible and, at the same time, cognoscible. In fact, the two terms cannot be dissociated easily, especially in what we call contemporary science, as demonstrated by an already extensive literature on representation in science (Daston, Galison, 1990; Latour, 1990; Lynch, Woolgar, 1990b; Pauwels, 2006). Despite this, we encounter studies that analyze the images produced in scientific and artistic contexts much more frequently than those investigating the practices used to produce these images. There is also a relative lack of ethnographic research on how these images are produced and legitimized as true knowledge of the body.

This article intends to help fill this gap by studying the contemporary practice of producing truth about the body through extensive use of images and what I call digital objects (Monteiro, 2009, 2010). These objects or virtual models in 3D are 'manipulated' by scientists in order to investigate the properties of specific structures in the human body and determine their functions. Built using mathematical codes, these models are thought to be faithful representations of natural processes and the modeling and digitalization processes studied here are based on this legitimacy.

I seek to construct a comparative analysis with another practice that was very important in producing knowledge of the body, a practice that helped define some of the foundations for modern empirical science: the anatomy lessons of Renaissance Europe. My objective is to investigate the similarities and differences in these two rituals for producing knowledge and visualizing the body. I try to understand the potential displacements in our current means for visually understanding the body and the means considered to be legitimate for producing truth with respect to the same body.

The comparison between Renaissance anatomies and technological practices is not unprecedented. Commentaries on current visualization technologies make extensive use of comparison with anatomy theaters (Daly, Bell, 2008; Thacker, 1999; Van Dijk, 2000). As far as I could ascertain, none of these studies directly investigates this comparison with the objective of understanding how contemporary rituals for producing visual evidence are displacing consolidated paradigms based on the imperative of direct observation of the body, as established in Renaissance theaters. From this viewpoint, I seek to advance the debate on the social methods for producing corporeal evidence, in addition to interpreting current visualization methods based on computational modeling as displacement (and not just continuity) of the principles established during of the birth of modern science.

The decision to compare modern techniques with the anatomy theater is justified by the desire to contrast body visualization practices at two critical times. The first was during the Renaissance, when scholastic anatomical knowledge practices, based on interpreting classical texts, gave way progressively to dissection and to observation of the body as the principal source of knowledge (Bellini, 2005; Thacker, 1999). The second point in time, today, has seen a transition from direct observation of the body to the growing use of digital representation as a way to see inside the body. Digital technologies, seen as the best way to eliminate mediation between the observer and his an empirical object, are replacing interventionist practices that require destroying the observed object (as in dissections). A comparative analysis of the two practices seeks to reveal continuities and ruptures between the means of producing knowledge by manipulating the body and by manipulating images of its internal structures in order to make current scientific methods for visualizing the body comprehensible.

The Renaissance anatomy theater represents a knowledge practice in the transition between the medieval period and the emergence of modern science. Public anatomies – relatively common in the principal academic centers of Western Europe – were odd public rituals and involved music and luxurious decoration in addition to the spectacle of the dissected body (Klestinec, 2004; Sawday, 1995; Wilson, 1987). This spectacle was surrounded by complex symbology, which included everything from permanent theaters built in accordance with Vitruvian proportions to placement of the guests based on their social position. The public anatomies were thus a way to disseminate knowledge to medical scholars and, simultaneously, dramatic spectacles in which the symbolic order of the world, centered on the human body, was staged (Thacker, 1999).

Currently, however, the production of knowledge is primarily focused on the validation of code and in modeling the biological processes in which one seeks to intervene. On the other hand, the construction of digital visualizations seeks to produce virtual replicas of the structures being observed, replacing direct analysis of live material with manipulation of digital objects. This manipulation is seen as direct access to the truths of the body that would be inaccessible through other means, which is made possible by the increasingly sophisticated modeling of biological processes. There is therefore a rupture with the imperative of direct observation of the body and subordinate visualizations.

The effect is a sort of 'return to the text,' somewhat analogous to the principle that governed the first public anatomies in the thirteenth century. In them, the center of the spectacle was less the body than the cathedra, where the professor was socially and culturally the focal point of the scene. Revealing the knowledge contained in the classic works (such as those of Galenus) was the principle goal, with the body used as an empirical example – less relevant than the classical knowledge transmitted by the professor. The direct observation of the body became central to the empirical methods of understanding developed during the Renaissance and consolidated in works such as *Novum organum*, by Francis Bacon (2000), whereas today we see the importance placed in codes and models that aspire to be faithful representations of natural truth.

In modeling practices such as that analyzed here, validation of a mathematical code that seeks to describe the complex biological process of interest in computational terms is at issue. This validation of the code is part of a larger objective, that of controlling and modulating the observed processes in accordance with the interests of the physicians and engineers involved. In short, the researchers seek to “bring medicine and engineering closer,” in the words of Doctor Lewis[1], the scientist heading the project analyzed ethnographically in the study presented here. The production of knowledge about the body is based on manipulation of a series of visualizations (magnetic resonance images and 3D models based on them), in the context of collaborative, interdisciplinary discussion.

The field: formulating computational models of the human body

The ethnographic research underlying this study took place between November 2006 and March 2008. The objective of the project developed by the group studied here was to model heat transfer in prostrate tissues in order to develop a new type of surgery including laser ablation of tumors. It made broad use of visual representations in two, three and four dimensions, and the production and discussion of visual objects was a central part of the activities observed.

The team of scientists is located at one of the principal public universities in the Southwest of the United States. The group works with data collected at a research hospital located in another city 258km away and processes this information with the help of the university’s supercomputers. The team includes professors, post-doctorate researchers and graduate students. Their areas of specialization include computer science, civil and biomedical engineering, applied mathematics, computational mechanics, scientific visualization and medicine. The scientists come from various countries, including India, China, Iran, the Czech Republic, Poland, France and the United States. Most of them have an interdisciplinary academic background, to some extent, with research careers that include a variety of areas and interests.

The group’s scientific objective is to produce a computer system providing correct predictions of the damage to tissues caused by heat and provide this information in real time to physicians performing surgeries to remove tumors from the prostrate. For scientists, this technology represents a new paradigm in minimally invasive heat therapies with laser ablation. Thus, the new treatment is seen as a way to reduce costs, surgery time and patient trauma. The principal objective is to use thermal magnetic resonance images to allow the surgeon to have greater control during laser surgery through data feedback between his clinic and the supercomputers. Cell symptoms (death or heat apoptosis) would be used to calculate the future effects of surgery in real time in order to allow the physician to adjust the procedure for each patient, increasing efficiency and reducing any collateral effects.

The ethnographic study included observation while participating in the scientists’ weekly work meetings, interviews with all group participants and observations made at their facilities. Thirty-two meetings were observed and the recordings were analyzed. All of the scientists were interviewed at least once. Participant observation was also employed during two talks and at an international conference in which the group participated. I attended a one-week workshop at the supercomputing facilities used by the group and made two trips to the research hospital.

Visualizing the body scientifically, medically and culturally

I do not intend to discuss the history of the cultural visibility of the body here, as the topic has been sufficiently explored by other authors (Van Dijk, 2005). However, it is important to stress the particularity of this type of visibility in Western culture, applicable to both Renaissance prosections and contemporary digital means.

First and foremost, I wish to highlight the era when what is commonly known as the Middle Ages transitioned to the Renaissance, when visual representations of the body became more realistic, based on direct observation (Kemp, Wallace, 2000). This visual culture emerged simultaneously in art and science, with the appreciation of classic Greek and Roman art and a linear perspective as realistic ways to represent the world. In that era, realism in representation was strongly associated with 'mathematicization' at a time in which mathematics was seen as a universal language and the ultimate measure of objectivity (Alfonso-Goldfarb, 2001; Cassirer, 2000; Chene, 2001; Donatelli, 2000). It is in this context that we must perceive the evolution of the meanings attributed to public anatomies throughout the Renaissance. Additionally, it is interesting to note how mathematicization, which has become the basis for scientific description around the world, has become even more important in a science based on computational models.

The question of corporeal visualization, already highly debated in the international literature, is increasingly popular among Brazilian researchers. For example, the philosopher Francisco Ortega (2006) analyzes the historical development of visualization technologies in the context of the increasing importance of vision over the other senses in diagnosis and understanding of the body. He believes that visualization technologies are broadly appealing beyond their success in medicine, interfering in more general cultural perceptions of corporality (Ortega, 2005b, 2006). The author also argues that medical visualization technologies reduce the body to a dematerialized dimension, thus losing its unity with the organic whole and becoming "a set of fragments without substance or materiality" (Ortega, 2005a, p.246; free translation). He believes that the replacement of the body with its image will result in its disappearance, and sees in the history of anatomy – including post-modern theories – an over-appreciation of the fragment to the detriment of the visceral nature of the body (Ortega, 2005a, 2006, 2008).

According to the anthropologist Lilian Chazan (2003), the visual culture and current visualization technologies contribute to reconfiguring both the body and the person. The author asserts that the current visual culture of the body is partly responsible for its subjectivation, increasing vigilance over the body through technology and helping create a 'fusion' between body and machine (Chazan, 2003). This fluidity between the technological and corporeal is also, according to the author, part of a process through which technology both helps reduce social tensions (for example through analysis of fetus images) and at the same time creates others that, in turn, are only seen as mitigable with the use of more technology. In other terms, one can say that an interdependence is created between images of the body and the body itself, mediated by increasingly omnipresent technology.

Even though the analysis presented here confirms, to a certain extent, the assessments of Ortega and Chazan – especially regarding the importance of the visual in processes related to understanding the body – I do not seek a global evaluation of 'contemporary corporality' or a reconfiguration of the notion of the person in Western culture, but rather focus specifically on some contemporary processes for producing truths about the body in scientific practices. The intention of the comparison with the anatomy theater is thus to contrast the practices of contemporary science with those that preceded them at the start of modern science. In both cases, visualization of the body occupies a privileged position in the process of crystalizing truths about the biological processes and materiality of the body.

The question of the primacy of the visual in producing knowledge has been the object of recent studies in the field of social studies of science and other areas. Studies in these fields of knowledge discuss the question of visual representation in science as part of a process of production and crystallization of truths about the natural world (Latour, 1990), creating what Michael Lynch calls an externalized retina that tries to render visible the ways in which certain theories and models perceive the fundamental truths of certain objects and processes (Knorr-Cetina, Amann, 1990; Lynch, 1990; Lynch, Woolgar, 1990a).

Historical studies on the development of different visualization technologies describe a process of slow hegemony of imagining processes revealing the internal structures of the body (Pasveer, 2006; Van Dijk, 2005). Techniques such as artistic drawing and even photography begin to lose their legitimacy and 'scientific nature' when consensus agrees that technologically produced, non-invasive images are more objective than others. This process is described in a particularly rich manner by Lorraine Daston and Peter Galiston (1990). They trace the important historical parallel between scientific objectivity and visualization technologies. According to these authors, the idea that human mediation should be minimized underlies the development of successive scientific imaging technologies, in the belief that this maximizes the objectivity of the images. With the invention of technologies to produce and reproduce images in the nineteenth century, such as photography, cinema and X-rays, the notion of objectivity began to undergo important changes in what the authors call mechanical objectivity. In this new understanding of objectivity, the images produced by machines are considered superior ontologically to those produced by draftsmen or artists, for example, because no human interference is involved in their production.

The idea that an image produced by machines is free of subjectivity, with a renewed aura of objectivity, is a critical factor in understanding recent developments in science and the use of images for scientific research. The increasing adoption of digital forms and computational models in research is based on the assumption that computers do not interfere subjectively in image processing, and produce faithful portraits of the reality visualized. This notion is critical to interpreting the ethnographic data gathered by observing the group, because it is exactly the sensation that there is no subjective mediation between the body and its computational model that allows scientists to reify the digital object in their knowledge practices, treating these images and digital objects as substitutes for direct observation of the body. Direct observation of the body, which currently appears to be of decreasing importance in scientific practices, was the central feature in the development of the public prosections during the Renaissance.

The anatomy theater: revelation of the body as a performance

The first public anatomies of medical and scientific importance took place in Bologna, at the end of the 1290s (Wilson, 1987), and were performed by Professor Mondino de Luzzi. His text, *Anathomia corporis humani* (1316), became the most frequently used text for dissections in continental Europe during the following 250 years, until replaced by the work of Andreas Vesalius, *De humani corporis fabrica* (Vesalius, 2003). Therefore, public anatomies began at around the start of the Renaissance, which marked a broad transition to the modern era. Without delving into details of events and dates, I interpret the anatomies carried out during the era as part of a group of events that, in the context of Western Europe, represented a displacement of the medieval scholastic knowledge by a method based on direct observation of the body.

Mondino's anatomies were structured in a way that emphasized the professor, over the body visualized, indicating the still central role of classical knowledge to the detriment of the empirical evidence presented before the public. This tendency changed gradually over the centuries, and more explicitly when Vesalius, between 1530 and 1540, began to perform public anatomies in a notably distinct manner. In addition to eliminating the demonstrator (the surgeon who dissected the body during the reading of the text) and the presenter (the person indicating, with a pointer, the parts cited by the professor) by performing these functions himself, Vesalius made the body being dissected the focus of the performance (Wilson, 1987). Additionally, he made more extensive and effective use of anatomical illustrations which are even today held as a fundamental example of the start of modern anatomy.

Public prosections, held at various European universities, had implicit and explicit ties to the legal system and with unorthodox practices related to the growing need for fresh cadavers. Implicitly, they were an extension of capital punishment imposed on criminals, as a sort of punishment after death, when their bodies were exposed and used for educational and scientific purposes (Sawday, 1995). Negative connotations were also associated with public anatomies and their enactors were thought to be tied to grave robbing and violation of cemeteries. In various contexts, agreements between universities and governments guaranteed a supply of bodies from executions – also public (Ferrari, 1987; Klestinec, 2004; Sawday, 1995).

The anatomies evolved over time, demonstrating their instable position in European culture between the thirteenth and seventeenth centuries. Initially, they were restricted to medical professors and students, with an audience of no more than twenty or thirty people. They were specifically designed to transmit knowledge to future physicians. Over the years, they became increasingly public and elaborate. To avoid associations with grave robbing, for example, the knowledge to be gleaned through dissection was increasingly emphasized. They thus gained social status and began to be used, additionally, as a means to increase the academic prestige of the universities where they were held. Beginning with Vesalius, permanent anatomy theaters began to be built, with both the buildings and the public anatomies themselves enacting a universal order inspired by Vitruvian proportions and the idea of the hierarchies and relationships between the various parts of the universe. During this period, they became elaborate ceremonies accompanied by music and banquets.

According to Sawday (1995), the anatomies effected a transubstantiation of the body into knowledge. They made the order of the universe and the wisdom of God visible, incarnated in his greatest creation: man. There was no intention to investigate the body scientifically, in the current experimental sense, but rather the desire to make this divine order apprehensible, expressed through the dissected body and in the architecture of the permanent theaters themselves.

Eugene Thacker (1999, p.319-320) described the performance aspect of the anatomies, which sought to make the ontological principles of Renaissance humanism more palpable, in this manner:

> As may be guessed, the main attraction of the anatomy theaters lay in a certain type of voyeurism associated with a sense of real-time discovery before one's very eyes, a universalized glimpse into one's own interior. Added to this was, in the tradition of Renaissance humanism, the performative display of the metaphysical homologies between the (universal, male) body, the (mechanistic) cosmos, and a rationalized political and governing order: centralized hierarchical and functional parts and wholes ...

Anatomies and digital visuality: comparative views

The current use of digital visualizations of the body is different from the type of visualization described above. However, a comparison of the two is productive to reveal the broader meanings associated with both the former and the latter. If Renaissance anatomies sought to make a natural order – in which man was the center of a great 'mechanical system' – visible, current digital visualization methods abandon direct contact with the empirical body in favor of digital objects and increasingly sophisticated models. This abandonment is legitimized by the perception that digital technology is able to represent nature without subjective mediation, which makes it more faithful to reality than any other visualizations. Additionally, it abandons the idea of simple visualization in favor of manipulation of information that, due to this perceived direct connection with nature, is able to participate in practices producing corporal evidence. It thus seeks to validate a code that faithfully represents processes of interest to scientists, confirming the direct connection with the empirical through mathematics.

Beginning in the 1990s, with the emergence and growing diffusion of digital visualization technologies, a profound change in the visual culture of the body took place, and has not yet been properly analyzed by contemporary researchers (Thacker, 1999). Some authors suggest that this transformation revitalized the visual regime of the Renaissance anatomy theaters by bringing anatomy and the body back to the vanguard of medical science and making them the focus of public attention (Van Dijk, 2000). According to Van Dijk (2000), in addition to this public/spectacle function, projects such as the Visible Human – which built a digital anatomical model of the entire body for scientific and educational purposes – show continuity with the Renaissance anatomies in two other ways. First, a strong connection with legal and penal institutions.[2] Additionally, their *post mortem* educational use evokes the old lessons in public anatomies, in which the dissection of the criminal body was used to train young physicians.

Similarly to Chazan and Ortega, Van Dijk (2001) defines the cultural context of today as saturated by digital visuality, which legitimizes the predominance of this new regime in its medical manifestations to some extent. The author interprets this visual culture as that of an 'endoscopic gaze' because it prioritizes the view of the inside of the body to the detriment of other types of visuality. According to Van Dijk, the new technologies act as an extension of our gaze to previously inaccessible regions, an extension equally associated with a greater possibility of intervention. Thus, the illusion that virtual objects are more than a representation (because they are faithful copies of the body) is strengthened by the omnipresence of this visual regime in the broader culture.

Other authors highlight digital technologies for visualizing the body, such as magnetic resonance, as an important shift. Amit Prasad (2005), for example, defines this new context as the emergence of a new 'cyborg visuality' in which the previously impossible representations depend on computer intervention both for image acquisition and manipulation. Additionally, the author notes that treating resonance data as an image is a distortion: actually, it is manipulable, interchangeable data whose form redefines the relationship between the observer and the visual information in order to recontextualize the entire process of producing truths about the body, as could be perceived directly during the ethnographic study.

Producing evidence through digital images

In fact, we cannot comprehend the activities of the scientists analyzed if we think merely in terms of images. In the scientific practices observed, complex interactions occur between peers in various stages of their work and with various types of visualizations and virtual objects, for example 3D models of the prostrate (Monteiro, 2009). For the scientists, these visualizations represent the 'empirical' objects whose properties are the target of their analyses and group discussions. I noted that there was no emphasis on direct contact with biological organisms during the project[3]: the scientists produce and manipulate digital models based on data obtained by the research hospital (such as, for example, the magnetic resonance images) and, using them, produce their results and modify their models.

Most of the visualizations used by the group are not produced together, but rather individually by team members (professors, PhD students and post-doctoral researchers). The dynamics of the group includes both individual work and weekly group meetings. In the meetings, the participants update the group on the progress of their individual tasks, the results obtained and the difficulties encountered. Most interactions between the scientists occur during these meetings; objectives are defined and difficulties are assessed together.

As it is an interdisciplinary group, a range of communication problems occur during the project, analyzed in a separate article (Monteiro, Keating, 2009), given than not all members of the group have the same background and the same understanding of how to conduct their research.

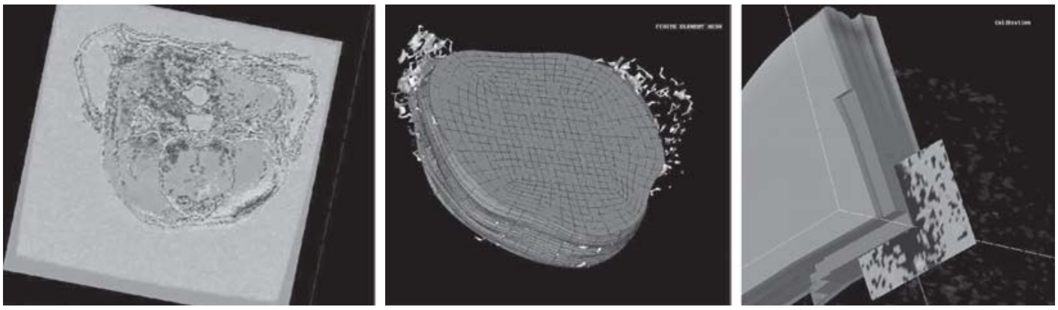

Figure 1: Different visualizations of the same object, the head of a dog. From left to right: a magnetic resonance image; a finite element mesh (a 3D representation of an object's geometry); and a visualization of tissue temperature behavior predictions (image rights granted by project scientists)

The project's principal goal, as mentioned above, is to produce a computational model capable of predicting heat transfer in prostate tissues with high accuracy in order to aid future tumor treatment using laser ablation. The final intended product is a tool that, based on pre-operative magnetic resonance images, provides the physician with a detailed prediction of the possible results of laser intervention for that patient. This model will aid the physician in deciding where to place the optical fiber conducting the laser, the laser power used and the exposure time. It would in fact be automation of these surgical stages, transferring part of the decisions that today are based on the physician's training and experience to the computational model.

During the period in which I conducted the ethnographic study, I was able to follow the scientists in their efforts to coordinate a system which they called cyberinfrastructure, the transmission of data between their institution and the research hospital involved in the project. This system, based on the use of the supercomputing infrastructure available at the university, is intended to ensure rapid transmission of image and temperature data obtained through magnetic resonance (from the hospital to the university) and the model that predicted surgical results (from the university back to the hospital). The objective is to reduce this time to a minimum so that information exchange takes place in real time, during surgery. In this way, the system could be a clinical tool, creating a new surgical protocol for prostate cancer and, at least in theory, for any other cancer treatable using laser ablation.

The laser was tested in different models: small containers containing gel; containers holding round objects of a size similar to the human prostrate; and even a canine prostrate embedded in gel. The goal of the tests 'dry runs' was to test both data transmission speed and the ability of the code to correctly model the objects of interest. They served to refine the computational tools that would be used to model the biological processes and structures in question. The primary difficulty is to build a 3D digital model that reproduces the topography of a natural object in all of its complexity – a huge computational challenge. Additionally, the models must be capable of calculating and reproducing complex processes related to heat propagation with the greatest accuracy possible, which makes the task even more arduous and dependent on the processing capacity of the supercomputers.

The final step I observed, which occurred at the end of the ethnographic study and about two years after the start of the project, was a full system test on a live canine model. The importance of this test lies in the fact that the computational tools would be used in a poorly controlled environment (a live dog), very different from the gel models. The multiplication of variables that could potentially complicate the modeling created great expectations with respect to the experiment, which was followed closely by the entire team, including physicians from the hospital.

I will focus on this specific event to illustrate a key moment during ethnographic observation, which provides privileged data to aid in interpreting the visualization regime operating in this specific case. The test, despite not being totally successful the first time, demonstrated the ways in which the scientists tried to make the prostrate visible (and manipulable) as a computational model. Additionally, it helps illuminate the ways in which the various visual and computational mediations influenced the progress of the experiment.

In this experiment, the issue of presence is displaced. The Renaissance anatomies entailed the ritualized presence of members of the university and of the community, whereas this presence makes little sense in the experiment discussed here. Only one member of the team was personally present during the experiment. All others (myself included) monitored it in real time through the Internet. The test can be described as a public 'ritual' for producing evidence, witnessed by individuals who could attest to its scientific validity, following the classic design of a laboratory experiment (Shapin, Schaffer, 1985), although witnessing of the results took place mostly through computer mediation. Witnessing this experiment through digital technologies was made possible by the high degree of objectivity attributed to the computational models and the visualization methods employed. The attributed objectivity allowed us to witness the computer-generated visualizations as if we were witnessing the event itself taking place.

The '*in vivo*' experiment sought to assess the reliability of the data transmission circuit between the hospital and the computers located at the university where the researchers developed the model. The scientists also wished to evaluate the reliability of the computational model's predictions, which had until then only been tested for inert objects. Luke, a doctoral student in applied and computational mathematics, was a member of the team responsible for coordinating the experiment on site at the research hospital. He later presented the results obtained to the other members. The discussion below, which summarizes the experiment, took place during a meeting on February 21, 2008, when Luke presented the experimental results for the first time:

> Everything from the past 4 months worked perfectly. We ran [the system] the first time ... It was a large event, with four different groups from the [research hospital][4] who had... It was like a dissertation defense, they had to coordinate everybody there. Hum we had

imaging physics, the MRI tech, the vets, and then the guys from the actual, hum laser company ... They were kind enough to let us run [the system] on their animal. since we were running on their animal we had to run quick, so we had like, one shot to get this right. Everything worked perfectly, but then when we started acquiring the thermal images. The noise in the thermal images was unlike anything that we've seen before. And so the filtering that was applied ended up really wiping out all the important thermal image part, all the important part of the thermal image, namely the heating, and just left the noise.

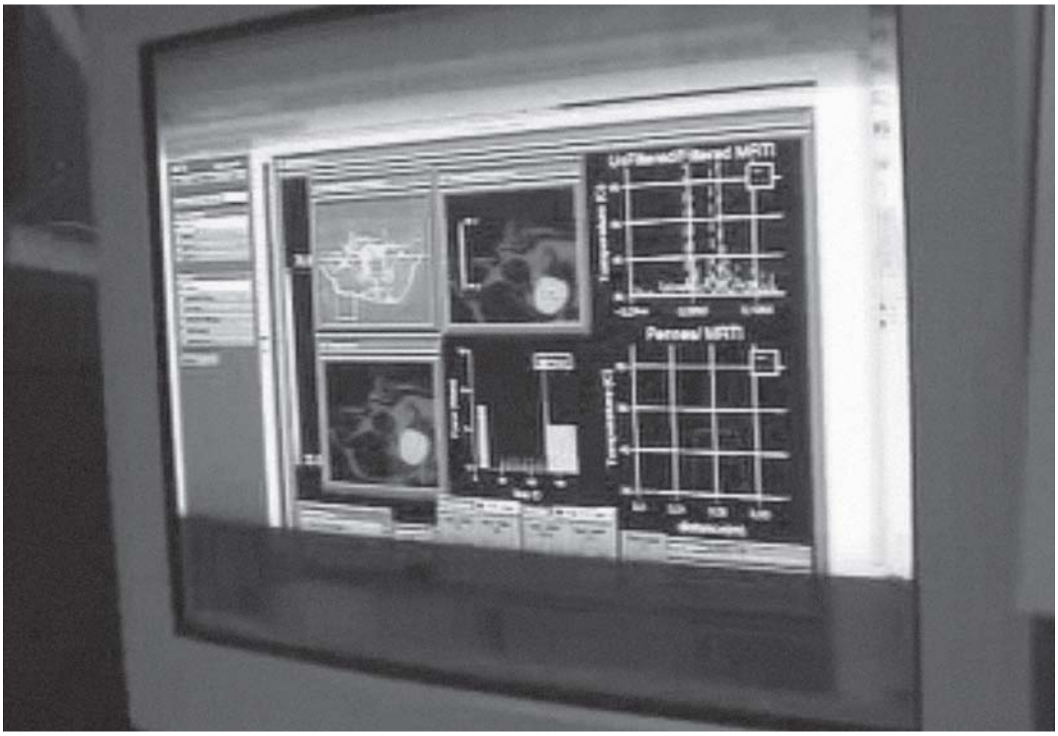

Figure 2: Example of how the experiment was transmitted online, 'witnessed' via computer. In the image, both the figures representing the comparison between the model and the actual temperatures observed in the tissue (upper right) and the visualization of the heat being applied to the dog (upper and lower left) are visible (Author's images)

As Luke explained, the experiment was a relative success because it revealed that the data transmission system acted as expected. It was a failure, however, in terms of the 'visibility' obtained, since it did not provide visualizations of heat behavior while the laser was used in the animal model. The filter used to process the temperature data to turn it into an image comprehensible to the scientists did not work as expected and did not provide a comprehensible visualization of the heating process. This means that the 'noise,' that is the information not relevant to the experiment (the temperature of the rest of the animal's body, for example), impaired the visualization and one could not visually distinguish the point where the laser was causing ablation.

Even though unsuccessful, this attempt demonstrates how the scientists sought to make the processes of interest visible: to be successful, the experiment should obtain images understandable to the unaided eye, in addition to data usable by computational models for the behavior of heat emitted by the laser within the canine prostrate. The failures in data collection and in producing images from the heating process were corrected in a later experiment, which allowed the scientists to observe how data collected empirically could be compared to data obtained through modeling, as shown in Figure 3.

The correspondence between the model and empirical reality is what is called validation and is considered the principal test of the truthfulness and viability of the model. This truthfulness is proven through visually similar figures, among other methods. Or in other words, the superposition of the lines of two figures (the model and that from the experiment with the dog, for example) indicates, for the group, the solidity of the model and its objectivity as a description of reality. As Lynn, a doctoral student in computational and applied mathematics, stated in an interview granted on September 24, 2007:

> Lynn – Oh yeah [laughs]. If you're going to write a paper without pictures in it, uh...
>
> Me – It doesn't make too much sense?
>
> Lynn – Well I mean in the computational world they want to see the results.
>
> Me – They want to *see*.
>
> Lynn – They want to see, exactly, because, if you just describe it ... [A] picture says one thousand words, right? So if you see the picture, and things look like they're lining up ... You can say it converged with this rate, or it matched within five percent, ... in your head, it might sound good, but when you see the picture, and like things almost line up... Like when Luke shows his hum slices of the MRTI data, with his predicted data, they're like right on top of each other, then you're like: "Yeah" [laughs]. You know, it's even more powerful like, even if that is five percent, it's so much more powerful to see it actually on top, then just the number.

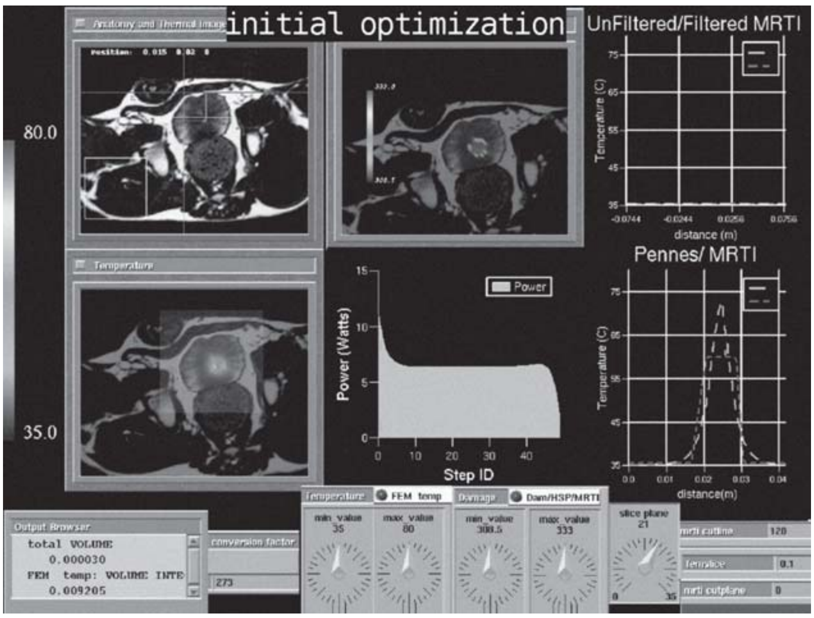

Figure 3: Various visualizations of the data from the *in vivo* tests of the computational model (Image rights granted by project scientists)

Lynn describes the visual impact of seeing two lines that converge, lines that illustrate that two measurements (one obtained empirically and the other produced by a model, for example) are identical or very similar. Such convergences are a constant feature of this project, given its focus on modeling. The search for convergence between projected figures and experimentally obtained data (whether in dry runs or in *in vivo* tests) is a fundamental part of what they consider a successful experiment. At the same time, Lynn's words demonstrate the importance of visuality in this experimental practice: the convergence between model data and data measured in nature, for example, is not fully understandable solely in terms of numerical representations (5%, for example), but must be capable of being visualized. In other words, the ability to convince other members of the scientific community, in the context of a multidisciplinary team or a scientific article to be read by institutional peers, depends on images that make the results 'visible.'

Conclusion: new ways of representing the body

The experiment thus demonstrates a process of visual production of evidence very different from that present in the anatomy theater. The differences are related both to the specific objectives of the two instances of visualization of the body, and to the relationship that each one establishes with the empirical bodies they make visible. Some elements can be understood as continuous from the time of the anatomy theater to contemporary digital visuality, such as those related to how knowledge of the body is related to the empirical body itself. In general, however, the discontinuities between these two moments in time are more revealing of the displacement caused by digital technologies in our knowledge practices and in how we make the body visible and cognoscible.

In experimental science, as in the example observed ethnographically, the focus of the scientists' activities is on producing evidence and not on staging a specific cosmology or a corpus of previously established knowledge. Despite this, there are elements of staging and spectacle that also operate in experimental science due to the complexities of scientific

Figure 4: The mediated visuality in contemporary science. On the left, veterinarians and researchers working on a dog ready to be irradiated with the laser, inside magnetic resonance equipment. On the right, monitors showing the visualizations available with the resonance equipment (Images from a video produced by the scientists present at the *in vivo* experiment)

visualization technologies. The production of visibility through data is not direct, as it passes through various aesthetic and scientific mediations.

Another fundamental change is the relationship with direct observation of the body. The latter only makes scientific sense when processed by the apparatus set up to capture images and temperature data. Or, in other words, as an empirical object, the body of the dog itself does not produce evidence, except through extensive processing work, with complex machinery prepared over various months. Thus, the relationship with the empirical is not direct, since only the data – captured, analyzed, manipulated and filtered – is presented later as evidence, consolidated in papers and other scientific publications (Latour, Woolgar, 1997).

In this respect, a possible convergence between the Renaissance anatomy theater (in its early manifestations) and contemporary visualizations is the fact that the suppression of the body and the materialization of the digital information produced increase the value of the 'text' (currently, as numerical information) to the detriment of the body observed. This same body is built, as an empirical object, through experiment and the knowledge one seeks to build on it (Hirschauer, 1991). There is destruction, even if partial, of the biological entity in order to produce evidence. This ritual must be public and shared to achieve scientific and social legitimacy. However, the public nature of the contemporary ritual is completely different from the Renaissance anatomies; the ritual is mediated by digital technologies without loosing its 'aura' of direct contact with reality. When seeing the images on the screen, we were experiencing the experiment live, in a way, watching it develop in accordance with the practices established there (in the sense that there was broad consensus with respect to the materiality of the experiment observed via the Internet).

Even though only Luke was present at the hospital, his direct experience with the technological apparatus and with the dog are worth much less, in the scientific sense, than the weeks that he and the others spent processing the data collected and later presented to the rest of the group. Additionally, Luke monitored the results of the experiment with the dog much more through his computer monitor (in addition to the other monitors available on site) than through direct observation. His understanding of the results was not, therefore, radically different from that of the other team members, hundreds of kilometers away.

Making something visible means making it cognoscible through specific means. The new forms of visuality made available by the new digital technologies are reconfiguring not only our visual culture, but also how we see nature itself. They are equally part of a process of rebuilding our relationships with knowledge, due to new ways of representing nature and its objects. In the case of contemporary scientific practices, there is no advantage of historical distance to create large-scale assessments like those developed for the Renaissance anatomy theaters. However, we can glimpse some productive paths in the debate on science and visualization, through the discussions presented here.

One important point should be highlighted: the insufficiency of the concept of 'visual' to account for the processes that occur in current knowledge practices, an aspect discussed in prior works (Monteiro, 2009). We can even debate if 'making something visible' is, in fact, the principal activity of the Renaissance anatomy theater, but I will refrain from addressing this here, due to lack of space. From the knowledge practices I could observe ethnographically, the concept 'visualization' limits the analytic focus and ignores the fact that scientists are not just observing images, but rather interacting with information sets in various ways. Even if viewing is fundamental to these processes, it is a relationship with objects in 3D and processing and manipulation of data that require engagement of various senses, in an interactive, integrated manner.

Additionally, we must analyze these practices beyond the question of how they make the body visible. When scientists engage in building virtual models of biological objects and processes, for example, these are actually representation processes involving the possibility of producing knowledge in a way other than mere observation. Computational models incorporate the idea of the possibility of predicting the effect of a surgical intervention, which creates the possibility of technological interventions in the body far beyond those currently available.

The increasingly consolidated belief in the legitimacy of computational models is opening the doors for the use of 4D models, in which the fourth dimension, time, is included. This type of modeling, which also corresponds to the automation of various medical practices, questions our relationships with the future based on present knowledge, not only in the field of medicine, but in all areas which invest in technology as a resource able to predict problems and calculate solutions on its own.

In the study presented, I sought to interpret the meaning of the circulation of images, data and theories that bring together material bodies, visualization techniques and scientists, enabling the production of truth about the body in a biological sense. At the same time, this mechanism for producing truths is associated with practical, instrumental methods for accessing and controlling biological processes, and a strong relationship with marketing of new medical treatments and with academic prestige. The construction and validation of computational codes and models is part of a process to control the body using technology and improve surgical techniques. The association of engineers, biologists and physicians provides a vision of the body detached from its materiality, which depends on digital mediation thought of as transparent. It thus reinforces the idea that the body is the legitimate object of engineering, and should be reconfigured and not just described and observed.

However, if there is a type of 'return to the text' or a relative devaluation of the empirical body in the knowledge practices addressed here, this apparent continuity between the anatomy theater and contemporary science has very different meanings in the two time periods in question. The very text read by the professor during the thirteenth century anatomies represented knowledge. The empirical body being visualized, in the form of a cadaver exposed to the public, was more illustrative and was greatly subsumed by book knowledge. Similarly, the holders of book knowledge were much more important socially than those who dealt directly with the body, a hierarchy that inverted with the passing of time from the Renaissance to modern science, from the fourteenth to seventeenth centuries.

What we see currently is an apparent suppression of the materiality of the body, as perceived by some authors and suggested by the ethnographic discussion. I would seek, however, a reading that did not depend on the idea of 'dematerialization,' because I do not think this is the most important analytical axis to be observed in this situation. We must remember that the computational models being developed by scientists emerge from observations based on empirical bodies, later validated with respect to this empirical nature. Thus, the body continues to be relevant in the sense that it does not disappear completely from the knowledge production processes. However, the ritual itself has been displaced: it is no longer the primary source of observations made by scientists; now, manipulated and observed digital objects are the fundamental source of analytic insights regarding the biological processes of interest.

Additionally, these objects have a type of materiality that appears in two ways. The first is with respect to the scientists' perceptions. They understand the digital visualizations to be objective expressions of the characteristics and internal relationships of the body. Because of this, they are no longer mere images, but rather data revealing the materiality of what we wish to reveal. The second is the materiality that the digital objects acquire in the process of producing knowledge, by being manipulated by the scientists. More than mere processes of visual observation, knowledge is produced, as already mentioned, in an integrated way through interactions between the researchers and the visualizations. Vision is not the only sense at play; aspects of perception related to texture and other spatial characteristics of these visualizations actively participate throughout the process.

What perhaps defines the specificity of the contemporary knowledge processes observed here is the way in which the models are built interactively and validated based on correlations with *in vivo* experiments. However, these experiments and models acquire meaning as a set of data, allowing a unique comparison through a code. The materiality of the biological body is a fundamental part of these practices, but in a completely different way both from the first prosections anatomies and from the later ones, in which observation and manipulation of the dissected cadaver were emphasized. At the center of contemporary practices is the manipulation of digital objects, which enables flexibility unattainable through other means. This manipulability, in turn, appears as one of the principal objectives of contemporary means to access the body. Modulation of biological responses, making predictions and automating surgical interventions can all be seen as part of a larger project, the growing search for control and manipulation of the body in its materiality, whose principal characteristics have not yet been analyzed. The project analyzed here sought to advance in this direction by building digital models of biological processes in the attempt to create an automated surgical intervention. In this respect, the new means of access to the body, through digital models or other technologies, represent one of the fundamental themes to be critically analyzed in contemporary science.

NOTES

[1]All team member names cited here are fictitious.

[2] The first 'visible human' to have his cadaver digitalized was an executed criminal, as in the public prosections.

[3] An exception was the contact Luke had with the animal model which was used in the first *in vivo* test of the system. There was also the work of Laura, a doctoral student in biomedical engineering, with cultures of human prostrate cells. During the period observed, this work generated no concrete results for the project as a whole, and is still in an initial stage of development.

[4] I chose to not name the hospital, to preserve the anonimity of the project participants.

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