GE 301 SCIENCE, TECHNOLOGY AND SOCIETY

TERM PROJECT

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Responsible MRI: RMRI

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1. Introduction

The notion of responsible innovation and research enables newly developing technologies to be shaped by democratic societies, and allow for values to be inscribed upon the said technology. In this context, Magnetic Resonance Imaging (MRI) technologies can be analyzed with Responsible Research and Innovation (RRI) techniques. This research conducts such an analysis on MRI technologies, and evaluates the current existing or nonexistent RRI dimensions within the scope of the National Magnetic Research Center (UMRAM) located in Ankara, Turkey. The aim by conducting this research is to provide information and evaluate concerns regarding social, cultural, technical and environmental aspects of MRI technology developed in this research facility, as well as provide solutions in the scope of RRI involving the research facility, stakeholders and other aspects of MRI. The research conducted shows that most of the social and environmental risk assessments and solutions are resultant from preexisting governmental regulations, so the values considered in the MRI technology of UMRAM should be broadened with the inclusion of stakeholders such as patients and experts, reflection on possible social impacts of MRI, upstreaming assessment and anticipation of possible risks as well as responding to new insights and developments occurring in the technology over time in order to establish a sustainable and socially conscious medium for research and innovation.

2. Theory

The preferred theoretical approach for this term project is Responsible Research and Innovation, which basically aims to encourage stakeholder engagement, broaden current assessments, place values at center stage, do responsive experiments, monitor RRI process and aim for a shared value for any industry [1]. For the chosen research center UMRAM, the approach of RRI has chosen to be the most suitable, since the industry of MRI machines and its users, being mostly doctors and patients, are in a mutualistic cycle within themselves, where they both get affected from and affect the industry. Since UMRAM identifies itself as a research and development institution, the majority of technological research concerns itself with the technical aspect and social aspect of the developments can be prone to be overlooked. In addition the MRI industry inevitably concerns itself with substantial matters like privacy, health risks and patient experience, which all can be better analyzed through the lens of RRI, since there are issues with values and trust. Also it should be noted that

UMRAM is a research institute and non-mature technologies within the MRI industry are being developed there. Consequently, applying such a project here with RRI will enable democratizing the technology and broaden the existing assessment initiatives, with anticipation, reflexivity, inclusion and responsiveness [1]. Anticipation takes a more mature tone for research institutes as often an experimental approach is adopted, which might have unmatched or unexpected results. Hence, a foresighted evaluation establishes the core of addressing responsibility at research institutes like UMRAM. Furthermore, a research institute must adopt a malleable structure in order to shift its focus to correct direction when dead ends are reached. These dead ends might include social dilemmas and in such cases, the research institute must be able to respond to external input for adjusting its vision and direction. In addition, during such situations, a research institute must constitute a middle ground for all parties in order to create sustainable development.

3. Background Research

3.1 General Information about MRI

Magnetic resonance imaging (MRI) is a medical imaging technique that uses a generated magnetic field and other electromagnetic waves to construct a detailed image of the organs and tissues in the body.

Most MRI machines are large, tube-shaped magnets and when somebody is getting scanned they lie inside an MRI machine. The applied magnetic field temporarily realigns water molecules in the body. Radio waves cause these aligned atoms to produce faint signals, which are used to create cross-sectional MRI images. MRI is a noninvasive way for your doctor to examine your organs, tissues and skeletal system. It produces high-resolution images of the inside of the body that help diagnose a variety of problems. Because MRI uses powerful magnets, the presence of metal in the body can be a safety hazard if attracted to the magnet [2]. Moreover, there may be other safety hazards that can be both due to the additional techniques used in the MRI to get better images of the body and due to some complications that may be triggered in the people with chronic diseases, implants, pregnancies, etc. Additionally, some problems also rise about doctor-patient confidentiality and overall energy consumption of the machine.

3.2 UMRAM

The National Magnetic Resonance Research Center, (tr. Ulusal Manyetik Rezonans Araştırma Merkezi), also known as UMRAM, was established in May 2009 at Bilkent-Cyberpark with the support of the Turkish Ministry of Development. Currently, UMRAM is housed in Aysel Sabuncu Brain Research Center. UMRAM has been the host of new emerging technologies, and is the research facility to produce the first fully national MRI device. The mission of UMRAM is to promote, facilitate and conduct research on magnetic resonance imaging. UMRAM brings together an interdisciplinary group of investigators to study and use the technology of magnetic resonance imaging, as well as pioneer new imaging techniques. Currently the center consists of four research groups: MRI Hardware Engineering, MRI Software Engineering, Psychology and Neuroscience, and Radiology. UMRAM makes research and development projects regarding these fields, as well as creating brand new, fully national technological devices. UMRAM also has animal research, electronics and psychophysics laboratories. UMRAM has an open access policy of use, i.e. it is open to researchers who would like to use the facilities, and can provide staff support for data collection. There are many research groups and laboratories, hosted by many professors from different backgrounds. Professors have their own research groups, where they are free to recruit undergraduate, graduate and postgraduate researchers willing or volunteering to make contributions. Results of the conducted research are open for access worldwide, and are often presented in official research conferences [3].

3.3 Health Hazards of MRI

There are some implied yet mostly inadvertent health hazards of MRI, that can be sensitive for some of the users with different backgrounds. One of the major contrast agents used in thought-to-be-safe forms in MRI scans is Gadolinium which is a heavy metal and is highly toxic to humans. Recent findings have shown gadolinium deposition in the brain. Thus, gadolinium usage is decreased and regulations are reviewed [4]. In the past years, evidence supporting association between Gadolinium deposition and development of NSF (Nephrogenic systemic fibrosis) has increased [5]. While gadolinium dosage can be decreased for specific clinical applications, decreasing the administered dose of gadolinium might also cause a non-diagnostic scan [6]. So, one should be careful while setting the gadolinium dosage. Due to the said risks of gadolinium, it is suggested to minimize the gadolinium usage. Instead, employing different imaging methods that have lower potential risks is advised [6].

Heating caused by MRI is another worrying effect. Exposure of tissues to radiofrequency (RF) pulses produced by MRI induce currents in said tissues, which consequently leads to heating [7]. In particular, electric current induced by a varying magnetic field in a conductive object might cause implants to heat up and damage the tissues around the implant [8], [9]. In order to avoid heating tissues, Specific Absorption Rate (SAR) [10] is commonly used in MRI machines to calculate the power deposited by an RF pulse to a tissue and cut the RF field if it exceeds certain values [11]. However, these calculations are conducted using the model Visible Human Male and scaling it based on weight only [12], disregarding the individual patient anatomy. It is also to be noted that the model used in these calculations, Visible Human Male, is a model that is solely based on the biological male body, completely disregarding the various tissue types and their characteristics belonging to the biological female body [13].

3.4 Privacy Issues Regarding MRI

In order to create a non-instrumental mutual trust, privacy issues regarding MRI should be understood in a broad perspective. There has been a paradigm shift over the last decade with respect to data ownership, partially driven by recent events in which personal data was used without consent of the individuals for monetary or political motives [14]. Different patients from varying cultural, social and economic backgrounds may focus on diverse concerns about privacy. The desirability of neuroimaging applications becomes controversial when specific applications embody conflicting values and desires. Depending on the weight given to these different values and desires, the application is perceived as desirable or undesirable [15]. In addition, various institutions and countries have different policies about data sharing and its regulations therefore researchers, depending on where they reside, must work in line with these legislations. With respect to that, the transparency about the procedures and possible violations of the privacy in a scan should be discussed in a RRI perspective.

Another privacy issue is related to distinguishing brains. It is possible to classify brains according to brain types. However, the knowledge is limited so concerns are premature; but, it is likely that this problem should be addressed in near future [16], [17]. In addition, there is a possible risk of facial reconstruction using software and MRI images, which raises questions about privacy [18]. A long-term study at the Mayo clinic has collected more than 6000 MRI scans. Later, they reconstructed the faces of 84 subjects using a facial-reconstruction subject and successfully matched 70 of them with the subjects [19]. Usage of MRI scan data in this way worried the experts and made them more serious about the privacy threat. This study raises the question that there are many institutions that do not readily have to comply with the "Privacy Rule", such as life insurance companies, federal and state government, criminal justice officials, and how to regulate these extra people [20].

Privacy issues regarding MRI scans could potentially invalidate the 5th amendment for the sake of research specifically but cannot do such things as reconstruct your brain. Field-based remote (to mostly low and middle-income countries) MRI research gives rise to unattendant ethical and social issues, since it is possible to distinguish some types of psychological illnesses or neuro-diverse brains through the scanning and even teach machines to see the world through the scanned brains [21]. Furthermore, recent work on algorithms for decoding and analyzing the brain data acquired from functional magnetic resonance imaging (fMRI) scans to explain people's mental conditions creates the possibility of institutions such as prisons and schools to make obligatory neural assessments [22]. A way to responsively overcome this is to strengthen the communication between the researchers and the local community to sustain local values and work with ethical concerns in mind. However, the most important element in data sharing is allowing the participants to make informed decisions about how they want their data to be used, and, within the law of the specific country, to follow the participants' wishes [23].

3.5 User Experience, Accessibility & Issues Related to Actors in MRI Technology

To broaden current assessments and overcome the main observed barriers, a successful stakeholder engagement is a crucial step. User experience does not only broaden the values and issues addressed, but it also places the values of the users at the center and reinforces mutual trust that is not instrumentalized.

Patients are one of the crucial users of MRI. They undergo MRI scans frequently and their experience is an important factor for the successful operation of medical scans [24].

Therefore, companies are slowly focusing on the patient's experience and trust to robust the imaging by making MRI scans less of a 'disease repair shop'. There are many cases where people have complained about the tight spaces of MRI, loud noises of the scans and PNS (peripheral nervous stimulations) that cause a tingling sensation or twitch in the muscles that do not introduce any harm. Yet these affect the quality of experience and many methods exist that can potentially overcome these discomforts but the last, such as providing music in non-brain scan MRI scans, meditation, coaching and ambient room themes. Moreover, these methods can be personalized and used with different patient groups such as pregnant women, children, people with pacemakers and patients with different kinds of conditions that will make them comparatively more uncomfortable. Trying to include the values and instilling more apprehensiveness of the patient experience will potentially target reflexivity dimension and potentially surface positive experience. With positive patient experience comes the positive doctor and department experience, while as a consequence the number of rescans decreases and diagnosis becomes more efficient and easier [25].

3.6 Sustainability Risks of MRI Research

Sustainability has many definitions. One of them is that sustainability oriented innovation can be defined as the commercial introduction of a new or improved product, service or system that leads to "environmental and (or) social benefits over the prior version's physical life cycle" [25]. Through this, a positive impact is aimed to be created on the economy, environment and society such as energy efficient machines and user/customer satisfaction [26], [27].

MRI consumes a great deal of power. The aggregated energy consumption of cooling the MRI systems represent almost half of the combined consumption of energy consumed by the whole system [28]. Its energy usage can be equivalent to a town with almost 900 people.

In addition, the amount of electronic waste (e-waste) globally has doubled in just five years, from approximately 20 million tons to 40 million tons of e-waste generated per year. One of the contributors to e-waste globally is due to MRI research. In 2016, the global amount of e-waste reached an all-time high of 44.7 million tons. E-waste is an invaluable unconventional resource due to its high metal content, as nearly 40% of e-waste is composed of metals. Unfortunately, the rapid growth of e-waste is alarming due to severe environmental impacts and challenges associated with complex resource recovery that has led to the use of toxic chemicals. Furthermore, there is a very unfortunate ethical issue related to the flow of e-wastes from developed countries to developing countries. At this time, e-waste is often open pit burned and toxic chemicals are used without adequate regulations to recover metals such as copper. The recovered metals are eventually exported back to the developed countries. Thus, the current global circular economy of e-waste is not sustainable in terms of environmental impact as well as creation of ethical dilemmas [29].

4. Method

The data were obtained through various interviews. In order to have a broad perspective in the findings, the interviewees were chosen from varying statuses and roles in the research center. Thus, an engineer, an Electrical and Electronics Ph.D student and a Professor of Electrical and Electronics Engineering were interviewed. These interviews were recorded with an audio recorder and transcribed in order to analyze. In the process of analyzing the interviews, the major topics that the questions were centered around were identified. These topics were further separated into relevant subtopics in order to identify the key elements of the case in order to classify the areas of concern.

TABLE 1: THE CLASSIFICATION OF INTERVIEW CONTENT

Topics	Subtopics
Technical Information	MRI Properties
	Stakeholders
	Research Areas
Risks	Health Concerns
	Privacy Concerns
User Experience	Patient Experience
	Expert Experience
Sustainability	Energy Consumption
	Recycling

The transcripts of the interviews were analyzed and coded on QDAMiner using the classifications in Table 1. Thus, the sections of the interviews relevant to the areas of concern were isolated and listed.

5. Findings

5.1 Technical Information

5.1.1 MRI Properties

The MRI machines used in UMRAM were briefly explained by the interviewees, some technical information was given in terms of the machines' hardware compartments, image qualities and magnetic flux intensities. The engineer states that UMRAM owns and makes use of three MRIs; a 1.5 Tesla MRI used for test and research, a 3 Tesla MRI machine used in the scans conducted on patients and research subjects and a 1.5 Tesla prototype. "Tesla" is a measurement of the magnitude of a magnetic field. The 1.5 Tesla prototype MRI is a collaboration with ASELSAN and is the first national MRI prototype. Despite the better image quality 3 Tesla MRIs provide, the domestic MRI project focuses on conducting faster scans with the frequencies used in the 1.5 Tesla MRI machine. UMRAM also houses research on coils, gradient coils, receiver coils and the "imaging point".

In addition to the engineering research groups, there also exist neuroscience research groups actively conducting research in UMRAM. The engineer explains that these neuroscience groups research the parts of the brain that function in response to certain tasks, then analyze these in order to reconstruct the brain as an image. These groups also make use of functional MRI.

The more general name of MRI is nMRI, nuclear magnetic resonance imaging. The professor clarifies that nuclear magnetic resonance refers to the resonation of the nucleus and has nothing to do with radiation or nuclear energy. What is excited in the material being scanned during MRI scans is the hydrogen atom. What makes hydrogen atoms a crucial part of the imaging process is the fact that hydrogen atoms are abundant in the human body and lead to very high signals. Thus, it allows the creation of high-quality images. The professor states that when excited under a magnetic field, hydrogen atoms start resonating. This is called magnetic resonance. With the application of radio frequency (RF) pulse, an echo signal is received and used to obtain the image. The transmitter and receiver design is dependent on the resonance frequency and the applied magnetic strength. By modulating the magnetic field, the resonance frequency can be varied over time. The resultant field is called the gradient magnetic field.

There exist three types of magnetic fields that are used in MRI. The first field is a strong, linear magnetic field called the constant magnetic field. The second is the gradient field, which is fluctuating and slowly varying over time which might result in the creation of currents in the nerves of patients. The final field is the field at radio frequency: the resonant frequency.

5.1.2 Research

The research on and including MRI machines can be analyzed by separating them into two groups: current research that is being conducted and future research to be conducted.

TABLE 2: THE CURRENT AND FUTURE RESEARCH ON MRI

Current Research	"The images we get from MRI are useful for diagnosis and doctors may use these results for finding the problems with the patients." [Ph.D Student]
	"Hardware has been trying to improve for years, but it's still possible to further improve it because the physics of fMR are awesome, and it's very difficult to build devices close to their physical limits to make the most of them." [Professor]
Future Research	"MRI machines are big machines and cannot be used in ambulances, bedside applications. So that research and recent studies focus on making the MRI machine smaller, so that it can be installed in ambulances." [Ph.D Student]
	"It takes 10 units of energy to get one unit of something, and one of our research topics is to increase its power efficiency, and many places in the world are working on it." [Professor]

5.1.2.1 Current Research

MRI is a key component for ongoing medical research. It is used in the imaging of body parts such as head and abdominal imaging, and proves to be very useful for the medical industry and doctors. The Ph.D. student claims that the results of MRI scans greatly contribute to the diagnosis the doctors come up with for the patients.

On the other hand, the research group led by Professor is concerned with the hardware aspect of the MRI machine. According to Professor, despite being an area that researchers have been attempting to improve for years, hardware still has space for growth. This is due to the fact that the physics of fMR are extremely extensive, and it is extremely hard to produce devices that are close to the physical limits, which is highly desired in order to make the most of the MRI technology.

5.1.2.2 Future Research: Power & Size

Future research regarding the MRI machines is expected to center around their power consumption and size. It is stated in Table 2 as "It takes 10 units of energy to get one unit of something" by the professor, highlighting the fact that MRI machines are lossy devices, and the amount of energy lost in the process can not be neglected. This problem is one of the research interests of UMRAM and the research group led by Professor and there exists research all around the globe focusing on this problem. Future research is expected to follow the trajectory of these in order to optimize the power consumption and loss of MRI.

Another area of interest that is expected to be a central part of future MRI research is the large size of the MRI machine and the limitations its size brings. As MRI machines are fairly large, they can not be implemented into ambulances or work as bedside appliances. The Ph.D. student explains that it is desired to make the MRI machine smaller, more portable, so they can be installed into ambulances. These machines are called ultra-low MRI. It is to be noted that this also requires the optimization of the power consumption of the machine, once again highlighting the importance of research centering around power efficiency.

5.1.3 Stakeholders

There are many stakeholders involved with the MRI technology from various areas of expertise. The initial use of the MRI technology was to provide an understanding of the structure of substances, and was developed by chemical engineers for this purpose. Currently, it is a common technology used in the Turkish radiology community due to its ability to produce data necessary for the diagnosis of many diseases. However, beyond its medical use, it is also a research tool for those aiming to get a better understanding of the human body and how it functions. MRI contributes to the understanding of the brain and its functions due to the images obtained from it, and is frequently used by neuroscientists. Professor states that currently MRI is the most important tool in the world to understand how the brain works. Thus, in addition to the patients and doctors, those from different areas of science are also stakeholders for this device.

MRIs are also used outside of medical and chemical research, with its subjects being nonhuman. Veterinarians and veterinary faculties use MRI for both animal health concerns and for studies on animal anatomy. Plants, fruits, vegetables and foods are also scanned for various reasons. The professor gives an example of the use of MRI in the food industry as the measurement of the oil content and water content of sunflower seeds. This makes it possible to understand what percentage of sunflower oil is available in the seed without actually removing the oil from the seed. It is economically critical for the sunflower oil industry as it allows companies to come to a decision on whether to buy the sunflower seeds from the producers right after scanning them with nMR depending on the oil percentage. Overall, many shareholders from various industries are involved with the technology.

5.2 Risks

The two major risks involved in MRI are privacy risks and risks concerning health and safety.

TABLE 3: THE PRIVACY RISKS OF MRI

Privacy Concerns	"Situations concerning the patient and the doctor should remain between them. To protect it, the doctor and the hospital are responsible for it." [Professor]
	"Patients might not want to share these images with others though doctors might see." [Professor]
	"Typically, what is done is not to mention the patient's name in any study, remove it from the database immediately, and use it there if a special code is needed." [Professor]
	"So, only personal information is requested. In works conducted for such outsourced research, it is everyone's responsibility within the scope of their own project to keep what we call patient confidentiality, within the scope of their own project." [Engineer]

TABLE 4: THE SAFETY RISKS OF MRI

Health & Safety Concerns	"The radio frequency signal causes radio frequency currents in the body, which leads to heating. This is the same with cell phones, so is MR. Overheating is undesirable, of course, but we do calculations to reduce the warming." [Professor]
	"Another issue is the heat accumulation at some parts of the body because of the radiofrequency waveforms." [Ph.D Student]
	"Also, you should never go inside with anything metal to MRI machines because magnets attract, and even if they don't, ferromagnetic materials can heat up." [Engineer]
	"Since the nervous system works with an electric current, if the magnetic field is strong enough, the nervous system is stimulated, but these are very small feelings." [Professor]
	"If someone enters with a pair of scissors, and the scissors are something ferromagnetic, they can fly off and stab someone." [Professor]
	"MRI mostly affects the under-skin fluids of the body. It may have some effect on the fluid circulating inside the inner ear, which is related to the balance of the person." [Ph.D Student]

5.2.1 Privacy Concerns

Interviewees explained the type of personal data collected from patients and reflected on the handling of sensitivity data. Engineer states that they ask all patients to fill in a participant form. They take information, such as TR ID number, name, surname, date of birth. She further emphasizes that in works conducted for such outsourced research, it is everyone's responsibility within the scope of their own project to keep what we call patient confidentiality, within the scope of their own project. On this matter, Professor explains that, typically, what is done is not to mention the patient's name in any study, remove it from the database immediately, and use it there if a special code is needed. This is how it is applied even if it is a healthy individual. Normally, the patient's name, surname, age, and weight are asked while taking the image, but only the necessary parts are taken from the recorded file, and the patient's name is destroyed when the files are provided to other people who use them.

Professor emphasizes that it is the responsibility of the instructor who runs the project to protect this information. The information exchanged between the patient and the doctor should remain between them, and the doctors and the hospitals are responsible for the protection of this information. The professor adds that it should also be considered that the patients might not want to share the images of MRI scans with third parties. This should also be kept in mind during privacy protocols.

5.2.2 Health & Safety Concerns

MRI is a comparatively safe technique; however, there are some healthy and safety concerns surrounding it due to its working principles. One of its fundamental parts, radiofrequency coils, induces radiofrequency (RF) currents. RF currents in MRI make the tissues heat up. According to the professor, the principle here is similar to what happens with cell phones. As overheating is unwanted, calculations are made to decrease the heating levels. The intensity of the magnetic field is calculated according to the FDA limits and more than the calculated intensity is tried not to be used. If the intensity increases abruptly, then it may hurt the patient. However, the current devices are not capable of this drastic change in intensity. The body heat not increasing by more than 1 degree Celsius is one of the safety criteria. This amount is what normal people can experience in their daily lives without complications and is confirmed by daily life experiments. The professor adds that a lot of security measures are followed inside the machines. There are some programs that measure the safety of the machines via calculations and another program to check the calculations of the previous program. Even if there is something going wrong with the software programs, the hardware ensures the safety to some degree. That is why accidents in imaging management happen rarely. So, even if people are scared that MRI would stop their hearts, the calculations demonstrate that it is not the case. The Ph.D. student states that there may be some cases where high magnetic fields such as 7 Tesla may cause dizziness and leave a metallic taste in patients’ mouths. This dizziness is caused by MRI affecting the fluid-filled channels in the inner ear which is related to balance. However, there is no case where a person entering a high magnetic field gets significantly hurt.

There is a second magnetic field in MRI which is called gradient. This field can cause excitation in the nerves by the changes in it as the change in magnetic fields induces a current. When the said current is induced in the nerves of the human body, it stimulates the nervous system. However, the Professor highlights that the stimulation is pretty weak. The Ph.D. student adds that the switching noise of the gradient coils might be uncomfortable for some patients and without using an ear protection apparatus, patients' ears might be damaged.

Apart from the harmless symptoms the magnetic field causes in the human body, some materials called ferromagnetic materials can create huge risks if the personnel does not pay enough attention. The professor gives the example of a person with a pair of scissors made of ferromagnetic material entering the MRI environment. The scissors might fly away due to the magnetic field inside and hurt someone. The magnetic force inside the MRI machine is so strong that this effect can be named as the missile effect. There is an unfortunate example of this situation happening in a hospital outside of Turkey. A patient getting an MRI needed an oxygen tube. When the personnel brought the oxygen tube inside the MRI environment, the oxygen tube hit the patient due to the magnetic force and killed them. There are precautions taken to prevent this type of accident. However, the professor states that as the magnetic field cannot be seen with our eyes, it might be difficult to work with it for people who are not familiar with the concept of magnetism. This situation demonstrates that people who do not know how to operate the MRI machines properly create the biggest risks and the MRI machines must be kept behind closed lock doors.

5.3 User Experience

User experience can be separated into two groups: patient experience and expert experience.

TABLE 5: THE PATIENT AND EXPERT EXPERIENCES

Patients	"Patients normally say after the MRI imaging, they feel dizzy and feel a sense of falling. Because MRI mostly affects the under-skin fluids of the body. It may have some effect on the fluid circulating inside the inner ear, which is related to the balance of the person. Another issue is the heat accumulation at some parts of the body because of the radiofrequency waveforms." [Ph.D Student]
	"There may be things like dizziness, a metallic taste in the mouth." [Professor]
	"The radio frequency signal causes radio frequency currents in the body, which leads to heating." [Professor]

	“Switching noise of the gradient coils may give discomfort to the patient and if an ear protection is not used, patients’ ears may be hurt.” [Ph.D Student]
	“MRI may also cause peripheral nervous system and motor nervous system stimulations.” [Ph.D Student]
Experts	“We do not have interaction with doctors and patients.” [Engineer]
	“Regardless of the reason to image a person, all experts are required to receive approval from the Ethics Committee.” [Engineer]

5.3.1 Patients

One of the common symptoms among patients after and during getting an MRI is the feeling of dizziness, the sensation of falling and a metallic taste in the mouth. The Ph.D. student explains that the reason behind these symptoms is that MRI has an effect on under-skin fluids of the body. When MRI affects the fluid-filled channels of the inner ear which is responsible for balance, patients feel dizzy. The professor adds that radiofrequency (RF) waveforms damage the tissues as they cause heating. To avoid it, FDA provides limits for the RF exposure. In the case of exceeding the limits, patients might get hurt.

Gradient coils in an MRI machine also creates an uncomfortable experience for the patients. While the gradient coils are switching, they create some noise according to the Ph.D. student. If patients are not provided with an ear protection apparatus, the noise might damage their ears. In addition, the Ph.D. student adds that there are some reports stating that peripheral nervous system and motor nervous system simulations might get triggered due to MRI.

5.3.2 Experts

Researchers and engineers in UMRAM do not interact with doctors and patients as they are focused on hardware design. However, the engineer acknowledges that some students who work on specific projects related to head imaging and fMRI interact with patients. Regardless of the person or institution that requires an MRI, the approval of the Ethics Committee is needed for human imaging.

5.4 Sustainability

Sustainability of MRI can be investigated through two main concepts: power usage of the MRI machines and recycling.

TABLE 6: THE POWER CONSUMPTION OF MRI AND RECYCLING

Power Usage	"Main magnet in an MRI machine consumes a great deal of power. Operating around 0 Kelvin decreases the expected amount of power." [Ph.D Student]
	"Gradient coils consume a lot of power as they work with 2000 Volts and 600 Amperes." [Ph.D Student]
	"Some components, for example, contain helium at 0 Kelvin, and it needs to have constant power for it to be constantly cold. In other words, there is no such thing as turning off the MRI. There is even an UPS protocol when the electricity goes out. Even then, there are parts that are constantly in working. So of course it consumes a lot of power. So there's a megawatt-level power dissipation going on because it's always been working." [Engineer]
	"MRI consumes more energy than other imaging technologies." [Professor]
Recycling	"Coils that are built once are most probably not used again, and are thrown out." [Ph.D Student]
	"Medical trash such as gowns and earbuds are thrown out. Batteries are recycled and most of the electronic components are used repeatedly." [Engineer]

5.4.1 Power Usage

After the installation of an MRI machine, it continues to operate constantly. The engineer reports that it needs to be on all the time due to a main magnet inside the MRI as the magnet needs temperature around 0 Kelvin to operate properly. Thus, the magnet needs to have a constant power to be cold constantly. So, they do not turn off the MRI machine. The Ph.D. student states that there are even protocols for the cases when electricity goes out such as UPS protocol which makes sure that some parts of the machine are still operating. Also, separate magnets in the MRI machine consume separate power. Aside from the magnets, gradient coils inside the MRI machine operate with 2000 Volt and 600 Amperes. Due to such requirements, the power dissipated is in megawatt-levels.

Compared to other imaging systems, MRI machines consume a lot of power. In that sense, every step to gain power is inefficient according to the Professor. In order to get 1 unit of image, 10 units of energy is required. The professor addresses that the researchers and the engineers in UMRAM are currently working on increasing the efficiency of the MRI imaging system. It is challenging to decrease the required power level as the reduced power levels might also cause the image quality to decrease.

5.4.2 Recycling

Electrical circuitry such as coils built only for a specific project are not recycled in UMRAM. The engineer clarifies that there are some storerooms to place their own products and if the said products are not used for some time, they throw them away. However, according to the Ph.D. student, they collect objects such as batteries and capacitors. Batteries are recycled whereas operative electrical components which are not burnt can be used again.

Biomedical waste is another type of waste in UMRAM. The engineer reports that they dispose of the biomedical waste as medical trash. Gowns and noise canceling headphones and gadgets that patients use are included in medical garbage. They are collected in one place and a team is responsible for picking up the medical thrash.

6. Analysis and Conclusions

The findings obtained from this research project show different dimensions of RRI in UMRAM and how it can be improved to increase the quality in the various aspects of the MRI machine and its experience. Initial findings show that MRI technology is a medical imaging technique used widespread globally and nationally, and is relatively less risky compared to other techniques such as PET Scans or Tomography. However, in-depth-research revealed some risk factors regarding user privacy and user health & safety. User interactions show that there are also concerns regarding the experiences of patients and experts of MRI device usage. Additionally, ongoing research in the field of MRI suggests multiple problems regarding the sustainability of this project, which, in this context, refers to the environmental issues caused by the device’s excessive power usage and wasteful research conditions in laboratories. The lack of communication between stakeholders and the presence of such problems emphasize the importance regarding the implementation of RRI procedures in this field, which this project aims to cover by analyzing it technically, socially and culturally for each finding.

6.1 Technical Analysis

The technical findings, which can roughly be divided into MRI technology and research procedures, have various social, cultural and unsurprisingly, technical implications. Other technical findings yielded information regarding the stakeholders associated with MRI technology and their interactions. The stakeholders consist mainly of engineers of chemical and electrical & electronics departments, neuroscientists, research faculties, medical and veterinary faculties, doctors, patients in the research and medical applications and economists, nutritionists, traders and companies in other contexts. Research regarding this field done by institutions, scientists, engineers and medical experts mostly benefit stakeholders such as humans, plants, animals and economically involved stakeholders such as companies and traders. It was found that the interactions of the stakeholders affect the development of this technology. As users of MRI require more features in the technology, the MRI devices constructed by engineers and scientists begin to accommodate such features. For this purpose, if RRI principles are used in the context of developing this technology, new values can be added to the features that get added to MRI technology. This way, the stakeholders may have a say in the inscription of social and democratic values to MRI devices. Our findings also reveal that the full name of MRI technology, which is nuclear magnetic resonance, was changed due to the confusion the word “nuclear” caused. This reveals that RRI steps were already in place to avoid confusion regarding the development of this technology, which shows a general cultural issue caused by the technical aspect of MRI. There is also a misconception regarding MRI damaging the heart, however, MRI could only have such an effect if the magnetic field was much stronger, which the technology currently lacks. In the far future, this could be an issue, however, there are currently RRI measures being taken to prevent such an issue as the technology develops. Further bottom-up approaches could be considered by UMRAM to further allow the inscription of values through reflexivity.

6.2 Risk Analysis

Findings regarding the risks of MRI show that there are certain implications associated with MRI technology, such privacy and health and safety issues. It was found that health & safety issues occur due to heating of various tissues and stimulation of the nervous system due to magnetic fields in the MRI device. RRI solutions to this issue involve international regulations set up for such heating by which international stakeholder view and commentary is taken, for example, the limitation put on the heating degree. In addition to this, risks such as these nervous simulations and heatings are attempted to be minimized by various computer programs checking and simulating whether the device is risk free. And, such risks are generally found to be relatively insignificant for the general patient regarding the view of the international regulations. Moreover, for the patients that do not fall into the general category, like children and people with various diseases, precautions are taken into consideration. However, most imaging techniques, involving MRI, use only "white adult male" as models for engineering technology development as a basis, which clearly lacks the diversity value for ethnicities, genders and age groups that have access to the technology, which calls for RRI developments for implementing and boradining the values of this technology. The major risk associated with MRI however, according to the analysis, was found to be the lack of knowledge regarding the technology in society, which is caused by some cultural perceptions of the principles associated with MRI. Since the working principle of MRI requires that strong magnets be used, it attracts the ferromagnetic materials when active. However, it was found that, due to lack of MRI culture within patients and medical personnel, severe accidents may occur, which is mainly caused by the lack of perception of the magnetic principles, due to how magnetic forces are invisible. Hence, an RRI implementation for this is either to limit the access to MRI devices except qualified personnel, and to educate the parties involved with associated risks of MRI. Additionally, a great cultural concern regarding MRI technology is the privacy issue. Although international regulations and standard procedures are being taken in testing and utilization of MRI devices, the main perspective patients have is that their privacy and data will be compromised. Although this is definitely not the case, the lack of cultural awareness regarding this topic shows that RRI techniques are necessary for broadening and integrating cultural values and the MRI technologies, and there is a lack of such studies/developments, in which reflexivity can become a key value in MRI.

UMRAM already follows some legislations and rules about data sharing and privacy, but they need to address the issues regarding privacy, diversity and other technical issues that come with the limitations of MRI more. The first proposed solution addresses diversity concerns by inclusion to utilize various different human models for their initial testing result, which was found lacking. Currently, UMRAM uses the male-body model when they are developing their technologies. If models corresponding to different genders, age groups and body shapes are used, the values could be broadened by reflexivity and add better results to simulations accordingly. UMRAM can further expand their responsibility on privacy concerns by providing participants the opportunity to consent to their data being shared, whether they'd like it to be shared anonymously or not, and inform them about the implications of data sharing. Greater safeguards can also be put under the law and UMRAM policies as a bottom-up approach to both protect the data to the greatest extent possible, while also sharing the data if the participant is willing. This can aid in the process of transparency for the privacy issues concerning MRI. Other technical risks could also be evaluated together with an external company, research center, facility or institution to identify risks in MRI, which allows for further inclusion and may bring light to problems that were previously unattended to, or any future problems concerning MRI, allowing for preemptive measures to be taken.

6.3 User Experience

Another key aspect to our findings was the user experience associated with MRI technology. User experience becomes a main concern in this area due to the patients and experts involved in this technology. MRI technology can cause some distress to the patient, as previously established in the technical aspects, therefore patient experience becomes an important issue when resolving with RRI. This is addressed by boundaries put regarding the distress of the devices put by official organizations, and research conducted to alleviate the issues. In addition to this, the distress caused by loud noises of the MRI device due to gradient coil switching were found to be alleviated with simple solutions such as earbuds. Experts also play a key role in the user experience aspect. Researchers and engineers in UMRAM do not interact with doctors and patients frequently as they are focused on different aspects of the MRI technology. Although, for MRI, the approval of the Ethics Committee is needed for human imaging, the fact that doctors, patients and engineers do not interact is a major RRI concern. More RRI conducts regarding inclusion would have a positive effect on the MRI development process.

Findings already indicate that UMRAM, from time to time, consults with some of the users, such that doctors sometimes use the MRI machines and inevitably give feedback about that. Yet, it seems that the range of users can be expanded from not just doctors, but to patients and technicians by using inclusion. Because UMRAM is a research oriented institution that improves products and ideas within a technological perspective, their main concern would not be the user experience but, like expected, it would be the interests of students, professors and partner institutions. So, the solution for a better user experience might be instilling anticipation towards developing new technologies that will challenge the use of MRI from the perspectives of medical experts, patients and technicians. Moreover, with scattered intervals, scenario-based workshops can be done to view the impacts of the developed products on the users, using reflexivity. Such that, when a research arises with potential capability to alter user experience, various stakeholders can be gathered to state their opinion about the experience of how badly or nicely, the new development alters the experience. In such a way, a RRI perspective can be implemented into UMRAM.

6.4 Sustainability

Environmental and sustainability concerns also appear as a main concern in our findings. Various technical aspects of MRI devices that cause environmental concerns. The main point is especially seen in the energy consumption of MRI technologies. Although RRI solutions are developed through various research projects, the MRI device consumes too much energy, and the current technology is significantly inefficient compared to its theoretical energy consumption. It is emphasized that the MRIs are lossy devices, requiring too much energy for a small task only to lose most of the energy in the process. It must also be noted that the MRI must always remain active due to its cooling requirements for various components. Additionally, it was found that certain parts used in the development of MRI technology are often not recycled, yet there are some measures taken against the recycling of batteries and electronic components. However, medical wastes such as gowns, earpieces are immediately discarded, and are not recycled. General RRI involved in MRI technologies are hence regarding keeping the system efficient and user friendly while making room for new technologies, and some values must be considered for the usage and disposal of MRI components and related items. If recyclable materials were used, or more efficient systems were established as a result of reflexivity in the dimension of RRI, this technology could establish and improve upon sustainability.

From our findings, we have seen that the current research about MRI also focuses on the size of the machine to make it more mobile and expand the application platform [PhD. Student]. Consequently, it is expected that smaller and less energy consuming MRIs are on their way, which might be an opportunity to implement sustainability while the technical aim is at the mobility of the machines. In order to achieve sustainability oriented innovation in the field of MRI machines, the proposed solution is to support the improvement towards smaller MRIs and to instill some stakeholder views into the development stages, through anticipation, reflexivity, inclusion and responsiveness that will make the machines less energy consuming, while still working in the same way with the same or improved life-cycle. The technology being developed has the intention of making small MRIs work at least in the same manner in a technical perspective: meaning that the imaging quality and the service it provides to the user and patient will be at least the same. And, inevitably with the decreased size, a less power consuming product will occur. Therefore, the focused point in terms of sustainability should be supporting the new technology and emphasizing its importance so that the new machines' life cycle is as good as the previous one. Moreover, a general step to sustainability can be to support refurbishing and recycling electronics. Research in the field of technology requires numerous times of trial and errors to have a successful product at the end. As a result, a lot of electronic waste occurs and most of the time these wastes are not recycled, they just go to trash, as our findings state [Ph.D Student]. Though UMRAM has a warehouse for storing old electronics that might be used again, most of the products there become forgotten and turn into waste. An immediate action towards solving this may be to encourage the researchers to revisit the warehouse to find some electronics that may be used, instead of immediately supplying a new product for the cause. Moreover, a long action plan about this problem might be to take a step towards collaborating with a company that recycles electronics. Through this, a positive impact can be created on the economy, environment and society in terms of sustainability oriented innovation.

In conclusion, RRI developments are already underway in MRI technologies, however values must be broadened and environmental concerns should be evaluated and possible solutions should be implemented more in-depth and actively then it is currently.

UMRAM's developments in MRI are promising, however it is essential to integrate social and democratic values to the technology. MRI is already a technology that is being developed for the benefit of mankind but some phases in development are lacking in terms of responsible innovation. By addressing the dimensions of RRI, which are reflexivity, inclusion, anticipation and responsiveness, the technology developed in UMRAM can be further bolstered by values. Achieving the solutions proposed in this research and searching for other possible instances where MRI might have risks or might present issues in the technical, social or cultural context may allow this technology to develop in a responsible way, hence becoming the Responsible MRI: RMRI technology envisioned.

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8. Appendix A - Interviews

A-1 Engineer

Q: Can you tell us a little about your research for the MR technology you are currently producing?

Engineer: There are 3 MRIs below that we are currently using here. One of them is the first national MRI prototype which is 1.5 Tesla, developed as a joint project with ASELSAN. The other one is also a 1.5 Tesla MRI used for testing and research. The other one is 3 Tesla. The 3 Tesla MRI is mostly used for human MRI imaging shots done on patients. “Tesla” is a measurement of the magnitude of the magnetic field of the MRI. A much better image is obtained in 3 Tesla MRIs, but in the domestic MRI project, a study is being carried out in order to shoot faster with the shooting frequencies used in the 1.5 Tesla and MR. But apart from that, there is research about the "imaging point", coils, gradient coils and receiver coils. Also, the neuroscience groups research the functioning parts of the brain according to some prepared tasks, then analyze it accordingly and reconstruct it as an image. They also utilize functional MRI. This is the sort of thing that is done here.

Q: Are there any privacy issues regarding MRI?

Engineer: So, we ask all patients to fill in a participant form. We take information, such as TR ID number, name, surname, date of birth. So, only personal information is requested. In works conducted for such outsourced research, it is everyone's responsibility within the scope of their own project to keep what we call patient confidentiality, within the scope of their own project.

Q: Is the energy consumed by MR efficient? Is something being done for this? Do you know anything regarding this issue?

Engineer: Well, when the MR is first installed, it already runs and continues to work all the time. Some components, for example, contain helium at 0 Kelvin, and it needs to have constant power for it to be constantly cold. In other words, there is no such thing as turning off the MRI. There is even an UPS protocol when the electricity goes out. Even then, there are parts that are constantly in working. So of course it consumes a lot of power. So there's a megawatt-level power dissipation going on because it's always been working.

Q: Are the user, patient or doctors' experiences being considered during the development of the MRI machine? How will they be used?

Engineer: In other words, if they want to image people, they need to get approval from the Ethics Committee. Whoever does it, even if it is a doctor, they need to get the approval of the Ethics Committee and to do human imaging. You know, they can't image people unless it's already approved. Other than that, there is another thing; if something is going to be imaged, other than humans, such as a Phantom or any such inanimate thing, there is no necessity for permission. Again, approval is required for animal imaging, but if something inanimate is to be shot, only the use of MR is permitted, for example, with the use of technicians. It's like a security procedure because they don't know how to use it. We are the technicians here, the researchers, they are using it. Other than that there is nothing much sought after.

Q: Do you ever do anything related to recycling in this production process? For example, do you throw the things you use away after you finish using them? What kind of things are you doing to alleviate this issue?

Q: There are also many tests on many PCBs and components. Are they discarded after they are tested if it is decided that a different one will be used? Are there any recycling processes related to these? Or is everything that is decided not to be used directly thrown away?

Engineer: So things like batteries, capacitors are collected. Batteries and similar stuff go for recycling, but most of the electronic components can be used over and over again if there is no problem. But if something is burned in the MRI, it is thrown out. Apart from that, there are gowns for patients. There are these noise canceling headphones and gadgets that you can put in your ear during tests. They are disposed of as medical garbage. They also get a team that picks up medical trash. We collect them in one place, and the team takes them away. So, it is not normally thrown away, except in such a situation.

Q: Since MR is always running, there is a lot of energy use. Are there any studies to optimize this energy use?

Engineer: Magnets consume a separate amount of power, for example, the magnet inside the MR and the different components required for its operation also consume separate power. There are also separate studies for RF. There is definitely a separate but special work for the magnet, specifically for the power, but right now there is no such thing in UMRAM. But there is definitely literature, so I don't know.

Q: There are safety procedures in MR, let's talk about it if you want.

Engineer: Basically, there are 2 safety precautions in MR, the PNS measurements, Peripheral Nerve Simulation and SNR Measurements which is basically the signal to noise ratio work as safety. Here at work, we make measurements according to the weight and height of the patient who comes in, and there is a warming up there, for example, if the patient stays for too long, it can become very overwhelming. There is work being done in that regard, hence keeping the imaging time short is also important due to this reason. Also, you should never go inside with anything metal to MRI machines because magnets attract, and even if they don't, ferromagnetic materials can heat up. If there is something on the patient's body at that job, you may not feel that you are undergoing an MRI when you enter, but it can warm up and irritate that area as well. There are procedures for it. You know, you're constantly being asked, like; don't leave anything metal on you. We have such a situation as . Is there anything else you can think of?

Q: It may be somewhat specific, but the specific absorption rate is also checked as a safety procedure in MR. The model used in these calculations is actually a universal model and is scaled only according to the size of the person entering the scan. Other than that, the tissue specification is the same as that of the model. In the cases where the tissues or the body parts of patients differ from that of the model, do the approximations made in this cause any damage?

Engineer: So it hasn't been that much until now, but for very overweight people, for example, this specific absorption rate shows the person's status as a percentage on the device. For example, when it is very high, as I said, it can rise very quickly at 120 or more kilos, but the device gives a warning at a certain point, but not too much. If I remember correctly, the maximum weight that can be taken inside is around 140. It's not taken over.

A-2 Ph.D Student

Ph.D Student: Here, we are working on MRI machines, which are useful for physiological imaging. For example, head imaging, abdominal imaging. This technology is useful for the medical industry and doctors. The images we get from MRI are useful for diagnosis and doctors may use these results for finding the problems with the patients.

Q: Are there any health risks of MRI? If so, can you talk about them briefly?

Ph.D Student: Let’s talk about drawbacks of the MRI. MRI machines have some risks but actually the risk of MRI is less than other imaging methods like CT (computed tomography) or XRAY because the patient is not exposed to radiation. So, this is somehow invasive(?) imaging technology but there are some side effects maybe. For example, patients normally say after the MRI imaging, they feel dizzy and feel a sense of falling. Because MRI mostly affects the under-skin fluids of the body. It may have some effect on the fluid circulating inside the inner ear, which is related to the balance of the person. Another issue is the heat accumulation at some parts of the body because of the radiofrequency waveforms. There are some limits provided by the FDA.

If those limits exceed, it may hurt patients and burn tissues. Another side effect is related to the gradient coils: the noise of switching gradient coils may give discomfort to the patient and if an ear protection is not used, patients' ears may be hurt. MRI may also cause peripheral nervous system and motor nervous system stimulation, but these are limited according to the reports.

Q: Are there any privacy issues involved with this technology?

Ph.D Student: Actually, we are taking images of the brain and other parts of the body and there is a privacy issue. Patients might not want to share these images with others though doctors might see. There are some protocols for safety, but I do not know them in detail.

Q: How much energy does MRI machines use?

Ph.D Student: MRI machines consume a lot of power. There is a main magnet in MRI, which consumes a lot of power; however, since it operates around 0 Kelvin, the consumed power is less than expected. Gradient coils also consume lots of power, I can give some numbers: 2000 Volt and 600 Amperes.

Q: Do you consider user, patient, doctor experience during development?

Ph.D Student: Not actually. Here, we are developing coils, but we do not have interaction with doctors and patients. But there are some students here who have interaction with patients for head imaging and FMRI studies. But, since we mostly work on hardware, we do not have that much of a connection with doctors or patients.

Q: Do you try to minimize energy usage?

Ph.D Student: Here, we do not work on optimization of the energy. The most important thing about the MRI is the cost. It is a very expensive machine, so we try to optimize the cost. For example, I work on gradient coils. The normal gradient coils and also the power amplifier used to drive the coils are very expensive and we are trying to decrease the cost by using low-cost, homemade amplifiers and also, we are using some methods to decrease the cost of the system for example normally MRI uses expensive sensors, we are developing some methods to get rid of the sensors so the cost would decrease.

Q: Do you work on projects aiming to improve sustainability? Do you recycle?

Ph.D Student: Actually, we do not recycle but we have some depos, we put our manufactured products there and maybe after some time, if it is not used, we will then throw them away. We are not recycling the things we have built again. For example, we are using the coil we have built once and after that most probably nobody will use it again.

Q: Who are the stakeholders?

Ph.D Student: As I said because we are working on the hardware, I don't have much to say about that but we have some medical specialists and doctors here, some radiologists, they usually make comments about their experience but I don't have extended knowledge.

Q: What is the future of MRI?

Ph.D Student: Recent study in this area focuses on the fact that MRI machines are big machines and cannot be used in ambulances or bedside applications. So that research and recent studies focus on making the MRI machine smaller, so that it can be installed in the ambulances. Power and energy usage of the machine in that case will be less. This is called ultra-low field MRI.

A-3 Professor

Q: First of all, can you tell us about the technology you have developed?

Professor: So, are you asking me as UMRAM, or personally?

Q: You can talk about both.

Professor: UMRAM is a center that hosts many projects. There may be great things going on here without my knowledge. The center here is a place that brings together those working on MR and creates an infrastructure for them. The main thing it connects to is that the MR machines are here. We have 3 MR machines serving the users. My research group is concerned with the hardware of the MR machine. Hardware has been trying to improve for years, but it's still possible to further improve it because the physics of fMR are awesome, and it's very difficult to build devices close to their physical limits to make the most of them. Existing technologies don't make full use of it; it's very difficult, and not even close. We are also trying to make important developments. Briefly, in MR, hydrogen atoms in a material are excited under a magnetic field and they enter into a resonance, we call this magnetic resonance. An echo signal comes out when an RF is applied. The design of this transmitter and receiver also depends on what resonance frequency it works at and the applied magnetic strength; by modulating the magnetic field, we change that resonance frequency over time. This is called a gradient magnetic field. Our main goal is to make them as an array, not as a transmitter and receiver that combines them.

Q: Well, now you've talked to us about MRI machines, which is the general focus of our project. What are the general applications of MRI, and who generally uses this technology? For example; doctors, patients...?

Professor: Its more general name is NMR, nuclear magnetic resonance. Its first use is as a technology developed by chemical engineers to understand the structure of the substances they study, and MR performs this function very well. Generally, only one substance is used for imaging, Hydrogen. The feature of hydrogen is that it is abundant in the human body and the signal is very high. Thus, it is possible to create good quality images. This technology is widely used in radiology in the Turkish community, because it is very useful in the diagnosis of many diseases. But it's also a good tool for people who want to understand the human body, especially how the brain works. For example, neuroscientists use a lot to see how the brain works, because the images obtained contain information about how the brain works, and even the most important tool in the world to understand how the brain works right now is MR. Apart from that, there are too many applications to count. For example, the veterinary faculty is used. This might be considered animal health, but it is also used to understand the anatomy of animals. In addition, images of foods can be extracted, images of plants can be extracted, images of fruits and vegetables can be extracted, and this has interesting applications. One thing that interests me is that nMR is used to distinguish how much oil is in sunflower seeds and how much water is in them, because it is possible to understand what percentage of sunflower oil is, without removing the oil, by putting the oil, which is the main money-making part, and the nMR device at the time of purchase can be purchased. Although it has interesting applications, its most common application is still in radiology.

Q: We would like to ask some questions about the possible risks of MRI. One of them is about patient privacy. As far as we know, patients come to you for experimentation, is there any method followed to protect their privacy after patients have experimented? Are there potential risks despite these methods being followed?

Professor: Of course, this is an important issue. For example, let's say someone has a tumor in their brain. We viewed it, but the person may want to hide it from others for certain reasons. It's something that happens a lot in medical school when it's used radiologically for this. The patient may not only be related to the MRI, for example, he learned that he had a blood test and has diabetes, but he does not want it to be announced, etc. Situations such as the patient and the doctor should remain. To protect it, the doctor and the hospital are responsible for it. There is a similar practice in research centers. When a patient or a subject comes, we get information about them. It is our responsibility to protect this information; it is the responsibility of the instructor who runs the project. Typically, what is done is not to mention the patient's name in any study, remove it from the database immediately, and use it there if a special code is needed. This is how it is applied even if it is a healthy individual. Normally, we ask the patient's name, surname, age, and weight while taking the image, but only the necessary parts are taken from the recorded file, and the patient's name is destroyed and put in front of other people, in front of the people who use the data.

Q: I have one more question about risks. You told us about nuclear MRI, it is generally used for health, but can this nuclear application harm human health?

Professor: The nuclear in your name now means “belonging to the nucleus”. Nuclear magnetic resonance means that the nucleus resonates, so this has nothing to do with nuclear energy or radiation. In order not to be misunderstood, we do not say "Nuclear Resonance Imaging" when imaging, we say "Magnetic Resonance Imaging". Thus, we eliminate the word "nuclear", otherwise there is no technology that really includes nuclear reactors or radiation. There are three types of magnetic fields used in magnetic resonance imaging. One is a linear magnetic field, it's very strong, the other is a fluctuating but slowly varying field but still strong. The other is the field at the radio frequency, the resonant frequency. They have different types of effects. These are not things that have lasting effects like X-Ray, and they just happen at that moment and never happen again. Therefore, subjects can repeatedly enter the device and stand still for hours. If we list the things that can happen, the first of the magnetic fields, the constant magnetic field, 1.5 Tesla also works, there is no problem at all. Only, something can happen, which is the biggest risk. If someone enters with a pair of scissors, and the scissors are something ferromagnetic, they can fly off and stab someone. There is a very strong attraction in the MR machine; it can also be called the missile effect. Not in Turkey but in a hospital, someone needed to use an oxygen tube in the MRI. In this case, the oxygen tube got attracted by the machine's magnetic field and killed the patient. Of course, precautions are being taken for this, but since the magnetic field is not a visible thing, it is difficult for people who do not work with it or who are not there all the time to understand. That's why it's the biggest risk for people who don't know how to hang around, and that's why these machines are always locked behind closed doors. This is the most important problem. In a very high magnetic field, say 7 Tesla, if he moves his head a little bit inside the magnet, he might feel something, but it's okay, it still has a physical effect. There may be things like dizziness, a metal taste in the mouth. In this type of thing, there is no one who has entered the higher magnetic field and suffered significant damage. The second magnetic field, called a gradient, can stimulate or excite the nerves. The changing magnetic field can create a current in the nerves in the human body. Since the nervous system works with an electric current, if the magnetic field is strong enough, the nervous system is stimulated, but these are very small feelings. Does it stop the heart that everyone is afraid of, but calculations show that we are far from this limit, so if the magnetic field is increased drastically, which we are not at that level, it will cause pain. If it is increased even more, there may be some unwanted things, but none of the devices are capable of doing this. The third issue is heating. The radio frequency signal causes radio frequency currents in the body, which leads to heating. This is the same with cell phones, so is MR. Overheating is undesirable, of course, but we do calculations to reduce the warming. There are calculations and safety factors to calculate the intensity of the magnetic field we give and not to give it more than that. We also set criteria such as not heating the body above 1 degree Celsius, which is the amount of warming that normal people can handle, which is confirmed by experiments in daily life. Also, there are threefold security measures inside the devices, and the programs do these calculations, and there is another program that checks the calculations of this program. If there is something overlooked here, the hardware also provides security. Thanks to these measures, the number of accidents in imaging management is very low.

Q: How much energy do MR devices use during your research and are there any work done to minimize this energy?

Professor: Yes, this is a subject that I focus on a lot, and it is very important in the world right now. It uses a lot of energy, and it consumes more energy than other imaging systems. The amount of currents or power supplied to create the magnetic field is in the order of kilowatts. There is inefficiency at every stage to gain power. It takes 10 units of energy to get one unit of something, and one of our research topics is to increase its efficiency, and many places in the world are working on it. It is a challenge to reduce the energy level spent and keep the quality of the image high.

Q: Finally, can you tell us about the future of MR technology?

Professor: Everyone has another future in mind, and they are working on that in order to be at the beginning of that future. For me, of course, I think that the future is about the very efficient use of the MR devices that we talked about, transceivers and gradients in the form of a series. After that, according to the subject, topics such as neural networks and artificial intelligence have entered into MR. The performance of the device is increasing day by day and the price is decreasing, but doctors and users want more functions. The device is coming back by increasing its price again, so I expect its functions to increase even if the price does not decrease in a short time.

9. Credits

İremsu Taşkın: İremsu did two interviews, one with the engineer along with İdil and the other with the professor along with Dora. She coded all three of the interview transcripts on QDAMiner. She conducted the research concerning heating of the body stated in the Health & Safety Concerns. She wrote the Technical Information section in the Findings and revised the Sustainability section as well. She contributed to the Health & Safety Concerns section in the Background Research part and wrote the Method section. She conducted a literature scan on the health risks of MRIs and the implementation of Responsible Innovation in research concerning the brain, specifically focusing on neurotechnology and the implementation of RRIs in the development of these technologies.

Ezgi Saç: For the report, Ezgi has written the first draft of theory, has written the background research of General Information about MRI, half of the Privacy Issues Regarding MRI, User Experience and introduction paragraph of Sustainability. She has also written solutions for User Experience and Sustainability in the Conclusion and Analysis part. Also in terms of interviews, Ezgi and Önder have done the interview with a PhD student and written its transcript.

Ayçe İdil Aytekin: Idil wrote the Healthy & Safety Concerns, User Experience and Sustainability parts of the Findings. She further contributed to and revised the overall Findings and the Background Research for UMRAM. She and Iremsu made an interview with an engineer working at UMRAM. She also made some contributions to literature scans related to privacy, health issues and Responsible Innovation regarding MRI.

Önder Soydal: Önder has conducted research on safety problems on health issues regarding gadolinium accumulation and wrote the corresponding part. He also studied e-waste and energy problems under sustainability risks of MRI search and contributed to corresponding writing. In terms of interviews, he and Ezgi made an interview with a PhD Student and he transcribed most of it. Önder further participated in quotation editing including paraphrasing and formatting at the research section. He also contributed to the theory section.

Dora Tütüncü: Dora has written the conclusion and analysis part, and elaborated on the findings holistically. He evaluated the findings within the four dimensions of RRI, and proposed solutions to the concerns regarding MRI technology in UMRAM. He has also conducted interviews with the Professor along with Iremsu. Additionally, he transcribed and translated two of the interviews. He has made some contributions to the environmental and risk literature scan, and provided some support to the findings & theory. He also did the background search and wrote the part related to the research conducted in UMRAM.