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# ASSESSMENT OF INNOVATIVE TECHNOLOGIES APPLICATION IN MEDICAL IMAGING IN PORTUGAL

Joana Filipa Soares da Silva

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NOVA Information Management School
Instituto Superior de Estatística e Gestão de Informação
Universidade Nova de Lisboa

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# ASSESSMENT OF INNOVATIVE TECHNOLOGIES APPLICATION IN MEDICAL IMAGING IN PORTUGAL

by

Joana Filipa Soares da Silva

**Advisor:** Vitor Santos

**Advisor:** Carolina Santos

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“Quero ignorado, e calmo
Por ignorado, e próprio
Por calmo, encher meus dias
De não querer mais deles.

Aos que a riqueza toca
O ouro irrita a pele.
Aos que a fama bafeja
Embacia-se a vida.

Aos que a felicidade
É o sol, virá a noite.
Mas ao que nada espera
Tudo que vem é grato.”

*Fernando Pessoa*

## ABSTRACT

For the past few years, despite the Portuguese government announcing the upgrade of the Portuguese healthcare system, it is possible to verify the missing investment in that infrastructure, equipment and services. The lack of quality and the unavailability of modern equipments and infrastructures are some of the usual complaints of the healthcare providers and patients.

This study aims to analyze and explain, the gaps between innovative technologies available in the market and the present implemented technologies in the Medical Imaging area in Portugal and, with the collected data, build an explanatory model of the motivations for the lack of investment.

For the collection data purposes, 102 subjects were inquired, from multiple Portuguese hospitals and healthcare clinics related to medical imaging, with physicians, suppliers, service providers, and Senior Diagnostic and Therapeutic Technicians roles. After analyzing the data, it is possible to conclude that Portuguese medical imaging services need updated equipment and improved technology, more human resources, and training. Managers of healthcare organizations, mainly from the public sector, are motivated primarily to save costs due to the increasing healthcare organizations' expenditures. These facts are incurring in wrong diagnoses, patient dissatisfaction, and lack of confidence in Portuguese healthcare providers.

## KEYWORDS

Technologies; Computational; Medical Imaging; Innovation; Healthcare; Portugal; Services

# CONTENTS

## LIST OF TABLES



## LIST OF FIGURES



## LIST OF CHARTS

# LIST OF ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| **AI** | Artificial Inteligence |
| **CADe** | Computer-aided detection |
| **CADx** | Computer-aided diagnosis |
| **CAT** | Computed axial tomography |
| **CNN** | Convolutional neural network |
| **CT** | Computed Tomography |
| **DL** | Deep Learning |
| **EDPSO** | Enhanced Darwinian Particle Swarm Optimization |
| **fMRI** | Functional magnetic resonance imaging |
| **GDP** | Gross Domestic Product |
| **IP** | Image plate |
| **MI** | Medical imaging |
| **ML** | Machine Learning |
| **MRI** | Magnetic resonance imaging |
| **PACS** | Picture archive and communications systems |
| **PET** | Positron Emission Tomography |
| **PRISMA** | Preferred Reporting Items for Systematic Reviews and Meta-Analyses |
| **PSO** | Particle Swarm Optimization |
| **SPECT** | Single Photon Emission Computed Tomography |
| **US** | Ultrassonography |

# 1. Introduction

## 1.1. Background

Healthcare and technology, as we know it today, have been working together for many decades. At this moment, the technological evolution in healthcare has a direct impact on healthcare institutions. In such a way, that is possible to comprehend the processes' integration, the security improvement, the data treatment and the medical practices in hospitals and clinics, and the usage of equipment and services to diagnosis and care (Coccia, 2020).

In the last 40 years, it is possible to verify that Portugal made signs of progress in healthcare treatments and resources, such as technologies applied to health. In this period, Portugal reached a higher level in its health system, presenting a decrease of 94% of the Gross Mortality Rate, comparable with the main international partners (time window from 1970 until 2008) (Eira, 2010).

In such a way that, in *Programa XXI* from *Governo Constitucional 2015-2019*, the Portuguese government made the commitment to "*Modernize and integrate information technologies and the existing network to keep the old and sick people most of the time in a familiar environment, developing telemonitoring and telemedicine*" (Governo de Portugal, 2014).

Despite the evolution and development in health technology, the time between the technology being delivered to the market and the introduction of the Portuguese National Healthcare System of Portugal (SNS) have a significant discrepancy.

Has Cabral mentioned in 2002, the patients are unsatisfied with the services provided by public healthcare institutions despite the increase in health costs above inflation. He was able to verify that only 50,3% of the patients were satisfied with the healthcare services provided in an emergency service (Cabral, 2002). The drives for the dissatisfactions were the inadequate service, the outdated hospital infrastructures, the lack of means of diagnosis, the incapacity of communication presented by the service provider with the patient, or the lack of adequate information (Figueiredo, 2008).

As denounced to journal *Diário de Notícias* by Alexandre Lourenço, president of Portugal Association of Hospital Administrator’s, alleges that the lack of technology investment since 2009 resulted in a risk of healthcare technology obsolescence (Nunes, 2019).

Also, a study carried out by Deloitte in 2011 reveals that the financial unsustainability of the healthcare system in Portugal is one of the main problems mentioned by healthcare stakeholders (Deloitte, 2011). Over the last few years, it is possible to observe the increase of the private and public general expenditure in healthcare, having the growth of public expenditure exceeded the growth rate of GDP (Gross Domestic Product).

In comparison with other European countries, it is possible to verify that public expenditure in a total of healthcare expenses in Portugal is low, which reveal that have an additional expenditure in healthcare supported by the Portuguese population, not reflected in taxes (Deloitte, 2011), increasing the search for private healthcare services.

It was observed by Figueiredo in 2008 that hospitals need to create better processes to manage their services, improving their MI services with innovative technologies. Without investment in improving their infrastructure, they will have to lead with the high costs for the different support services and for the weak potential performance of the technology. He suggested, as well, the acquisition of new medical equipment with radical innovation characteristics, with a focus on rare diseases (Figueiredo, 2008).

As defended by Mamyrbekova, innovative technologies and their development bring new opportunities to primary healthcare to renovate their practices and ways to guarantee the efficiency of the healthcare services. The changes in education, politics, and practices, as new communication models, improve the efficiency of patient care (Mamyrbekova, 2020).

## 1.2. Motivation/Justification

Daily, innovative technologies are coming up to the market in many healthcare areas. Portugal is a country with a high concentration of old population in locations far away from the principal's cities, with low access to healthcare technicians, remote medical diagnosis, and care. With investment in healthcare technology is possible to beat the lack of healthcare services in remote locations and increase patient healthcare services satisfaction.

Miguel Guimarães, from *Ordem dos Médicos*, mentioned in 2019 that medical equipment usually has a 10 years amortization, but its usage goes beyond that period, being a visible problem in multiple departments and hospitals. However, it's more severe in medical imaging, gastroenterology, and emergency services. Since the lack of light in the surgery block, the missing update of the vital signs monitors in patients' rooms and damaged CT equipment's (Nunes, 2019). In the same report, it is referred that doctors rent medical equipment from the private sector to execute their work since the equipment of National Healthcare Services is damaged.

However, it is possible to verify in the declarations by healthcare organs mentioned above, despite the proposal in 2015 of Programa XXI from Governo Constitucional 2015-2019, the improvements predicted for the National Healthcare Service in Portugal are not being accomplished.

In the most popularized cities in Portugal, it is possible to find hospitals and clinics with outdated medical equipment for diagnosis and treatment, and, in consequence, they face a delay in diagnosis and wrong diagnosis of pathologies, as well as medical demoralization.

On the other hand, European Fund for Confinement Projects, as example the European Fund for Regional Development, can support healthcare institutions with the costs for implementing innovative technologies in the Medical Imaging area (Instituto de Informática, 2021). The hospital of *Garcia de Orta* is one example of this program application in the Lisbon metropolitan area. From January 2019 until November 2020, the hospital of *Garcia de Orta* it compromised to invest in equipment with innovative technology for Magnetic Resonance Imaging, aiming to "improve the levels of efficacy, efficiency and the quality of the healthcare service provided" (SPMS, 2021). The program gave the hospital the possibility to retrieve half of the initial proposed costs.

There are not enough studies in the literature with the goal of understanding the reasons for the investment failure in healthcare technology in Portugal. For this reason, is relevant to the study of motivations for the gap between the innovative technologies in the market and the technology applied in Portugal Healthcare Services and the development of an explanatory model for that reason. Despite the problems being visible in all healthcare areas, they have more impact in some areas where IT is part of their nature. For that reason, in the present study, the focus area will be medical imaging, where computational technologies are an integral part of the technologies in evolve.

## 1.3. Objective

The present study aims to analyze and explain the gaps between innovative technologies available in the market and the implemented technologies in Medical Imaging areas. The following question was established as the center of the study:

*What is the gap between innovative healthcare technologies available in the market and the implemented technologies in Medical Imaging areas in Portugal?*

To achieve the purpose of this study are defined the next intermediary objectives:

- Literature review:
    - Definition of the main concepts, identification of the innovative technologies available in the study area, and the present technologies used in the healthcare institutions.
    - Systematic literature review about the healthcare technologies used in the last 5 years worldwide.
- Identify the technologies currently used in the study area in Portugal.
- Determine the intention of incorporating new innovative technologies in the near future in the Portuguese Healthcare System and understand the reasons for the lack of investment.
- Identify the usage gaps.
- Develop an interpretation model for the reasons why more innovative technologies are not applied to the Portuguese medical imaging services.

## 1.4. Study relevance and importance

The non-updated healthcare technology has a huge impact on care, diagnosis, and treatments provided in healthcare systems. Technologies such as nanotechnology (Gardner, 2015), medical robotics, big data (Latif, 2017), telemonitoring and telemedicine, artificial intelligence, and the Internet of Things (IoT) (Mamyrbekova, 2020) allow healthcare technicians to monitor and provide healthcare services to the patients locally or at long distance, with precision, and supporting technicians' decision making, based on the data collected over the years of healthcare practices.

Despite the compromise of the Portuguese government in 2015, as referred to in chapter 1.2., Portugal has medical equipment's in end-of-live to provide healthcare service to the Portuguese population. At the initial literature review for the present study, it was possible to verify the miss of implementation of the innovative technologies available in the market (Figueiredo, 2008; Nunes, 2019).

With the present study, we expect to provide to the Portuguese society, government, and healthcare institutions the current status of Portuguese healthcare services in Medical Imaging and provide the reasons why Portuguese healthcare face difficulties in implementing new practices and technologies to provide treatments to the patients.

## 2. Methodology

The methodology applied for this study is composed of three different phases: exploration, analysis, and conclusion, as shown in table 1.
The first phase, the exploration phase, has the goal of defining the background and the motivation for this study, developing the methodology applied for this research, and performing a preliminary literature review.
The second phase intends to understand the medical imaging techniques and the computational technologies applied and in research for this medical area, with the intention to develop and perform the data collection to answer the central question of this study.
The third phase, the conclusion phase, is expected the data analysis obtained from the analysis phase and describe the main conclusion by an interpretation model.

Table 1 - Methodology.

| **Exploration Phase** | **Analysis Phase** | **Conclusion Phase** |
|---|---|---|
| **Step 1** – Research and methodology definition<br>**Step 2** – Preliminary literature review | **Step 3** – Literature review<br>**Step 4** – Current technology and Innovative technology survey<br>**Step 5** – Gaps identification and analysis | **Step 6** – Results presentation and discussion<br>**Step 7** – An interpretation model construction<br>**Step 8** – Conclusions |

These three phases evolve into 8 steps:

- In the **first step**, it will be performed research to understand and define the background, to justify the motivation to develop the present study and determine the methodology to be accomplished to understand the gap between the innovative technologies available in the market and the implemented technologies in medical imaging services in Portugal.

- The **second step** incorporates a preliminary literature review with the intention to understand the current situation in the medical imaging services in Portugal and the innovative technologies most studied to integrate medical imaging equipment and software in the near future.

- The **third step** will be to realize a literature review divided into two substeps; the first substep will define the concepts for this study, describing the medical imaging techniques, how the images are collected, along with the identification and description of the innovative computational technologies applied to medical imaging; the second substep will be to performe a systematic literature review with the PRISMA methodology with the goal to identify the innovative technologies most studied in the last 5 years.

- The **fourth step** intends to develop a quantitative survey at Google Forms divided into three sections and delivered to senior diagnosis and therapeutical technicians, physicians, MI suppliers, and MI services providers in Portugal.

    - The <u>first section</u> of the survey plans to characterize the inquired subject, understand the MI techniques that are familiar to him and the knowledge of the computational technologies are used on a daily basis;
    - The <u>second section</u> plans to understand the improvement necessities detected at the equipment and the MI service by the inquired group;
    - The <u>third section</u> aims to recognize the main barriers to the improvement of MI services and to assess the knowledge of innovative technologies in study and used in medical imaging. The survey was developed based on the information collected during the three initial steps.

- The **fifth step** will be performed by analyzing the collected data. This step aims to assess the knowledge of the the enquired group of computational technologies used in medical imaging and their application in Portuguese MI services. Charts and tables will be used to support gaps identification in the equipment and technology and then it will be performed an analysis of the needs in Portuguese MI services based on the questioned group.

- The **sixth step** will carry on the structured presentation of the results and the detailed analyzes of the gotten answers, comparing the expected results with the obtained at the survey, based on the background/motivation for the study and the literature review. This step intends to understand the causes for the previously mentioned dissatisfaction of the patients, the non-investment in the MI sector in Portugal by clinics and hospitals despite the government intention, and the main goals of the healthcare institutions administration by the inquired group.

- The **seventh step** aims to develop an interpretation model with the causes and the effects based on the interpretation of the survey results and the outcomes of the literature review.

- The **eighth step**, the conclusion step, is intended to highlight the main aspects of the present study. The main pronounced problems by the Portuguese healthcare organisms, the motivations to the non-investments, the main issues detected at the medical imaging services at the private and public sector, as well to answer the central question of this study, "*What is the gap between innovative healthcare technologies available in the market and the implemented technologies in Medical Imaging areas in Portugal?".*

## 2.1. Systematic literature review methodology

With the objective to realize the systematic literature review, the imposed question was "which are the innovative computational technologies available in the market applied to medical imaging?".

To answer the proposed question was selected three databases, Scopus, Science Direct, and Web of Science (Table 3) and a query string (Table 2). The selection process of the databases and the keywords in this study was based on several attempts with different query strings related to the study subject and in multiple databases to obtain the maximum number of studies. The most relevant string to access the pretended studies was the follows:

*("computational") AND ("technologies") AND ("medical imaging")*

Table 2 - Keywords.

| Keywords |
|---|
| Computational |
| Technologies |
| Medical Imaging |

The process to obtain relevant studies was centered on digital search, selecting only three databases as mentioned in table 3.

The fact focusing only on three databases may exclude relevant articles. Perhaps I believe these three information sources have the most relevant documents. These information sources let access to a huge database of academic literature, articles, thesis, books, abstracts, among other document types, where it is possible to filter multiple scientific subjects.

Table 3 - Information sources.

| Information sources | Weblink |
|---|---|
| Science Direct | https://www.sciencedirect.com/ |
| Scopus | https://www.scopus.com/ |
| Web of Science | https://apps.webofknowledge.com/ |

Figure 1 illustrates the followed process to realize the systematic literature review using PRISMA[1] methodology.

[1] PRISMA means Preferred Reporting Items for Systematic Reviews and Meta-Analyses (retrieved from http://www.prisma-statement.org/)

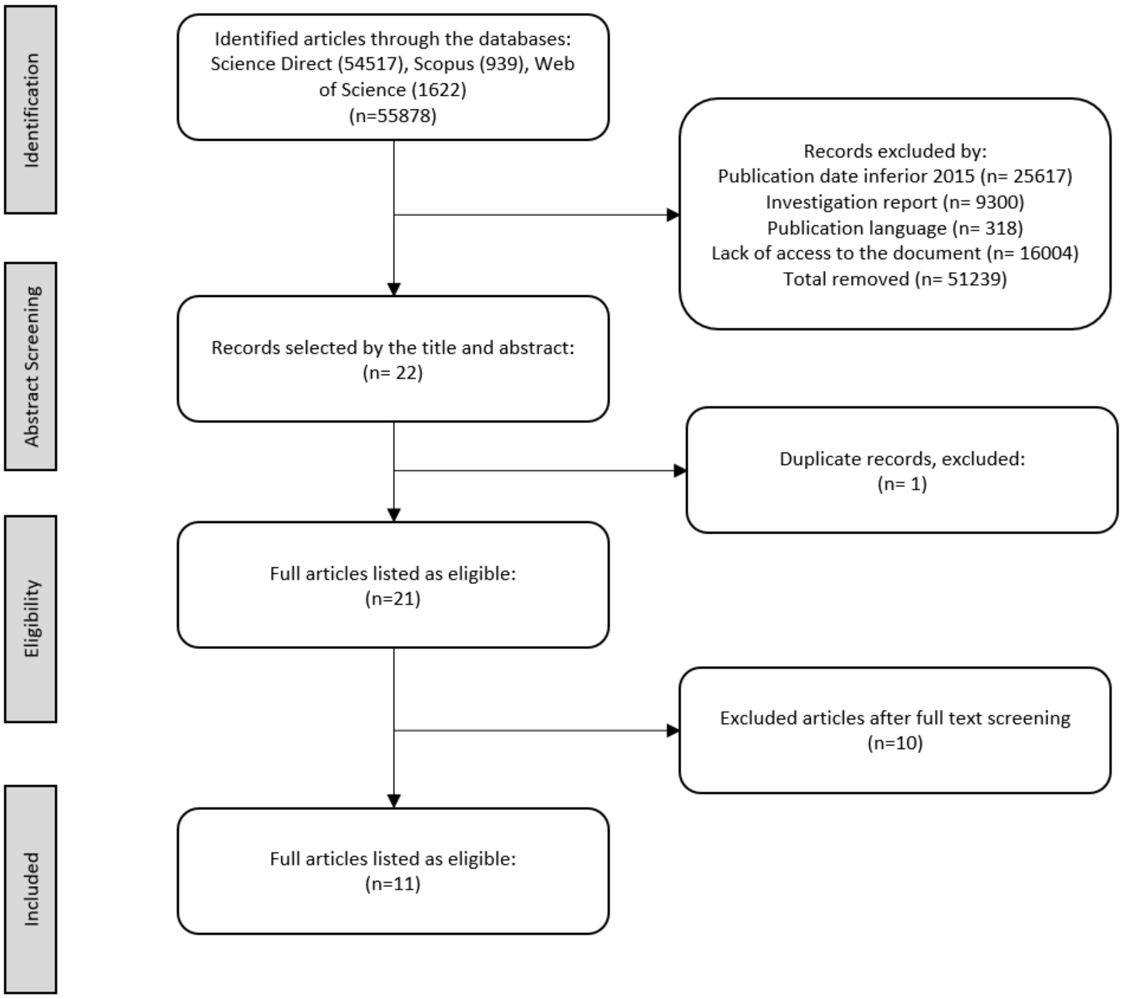


Figure 1 - Prisma flow diagram.

# 3. Literature Review

The influence of medical imaging in healthcare is increasing. With medical imaging, healthcare technicians can detect diseases earlier and treat patients with effectiveness. When their applicaton is focused on prevention and therapy, this can contribute to reducing healthcare costs on a global scale.

Medical Imaging consists of an important medical specialty that uses internal body image to realize diagnosis, that is, apply techniques and processes to create human body images to clinical diagnosis and treat diseases.

## 3.1. Medical Imaging techniques

Medical imaging uses four types of radiation to obtain medical images, X-rays, photons, radiofrequency, and ultrasound. Radiography and computed tomography use x-ray radiation, and nuclear medicine use photons, being both invasive techniques used to obtain body images. Ultrasonography and magnetic resonance imaging are non-invasive techniques applying ultrasound and radiofrequency, respectively, into the body to obtain the images. More details are specified below on how each technique works and delivers the medical images.

### 3.1.1. Radiography

The medical imaging technique of radiography, usually called X-ray, consists of an image diagnosis exam applying radiation X into the patient's body and obtaining a plane image. The image is produced by the radiation X that follows the relationship between the emitted rays and the received rays after passing to the body (Brant, 2019; Webb, 2003).

To obtain the image is used an X-ray beam, produced by a generator, will pass through the body section that is pretended to analyze. Part of the X-ray energy is absorbed by the body, depending on the density of the structure, and the remaining energy goes to the film or detector, producing the radiography (Brant, 2019; Webb, 2003).

The obtained image reproduces the difficulty of the X-ray passing through the body. The bone, which is the denser absorbs the radiation, is shown in the image in a clear tone. However, the structures with lower density are shown in a darker tone, for example, the air in the lungs (Brant, 2019; Webb, 2003).

Conventional radiography to obtain the X-ray images uses a film composed of silver crystals that are stimulated by radiation. In the process of revelation, it is required to use multiple chemical solutions that will provide different grey tones to the film. This process requires high time to obtain the final films, the usage of pollutant chemicals, and higher doses of radiation, being discontinued and replaced by digital radiography (Brant, 2019; Webb, 2003).

Nowadays, the usual procedure is digital radiography and direct digital radiography. In digital radiography, the image is obtained by a computer using a readable and reusable phosphor display that is stimulated by radiation and called an image plate (IP). Another procedure to obtain the image is using direct digital radiography, where the image is obtained directly in the computer. In this case, the IP is replaced by a detector directly connected to the computer that receives the data and processes them. These methodologies allow the post-processing of the images, being an added value to technicians and doctors. Digital radiography facilitates the sharing and archive of the exams, improving access to old images, comparing images, and access by internal or public networks (Brant, 2019; Webb, 2003).

### 3.1.2. Angiography

The Angiography technique delivers images that show the blood vessels selectively in the body. This type of imaging is used to examine diseases such as clotting of arteries and veins and irregularities in systemic and pulmonary blood flow. In X-ray angiography, an iodine-based contrast agent is injected into the bloodstream before imaging. The X-ray image shows increased attenuation from the blood vessels compared to the tissue surrounding them (Brant, 2019; Webb, 2003).

### 3.1.3. Computed tomography

Computed tomography is used to support physicians in diagnosing multiple diseases and assessing treatments. This method uses ionic radiation, similar to conventional radiography, with complex algorithms and is supported by computer systems to produce the images (Brant, 2019; Webb, 2003).

This technology, in the beginning, was denominated as computed axial tomography (CAT) because the technique was used to produce axial images, the gantry surrounded the body, producing one image per cycle. Between cycles, the bed with the patient moved millimeters or centimeters successively. Later, this technology evolved to helical, allowing the continuing bed movement and continuing gantry rotation, being called computed tomography (CT) (Brant, 2019; Webb, 2003).

The number of images or slices produced is proportional to the number of gantry detectors. Each slice matches a slice of the body in the study, and the thickness of slices is predefined by the technician (Brant, 2019; Webb, 2003).

Computed tomography enables the analysis of vascular system injecting contrast in the patient, complementing the study, usually called SPECT detailed in chapter 3.1.6. The contrast products are iodized, increasing the structures contrast with different blood flows, accentuating tumors or inflammations (Brant, 2019; Webb, 2003).

### 3.1.4. Ultrasonography

Ultrasonography (US) imaging is performed by a pulse-echo technique, where the transducer converts electrical energy to a brief pulse of high-frequency sound energy transmitting them into the body. The US transducer is as well the receiver, detecting the echoes of the sound energy reflected from tissues, assuming that the returning echoes as the source from along the line of the sight of the transmitted pulse. The depth of the echo is determined by measuring the round-trip time of the flight for the transmitted pulse and the returning echo, calculating the depth of the reflecting tissue interface, assuming an average speed of the sound in the tissue of 1,540 m/s. The image is obtained from multiple US pulses, and the shape and appearance of the resulting image depend on the design of the transducer used, sector, or linear array (Brant, 2019; Webb, 2003).

US examination is achieved by applying the US transducer onto the patient's skin using the water-soluble gel as a linking agent to ensure good contact and transmission of the US beam. The images are obtained in any anatomic plane by adjusting the orientation and angulation of the transducer and the patient position. The axial, sagittal, and coronal planes provide the easiest recognition of anatomy but may not be the best to demonstrate all anatomic structures, and the quality of the US depends heavily on the sonographer's skill and diligence. The best way to guarantee the diagnosis is by providing guidelines to the sonographer (Brant, 2019; Webb, 2003).

Doppler ultrasonography is an important system for real-time gray-scale anatomic imaging. The doppler effect consists of a change in the frequency of the returning echoes, compared with the transmitted pulse caused by the reflection of the sound wave from the moving object. In medical imaging, the moving objects of interest are the red blood cells in flowing blood. If the blood flow is away from the transducer, the echo frequency will be shifted lower. On the contrary case, it will be higher. The amount of the frequency shift is proportional to the comparative velocity of the moving red blood cells (Brant, 2019; Webb, 2003).

Duplex doppler combines real-time gray-scale imaging with doppler to determine the position of the sample volume in visualized blood vessels or specific areas in analyzes (Brant, 2019; Webb, 2003).

### 3.1.5. Magnetic Resonance Imaging

Magnetic resonance (MRI) is a non-invasive technique that uses magnetic fields and radio waves to produce detailed three-dimensional images. In comparison with CT, which analyzes only a single tissue parameter, as the x-ray attenuation, MR analyzes multiple tissue characteristics, including hydrogen (proton) density, the T1 and T2 relaxation times of tissue, and blood flow within the tissues (Brant, 2019; Webb, 2003).

The analyzes of the soft tissues are substantially better with MR than other imaging techniques, where the density difference of the protons available continue to the MR signal differentiate one tissue to another. The T1 measurement consists of the measure of the proton's ability to exchange energy with its surrounding chemical matrix. The T2 measurement is the of how to fast a given tissue loses its magnetization. Most of the tissues can be identified by the difference in their T1 and T2 relaxation times (Brant, 2019; Webb, 2003).

MR technique is based on the ability of a small number of photons within the body to absorb and emit radio wave energy when the body is placed within a strong magnetic field. The capacity to absorb and release radio waves is different at different, detectable, and characteristic rates to different tissues (Brant, 2019; Webb, 2003).

In the case of brain analysis, is usually used functional magnetic resonance imaging (fMRI) analyze the activity of brain areas after varied and different stimuli. This technique is used in localized injuries of the nervous system and epilepsy source location (Brant, 2019; Webb, 2003).

### 3.1.6. Nuclear medicine

Nuclear medicine is a medical imaging technique that uses radiopharmaceuticals (radioactive tracers) to diagnose by images and to apply molecular therapeutic. To track the path of the radioactive tracers is used computational tomography technology, which allows to scan more clearly tumor and monitor the growth, as an example (Brant, 2019; Webb, 2003).

Radioactive tracers are carrier molecules with a strong bond to a radioactive atom. The carrier molecules vary accordingly with the purpose of the scan. Some molecules interact with protein or sugar in the body, or they can attach radioactive atoms to blood cells to trace the path of the blood in cases of internal bleeding, using SPECT scan to collect the images (Brant, 2019; Webb, 2003).

Usually, the administration of the radioactive tracers can be done by intravenous injection. However, the radioactive tracers can also be administrated by inhalation, oral ingestion, or direct injection into an organ. It depends on the objective and the disease that is being studied (Brant, 2019; Webb, 2003).

The most common imaging modalities in nuclear medicine are SPECT (Single Photon Emission Computed Tomography) and PET (Positron Emission Tomography). The difference between these two modalities is the type of radiation used. While SPECT scans measure gamma rays, PET measures the energy delivered when the positron interacts with electrons in the body, annihilating each other and producing a small amount of energy in the form of two photons shoot off in opposite directions. The detectors in both techniques use the information of measurements to create images of internal organs. The SPECT scans are mostly used to diagnose and track heart diseases when PET scan is to detect cancer and monitor its progression, treatment development, and metastases detection (Brant, 2019; Webb, 2003).

### 3.1.7. Mammography

Mammography is a breast exam based on ionic radiation that allows the breast parenchyma analysis, detecting nodules, or clustering of microcalcifications. Digital mammography is a breast exam that allows simpler and faster image post-processing (Brant, 2019; Webb, 2003).

Usually, it is known as a women's exam but can be done in men. The quantity of radiation is low and is the only valid exam for screening for breast cancer in the general population (Brant, 2019; Webb, 2003).

## 3.2. Artificial Intelligence in Medical Imaging

Artificial intelligence has been the technology most studied and developed over the past few years to evolve and support medical imaging services (Ting, 2018). Nowadays is possible to observe the application of artificial intelligence by supporting the radiologist at their workload and improving the diagnosis, increasing medical images resolution, and supporting patient care.

Machine learning and deep learning, as subclasses of artificial intelligence, have been developed to support radiologists in decision-making, lesions detection, and performing radiologists' tasks without human intervention. These AI subclasses have a huge data need a barrier, along with patients and images data protection, making difficult this technologies development.

The next sub-chapters are described the main development in these technologies applied to medical imaging.

### 3.2.1. Artificial Intelligence

Artificial intelligence, as described by Oren and Pesapane, is a computer science that uses computational algorithms to dissect complicated data creating systems that perform tasks, that usually requires human intelligence, dividing in multiple techniques (Oren, 2020; Pesapane, 2018). In other words, it is a computer science that focuses on solving tasks that people can execute (Frockman, 2019).

The application of AI to medical imaging is one of the most promising areas in healthcare innovations, but its application goes beyond image processing and interpretation. From image acquisition and processing the report, follow-up planning, data storage, data mining, among others. Due to the wide range of applications, its expected a massive impact on radiologists daily life due to AI (Pesapane, 2018).

Amongst the AI applications for image interpretation, the detection is the most studied, followed by the rule out, diagnoses, and definition of the stage of the disease in the medical images. The development and application of AI algorithms in medical imaging, in general, need to follow three-step: training, validation, and testing. After the AI algorithm learns the features, then it can be used to assist clinical practices, reducing diagnostic errors, providing predictions, and reducing the interpretation time of medical images, in comparison with the human reader interpretation time (Obuchowski, 2019).

Usually, AI algorithms have the following four practical applications in medical imaging. The first one is the reader mode, when an image is applied to an AI algorithm, and the anomalies are also reviewed by a human reader during the image interpretation. The second application is the second reader mode, the application of the AI algorithm after the human reader performed his interpretation, to include additional findings, having in consideration the human reader interpretation. The third application is the triage mode, when the AI algorithm classifies suspicious detections in the images. The last one is the prescreening mode, when the AI algorithm focuses on cleaning images and provides a report, giving only the images with anomalies to the human reader. The AI algorithm is most used as the second reader mode as computer-aided detection (CADe) applied to detect breast, lung, and colon cancer imaging, helping the human reader to find lesions in the images (Obuchowski, 2019).

Nowadays, AI often detects minor image alterations with more relevant outcome variables, including a new diagnosis of advanced disease that requires treatment or that will affect long-term patient life. The biggest change that AI brings to medical imaging is the detection of pattern changes that are not easily detected by humans, showing impressive accuracy and sensibility. However, the improved sensibility brings problems by detecting subtle changes with indeterminate significance. In the case of screening mammograms, the artificial neural networks are no more accurate than radiologists in detecting cancer but have more sensibility for pathological findings, in particular for subtle lesions (Oren, 2020).

One study performed in 2019 showed that an AI algorithm (deep learning-based algorithm – chapter 3.2.2.) was able to distinguish four different diseases in chest radiography, malignant pulmonary neoplasm, active pulmonary tuberculosis, pneumonia, and pneumothorax (Hwang, 2019).

AI includes machine learning (ML) and deep learning (DL) that can help create systems to support health technicians to perform their daily tasks, with faster delivery and increasing value on the imaging analyses (Alexander, 2020). ML and DL can give physicians a complement to enable the development of new treatments, which will be detailed in chapters 3.2.2 and 3.2.3.

### 3.2.2. Machine Learning

Machine learning (ML) is a sub-branch of artificial intelligence, as an element of computer science that aims to build and leverage existing algorithms, usually centered on mathematical and statistical optimization, in order to launch generalized models that offer patterns and accurate predictions. Meaning that ML focuses on continuous data improvement, data mining, and task automation (Frockman, 2019).

One application of ML in medical imaging is the analyzis of MRI brain images to detect brain changes related to early ischemic stroke within a narrow time window with greater sensitivity than a human reader (Oren, 2020).

Another capability in ML is the ability to distinguish Parkinson's disease from atypical parkinsonism and multiple systems atrophies from progressive supranuclear palsy in conjunction with the MRI technique. To distinguish the diseases, ML, in conjunction with MRI, measures the free-water-corrected fractional anisotropy (FA) to develop disease-specific machine learning comparisons to differentiate forms of parkinsonism (Abel, 2019).

As mentioned by Chassagnon G., ML has more relevance in image interpretation. On the other hand, deep learning has shown an outperformance for a specific class of problems (Chassagnon, 2020).

### 3.2.3. Deep Learning

Deep learning (DL) is defined as a subset of ML where the computers learn useful representations and features automatically, directly from the raw data (Latif, 2017). This ability was allowed by the increasing availability of large datasets and the high computing capacity of graphic processing units. In medical imaging, the class of deep learning networks most used and studied is the convolutional neural network (CNN) algorithm (Chassagnon, 2020; Lundervold, 2019).

CNN algorithm is used to solve computer vision tasks, as hand-written numbers on bank checks (Hwang, 2019). In medical imaging, CNN represents a powerful way to learn useful representations of images and other structured data. CNN can be applied to improve the efficiency of radiology practices through protocol determination based on short-text classification and also be used to reduce the gadolinium dose in contrast-enhanced brain MRI without compromising the image quality. Another relevant application is the image registration of advanced deformability, allowing the quantitative analysis across the time of different images (Lundervold, 2019).

## 3.3. Systematic literature review results presentation

The systematic literature review was executed in May 2020 following the methodology described at chapter 2.1.

In the first phase, the identification phase, it was possible to identify 55878 documents (Table 4).

Table 4 - Results of article identification.

| Information sources | Identified studies |
|---|---|
| Science Direct | n = 54517 |
| Scopus | n = 939 |
| Web of Science | n = 422 |

In the second phase, the abstract screening was defined and applied the exclusion and inclusion criteria as described below in Table 5:

Table 5 - Inclusion and exclusion criteria.

| Inclusion Criteria | Exclusion Criteria |
|---|---|
| Scientific Documents | Publication date inferior 2015 |
| | Investigation report |
| | Publication language |
| | Lack of access to the document |
| | Duplicate records |
| Thesis | Themes not relevant to this study |

Considering the inclusion criteria of this study, there were included scientific documents and thesis that are directly related to innovative computational technology applied to medical imaging, used to improve the service provided to patients, and support healthcare technicians on a daily basis.

As an exclusion criteria, publications before 2015 were excluded due to the fact of fast evolution of the computational technologies in recent years, and computational technologies with more than 5 years start to be considered outdated. Articles not published in Portuguese or English, lack access to the report, and duplicated records were as well excluded.

After the removal of duplicated records, the selection of the eligibility articles (third phase) was performed in the following steps:

i) First, all abstracts without relevance and clearly outside of the study scope were removed.
ii) Then, the abstracts of the retrieved articles were analyzed if there were related to innovative computational technologies applied to medical imaging.
iii) Afterwards, the abstracts of the continuing articles were evaluated accordingly to the defined inclusive and exclusive criteria.
iv) Finally, the complete text of the articles was fully analyzed.

In the process of complete text analysis, articles that report overviews or reviews, without citations or incomplete articles that are not related to the aim of this study, were as well excluded.

Table 6 - Prisma records.

| Exclusion criteria | **SCIENCE DIRECT** | | **SCOPUS** | | **WEB OF SCIENCE** | |
|---|---|---|---|---|---|---|
| **1st phase** | Excluded articles | Total | Excluded articles | Total | Excluded articles | Total |
| Articles identification | N/A | 54517 | N/A | 939 | N/A | 422 |
| **2nd phase** | Excluded articles | Total | Excluded articles | Total | Excluded articles | Total |
| Publication date inferior 2015 | 24885 | 29632 | 543 | 396 | 189 | 233 |
| Investigation report | 9000 | 20632 | 214 | 182 | 86 | 147 |
| Publication language | 309 | 20323 | 8 | 174 | 1 | 146 |
| Lack of access to the document | 15782 | 4541 | 146 | 28 | 76 | 70 |
| Title and abstract | 4527 | 14 | 24 | 4 | 66 | 4 |
| **3rd phase** | Excluded articles | | | Total | | |
| Duplicated articles | 1 | | | 21 | | |
| **4th phase** | Excluded articles | | | Total | | |
| Full-Screen article | 10 | | | **11** | | |

In the included phase (4$^{th}$ phase), after performing the full-screen of the 21 selected articles, 10 articles were excluded, selecting 11 of them as relevant articles for this study.

### 3.3.1. Systematic literature review results analysis

The main conclusion after the analysis of the selected articles is that MRI, CT, and the US are the most studied medical imaging areas to embody innovative computational technologies. AI, ML and DL are the most relevant computational technologies, specially CNNs algorithm, being the DL most focused in medical imaging.

AI implementation in healthcare services is one of the most desired improvements of efficacy and efficiency of clinical care. AI has the capability to recognize patterns in images non-detectable by humans and support physicians' decision-making, based on the large volume of daily generated data and supporting the increasing demand for healthcare services. The aggregation of multiple data into integrated diagnostic systems bridge medical images, genomics, pathology, electronic health records, and social networks, being some of the improvements in healthcare services provided by AI (Bi, 2019).

Multiples investigators, since the 1980s, have been developing ML techniques for CADx (computer-aided diagnosis) with the objective to distinguish between malignant and benign breast lesions. CADx consists of an AI method that automatically characterizes the tumor by size, shape, morphology, texture, and kinetics. CADe has been developed, as well, to automate breast lesions detection by MRI (Bi, 2019).

US is the medical imaging technique that has the ability to produce real-time video, providing more information than a single image frame. To improve this technique, ML has been applied to the US to allow the classification or CADx, tissue segmentation, image registration, and content retrieval, being that the computer-aided disease diagnosis and classification consists of detecting or classifying lesions. This approach has been taken mainly in breast and liver analysis and has been improved greatly from the recent advances in ML (Brattain, 2018).

Maraci proposed an automated framework for fetal detection and pregnancy viability, meaning fetal cardiac activity, from a predefined free-hand US sweep of the maternal abdomen. This framework was developed to address the need to empower both the less experienced and the well-trained users of ultrasound. A central problem for this proposal was the need for high degree skills to perform a well-executed ultrasonography exam, and the framework proposed obtained 83.4% accuracy (Maraci, 2017).

As mentioned in section 3.2.3., CNN's algorithm is the most studied DL algorithm applied to medical imaging, being proposed to segment breast tumors (Caballo, 2020), detection of brain anomalies and diseases (Rai, 2020; Gottapu, 2018; Nunes, 2019; Coccia, 2020), and prostate cancer detection and diagnosis (Bi, 2019). The main reason for this application in medical imaging segmentation is due to the fact of unprecedented accuracy in classifying and detecting objects, face detection, and segmentation in the process of classifying images (Brattain, 2018).

MRI, as described in section 3.1.5., plays an essential role in the analysis of many diseases and conditions. In the beginning, CNN algorithms were used for medical image analysis, but their performance motivated the researchers to develop many new CNN architectures to support MRI image segmentation. Image segmentation refers to the process of dividing images into multiple regions with similar properties. Gottapi proposed a new CNN application, more specifically DenseNet architecture, for brain segmentation into a number of classes based on the type of tissue. The results demonstrate that the applied approach can accurately perform the segmentation and, in the near future, support physicians in Parkinson MRI segmentation (Gottapu, 2018). Other algorithms studied and applied to support MRI image segmentation are EDPSO (Enhanced Darwinian Particle Swarm Optimization) algorithm and PSO (Particle Swarm Optimization) algorithm (Vijay, 2016). The usage of DL in 2D image segmentation for breast masses detected in CT images without contrast got a high performance, with high classification discrimination of benign tumor and malignant tumors comparable to expert manual annotation (Caballo, 2020).

Rai proposed a Deep Neural network architecture named LU-Net for the detection of brain tumors into two classes, with or without tumor. As known, the identification and classification of brain tumors at an early stage plays a critical role in diagnoses. With the proposed architecture, it was possible to segment and classify MRI images for brain tumor detection with higher accuracy, lower layers, less complexity, and outperforming other deep neural models (Rai, 2020). Mehrotra also proposed a Pre-trained Convolutional Neural Network framework to classify MRI images of brain tumors into benign and malignant types with 99.04% accuracy (Mehrotra, 2020).

Generative Adversarial Models (GANs), a class of DL algorithm, was proven to improve MRI image resolution in the post-processing step by Gupta. The results of the GANs proved to outperform many standard other deep learning models on MRI datasets in improving image resolution (Gupta, 2020).

The search for an automated framework to detect malignant masses has increased over the past years. In mammography, besides some authors defending the usage of machine learning, Agarwal proposed the usage of the Faster R-CNN model, based on recognition, using the regions paradigm, proving the efficiency of his algorithm pre-trained. The proposed framework in his study has the capability to be implemented in a clinical environment, having the whole mammogram as an input and providing the suspected masses within the mammogram as an output. However, they don't have the capacity to distinguish benign and malignant masses (Agarwal, 2020).

# 4. Current technology and Innovative technology survey

As defined in the Methodology section, in the analysis phase, after concluding the literature review, a survey will be carried out with two main objectives: assess the nowadays status of the equipment and technology in medical imaging services in Portugal, evaluate the knowledge of computational technology application and usage in medical imaging in Portugal and estimate the motivation and barriers to implement innovative technologies in a short time in their services.

The survey will be conducted through quantitative research, based on a structured survey at Google Forms. To ensure the quality of the collected data some following interviewed subject characteristics were taken into account, as described below in the first section: the location of the subject in Portugal, the represented healthcare system (public, private, or public-private partnership), and the subject's professional qualification.

The survey has three sections. The first section aims to characterize the interviewed person and assess the need for improvement on the medical imaging service based on:

- Location by the district or region of the subject in Portugal;
- The healthcare system that the subject represents: public, private or public-private partnership;
- Subject's professional qualification;
- Assess the need for improvement on their medical imaging service.

The second section aims to assess the need for improvement detected on the medical imaging services in Portugal by their professionals based on the evaluation of:

- The classification of the rectification needed for the medical imaging equipments that the interviewed subject work with;
- The problems found in the MI service, e.g., outdated equipment.
- The requirements that are missing to guarantee the quality of the service, e.g. training and human resources.

The third section intends to assess the intention to implement innovative technologies in the medical imaging service based on:

- The general intention of the hospitals or clinics to incorporate innovative technologies into the medical imaging services is blocked by the implementations costs or not;
- The main barriers to implementing innovative technologies in the service.

The main barriers presented in the survey were based on the study realized by Paré in 2007 (Paré, 2007). The Paré study aimed to assess the main barriers to implementing PACS (Picture archive and communications systems) in two Canadian hospitals. One of the study-based frameworks, based on a literature review, highlighted the main barriers to innovation. The results show that the main barriers to innovation are:

- Project barriers, referring to financial problems faced when acquiring innovation, whether or not there are financial incentives linked to its use, and knowledge required for project management and for management of the resources allocated to the project.

- Technological barriers, as the selection of the hardware, software, security decisions, and the selection of technological infrastructure.
- Organizational barriers, refers to the integration and inserting technology into existing procedures and structures and the challenges inherent in learning how to effectively support the regular use of the technology.
- Behavior/Human barriers, as the resistance to change with individuals affected by the implementation as well as problems associated with organizational power dynamics. The resistance of physicians to information technologies is well documented.

The survey will be delivered to medical imaging clinics, public and private hospitals, and medical imaging suppliers in Portugal to obtain the maximum data to proceed with the analysis and answer the proposed questions to this study.

After collecting the data, two questions will be posed:

1) *What are the main problems or needs for improvement detected by the intervenient at medical imaging services?*
2) *What are the implementation barriers recognized to incorporate computational technologies at medical imaging services?*

The survey was elaborated, distributed and data collected in Portuguese regarding the language of the inquired group (Attach I).

To ensure the clarity of the survey, two piers of the university were required to analyze and suggest improvements to the questionnaire, providing the survey resolution average time.

## 4.1. Survey questions

Table 7 - Survey questions.

| Main questions | Sub-questions |
|---|---|
| | **1st section** |
| Subject characterization | In which sector are the healthcare institutions with which you collaborate? |
| | In which district or region are the healthcare institutions you cooperate? |
| | What is your role in medical imaging entities? |
| | In which medical imaging techniques do you work? |
| | In which medical imaging techniques you know of have implemented computational technologies? |
| | Do the medical imaging services that you work in need improvements? |
| | **2nd section** |
| What are the main problems or improvements detected by the intervenient at medical imaging services? | Which category of defects or needs of improvement do you find in the medical imaging equipment in your medical imaging services? |
| | What problems or needs of improvement do you find at the medical imaging equipment in your medical imaging services? |
| | At the medical imaging services you work in, which are the lacking requirements at the service? |
| | **3rd section** |
| What are the implementation barriers recognized to incorporate computational technologies at medical imaging services? | Disregard the implementation costs of computational technologies. Do you think it is possible to incorporate them in the medical imaging services that you collaborate with? |
| | Do you think it is possible to incorporate computational technologies in five years into the medical imaging services you work in? |
| | Which are the main barriers to incorporating computational technologies at your medical imaging service? |
| | Can you please specify barriers to integrating computational technologies? |
| Optional question | Which are the computational technologies that you work with weekly? |

## 4.2. Data collection and data analysis procedure

Data collection took place from May 26th until September 14th of 2021 through a survey presented on an online platform – Google Forms. During this period, the survey link was shared with physicians, suppliers, service providers, and Senior Diagnostic and Therapeutic Technicians by email and LinkedIn messages. Also, occurred some proposals to share the survey inside the companies and clinics by the inquired subjects.

It was possible to collect 102 answers at the 506 contacts, with a 9% margin of error with a 95% confidence level.

The data collected was organized in an Excel file accordingly with the three survey sections, exposing the data on tables and charts based on a descriptive statistical technique to calculate the distributive frequency of the studied variables.

At chapter 5, it is possible to see the survey results with the resource of a table, map chart, column chart, combo chart, and doughnut chart.

## 5. Results presentation and discussion

### 5.1. Results presentation

#### 5.1.1. Subject characterization

**Location**

Table 7 presents the number of answers per city or region. The higher responses were obtained at Lisbon (37%), followed by Porto (18%). 12% of the inquired subjects mentioned to work all over the country, being their roles suppliers and service providers. At the islands it wasn't possible to collect data besides the established contacts.

Table 8 - Number and percentage of answers per city/region.

| City/Region | Nº Answers | % Per city/region |
|---|---|---|
| Aveiro | 1 | 1% |
| Angra do Heroísmo | 0 | 0% |
| Beja | 2 | 2% |
| Braga | 4 | 4% |
| Bragança | 1 | 1% |
| Castelo Branco | 0 | 0% |
| Coimbra | 6 | 6% |
| Évora | 2 | 2% |
| Faro | 1 | 1% |
| Funchal | 0 | 0% |
| Guarda | 0 | 0% |
| Horta | 0 | 0% |
| Lamego | 0 | 0% |
| Leiria | 0 | 0% |
| Lisboa | 38 | 37% |
| Ponta Delgada | 1 | 1% |
| Portalegre | 0 | 0% |
| Porto | 18 | 18% |
| Santarém | 3 | 3% |
| Setúbal | 6 | 6% |
| Viana do Castelo | 3 | 3% |
| Vila Real | 0 | 0% |
| Viseu | 0 | 0% |
| North of Portugal | 3 | 3% |
| Center of Portugal | 0 | 0% |
| South of Portugal | 1 | 1% |
| Azores Islands | 0 | 0% |
| Madeira Islands | 0 | 0% |
| All country | 12 | 12% |


Chart 1 - Map with the percentage of answers per city.

## Sector

Almost half of the inquired group is employed at the private sector (46%), the other half works for the public and private sector (30%) or the public sector (22%)—only 2% of the group works for the public-private partnerships healthcare institutions.

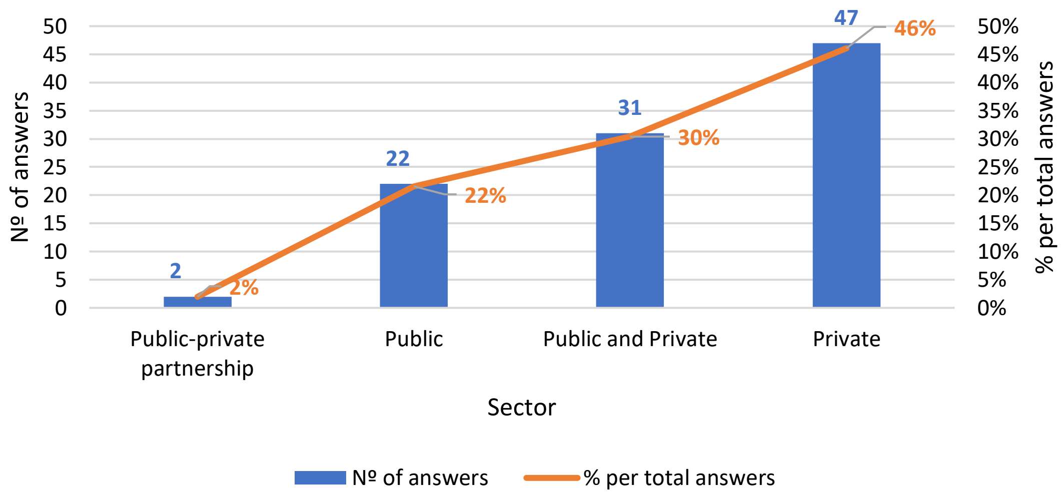


Chart 2 - Number of responses per sector.

## Professional qualification

Senior Diagnostic and Therapeutic Technician represents the higher percentage of the inquired group (75%), followed by the service providers (13%), the suppliers (10%), and the physicians (2%).

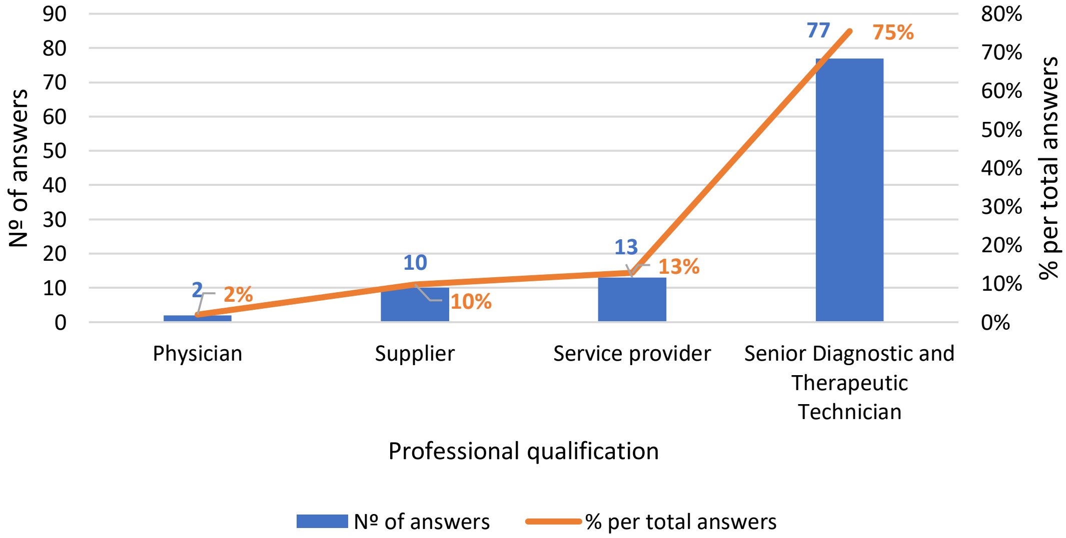


Chart 3 - Number of responses per role.

### Medical Imaging techniques

To the question "What are the medical imaging techniques you usually work with?" it was possible to conclude that CT, radiography, mammography, and MRI are the most common medical imaging techniques for the inquired group, representing 84% of the answers.

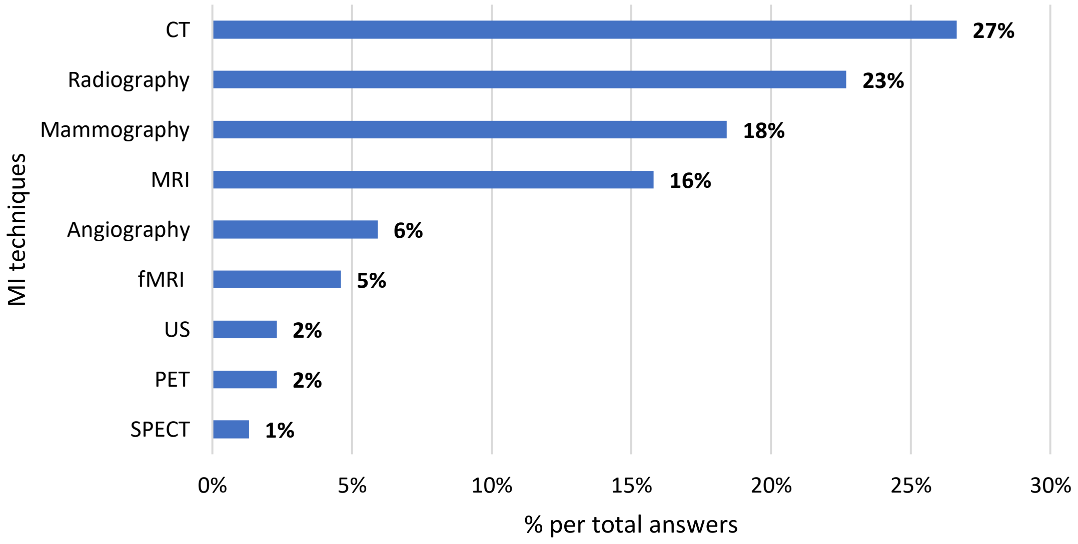


Chart 4 - Medical imaging techniques most used by the interviewed group.

### Knowledge of computational technology usage

To the question "In which medical imaging techniques you know of have implemented computational technologies?" the most referenced techniques are CT, radiography, MRI, and mammography, with 66% of the inquired answers.

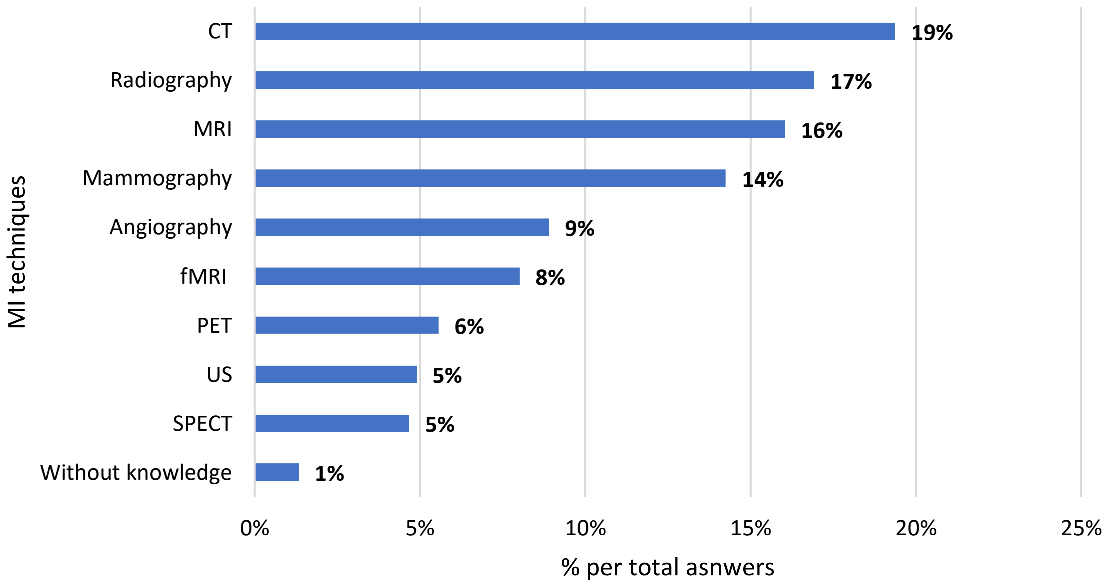


Chart 5 - knowledge of computed technology usage by the inquired group.

### Need for improvement

Chart 4 represents the answers to the need for improvement in medical imaging services where the subject works. 90,2% of the inquired say the medical imaging services need improvements, and only 9,8% of the answers assess the excellent conditions of the services.

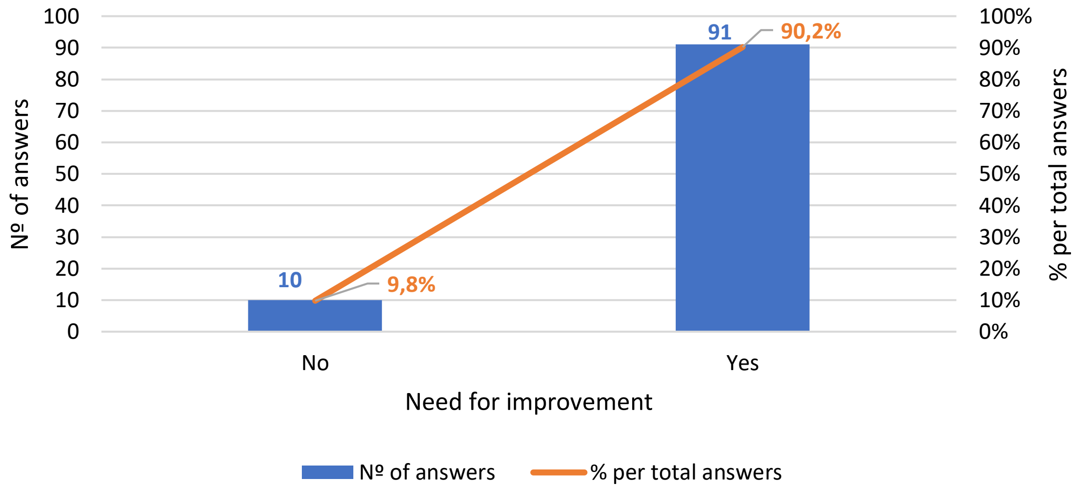


Chart 6 – Number of answers to assess the need for improvement on medical imaging service in Portugal.

## 5.1.2. Medical Imaging services improvement necessities

### Classification of the renovation needed

Software and hardware improvement necessities were the higher reported, with 76 % of the answers, followed by 14% of software improvement needed and 10% of hardware improvement.

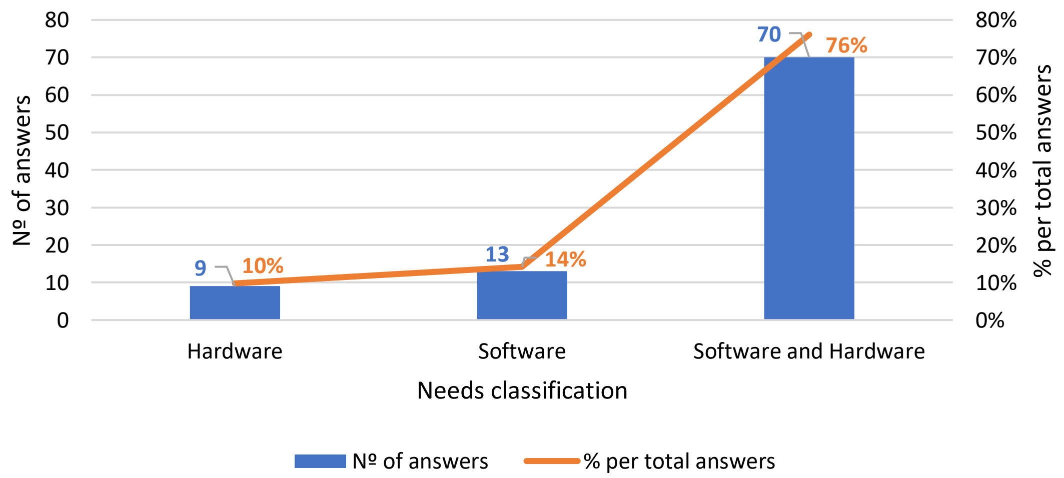


Chart 7 – Number of responses and percentage per total answers of classification of the rectification needed on medical imaging equipment in Portugal.

#### Need for improvement in medical imaging equipment at the MI service

The higher improvement necessity is the outdated equipment (43%) followed by the outdated technology (27%) in the medical imaging services. IT centralization and software incompatibility represents only 30% of the total answers.

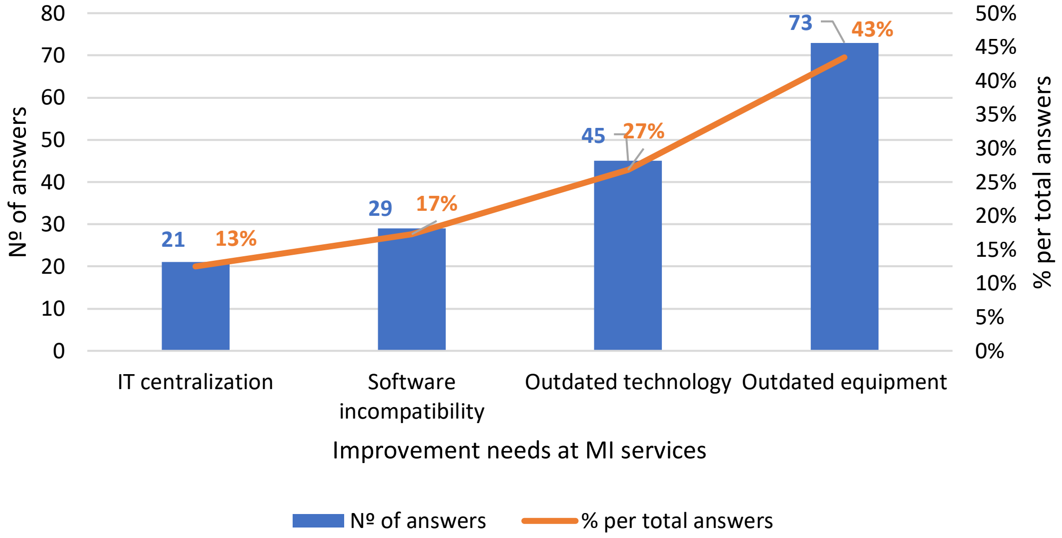


Chart 8 – Number of responses and percentage per total answers of necessities for equipment improvement.

#### Needs for improvement in medical imaging services

The most reported improvement in medical imaging services is the updated equipment, representing 33% of the responses. The necessity for training and updated software has a similar representativity with 25% and 23%, respectively. More human resources for the services represents 19% of the answers.

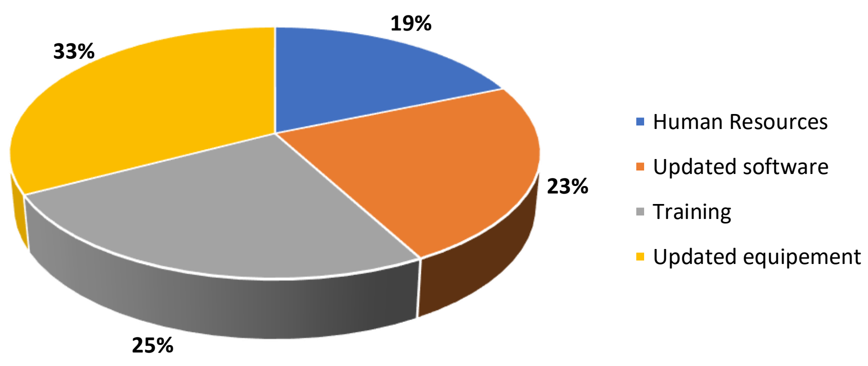


Chart 9 - Percentage of responses for the need for improvement in medical imaging services.

### 5.1.3. Assessment of the intention to implement innovative technologies in the medical imaging services

**The intent of the institutions to incorporate computational technologies despite the associated costs**

Despite the associated costs to the innovative technologies implementation on the medical imaging services, 62% of the inquired considered possible to execute. However, 36% mention that incorporation may be a possibility, and only 2% answered that there is no possibility to implement.

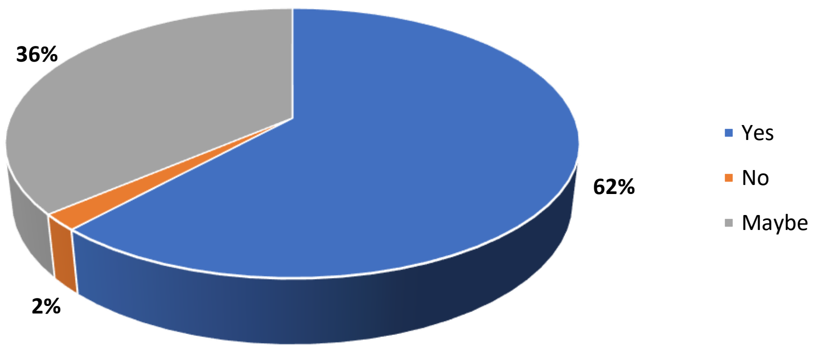


Chart 10 - Percentage of answers to the intentions to incorporate innovative technologies despite the associated costs.

**The intent of the institutions to incorporate computational technologies in five years**

Almost half of the inquired group (42%) does not have certainty of the intention to implement computational technologies in their services. The 36% answered affirmative to the will to implement, and 22% didn't believe in the incorporation.

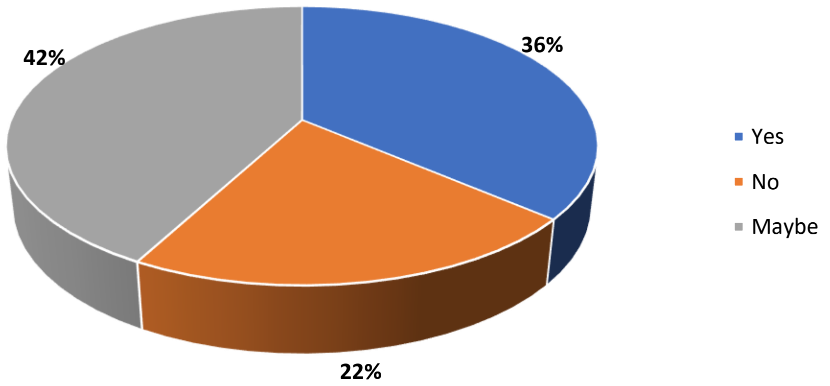


Chart 11 – Percentage of answers to the intention to incorporate innovative technologies in five years.

**Barriers for computational technologies**

41% of the interviewed group selected economic barriers as the main obstacle for computational technologies incorporation, followed by organizational barriers with 27%, human barriers with 14%, technical barriers with 9%, and project barriers with 8%.

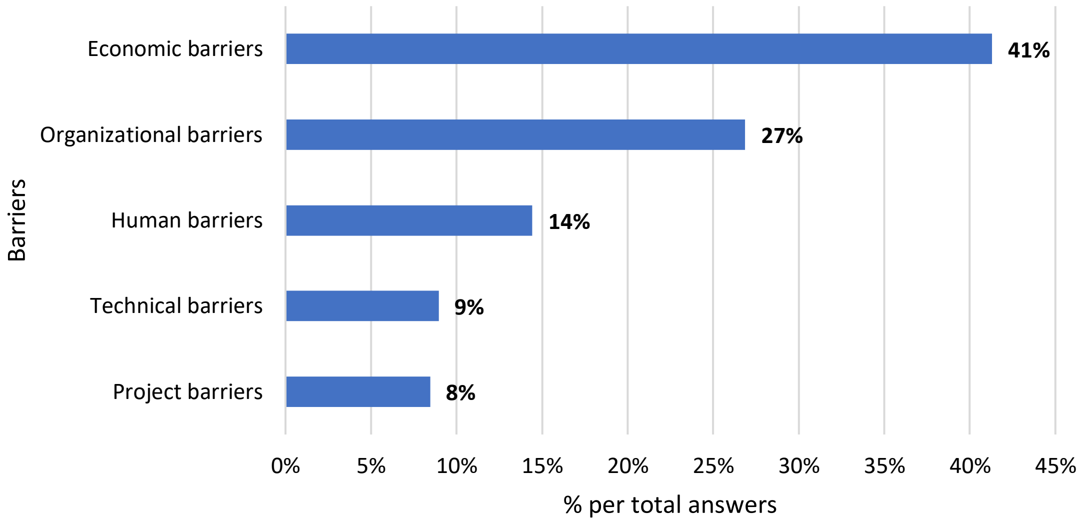


Chart 12 - Barriers for computational technologies integration healthcare organizations in Portugal.

**Reasons for non-incorporation of computational technologies**

To the question "Can you please specify barriers to integrating computational technologies?" it was possible to aggregate five main barriers.

1º barrier (61%): healthcare institutions are focused on financial savings — the incorporation of computational technologies comes with high costs and big changes in the services.

2º barrier (19%): physicians are not available to the changes those computational technologies will provide at the medical imaging services.

3º barrier (10%): C-level management of the healthcare organizations have a high complex decision-making process, turning the decision for the improvement into a challenge.

4º barrier (8%): Lack of trust and knowledge by the healthcare institutions about computational technologies performance, keeping the focus on today's model of work (human analysis) instead of computational technology analysis.

5º barrier (2%): Unfamiliarity of the top board of healthcare organizations with computational technologies and the benefits do the medical imaging services.

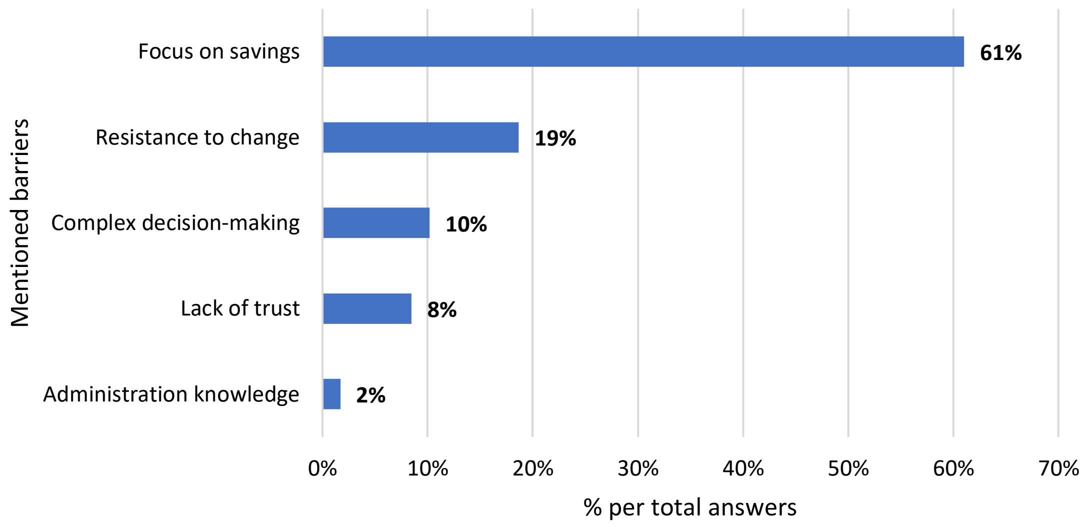


Chart 13 - Mentioned barriers by the inquired group about the motivations for the non-incorporation of computational technologies in medical imaging services in Portugal.

**Optional question**

To the option question "Which are the computational technologies that you work with weekly?" most of the inquired don't have the knowledge or don't use any computational technology. However, 22% of the questioned group referred to Computer-aided detection (CAD), and only 1% referred to Convolutional Neural Network (CNN).

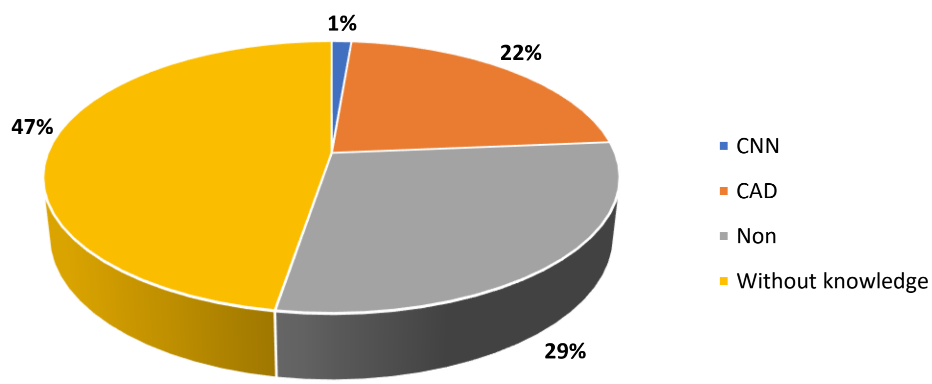


Chart 14 - Computational technologies weekly used.

## 5.2. Results discussion

The collection of answers were obtained mainly in the most populated cities of Portugal, with 55% of the responses from Lisbon and Porto. This result is due to the number of healthcare organizations in these locations. As INE published in the latest Portuguese National Statistic study in 2013, the number of hospitals in Lisbon was 59 and 45 in Porto for 238 hospitals in the country, representing 44% of the total hospitals in Portugal (INE, 2013).

The inquired group is mainly formed by senior diagnostic and therapeutic technicians, representing 75% of the answers. From the supply chain and service providers it was possible to collect 23% of the answers and only 2% of the inquired group represents the physicians.

Nowadays, computational technologies in medical imaging services are mainly applied to CT, radiography, mammography, MRI, and angiography, corresponding to the medical imaging techniques that the inquired group primarily uses. This information is validated by the systematic literature review for being the most studied medical imaging techniques to incorporate innovative computational technologies, with AI incorporated in their services.

As mentioned by the president of the Portuguese Association of Hospital Administrator's, in Portugal there has been a lack of technology investment since 2009. This information was corroborated by the inquired group, with more than 90% of affirmative answers to the need for improvement on their medical imaging services. The remaining almost 10% are represented only by the private sector.

To answer the question "*What are the main problems or improvements detected by the intervenient at medical imaging services?*" it is possible to observe that the software and hardware (chart 7) was the most mentioned problem. The outdated technology and equipment (chart 8), followed by outdated software and incompatibility and the lack of training (chart 9) at the MI services, are the main need for improvement mentioned by the questioned group. This information is confirmed in the literature review by the Portuguese journal (Nunes, 2019).

The motivations for the lack of investment in new technology at MI services in Portugal are mostly due to economic barriers, resistance to the change, with complex decision-making (chart 10, chart 12). As mentioned by the enquired group, the administration of healthcare organizations is mainly focused on financial savings due to the high investment and profound changes the innovative technologies available in the market represent to MI services. These motivations reply to the question, "*What are the implementation barriers recognized to incorporate computational technologies at medical imaging services?".* Another reason for the lack of investment motivation is the need to save due to the unsustainability of the healthcare system (Deloitte, 2011). The increase of private and public general expenditure on healthcare is increasing the need for financial saving, promoting the lack of investment in innovative technology, new equipment, and software, promoting the execution of the MI service with the outdated equipment and software over the years.

Therefore, the continuing usage of outdated equipment and software leads to an increasing search for private resources for updated equipment to collect MI with the goal to bridge the problems on the public equipment, raising the public expenses and the delay in diagnosis.

Almost half of the inquired group believe there may be a possibility to implement innovative technologies in the MI services in the near future (approximately 5 years). When it was requested not to consider the costs, 62% of the inquired group believed the healthcare institutions had the intention to incorporate these innovative technologies in their MI service. This confirms the economic barrier as the main motivation for the non-implementation of innovative technologies in MI services.

The main question of this study is "*What is the gap between innovative healthcare technologies available in the market and the implemented technologies in Medical Imaging areas in Portugal?*". The survey results demonstrated that MI services in Portugal have a huge need for upgraded MI equipment, to incorporate innovative technologies, increase the investment in human resources training, and acquire more human resources to fulfill the need at the MI services.

The majority of the inquired group does not use computational technology at their MI services or are not aware of their application (76% of the group), as demonstrated in chart 14. However, this fact does not allow me to affirm that no computational technology is used in their MI services but demonstrates the deficiency in human resources training.

The ML algorithm – Computer-aided detection (CADe) – is the computational technology mentioned by the inquired group. This algorithm had the first implementation in mammography in 1998 and nowadays supports X-ray and CT image readers primarily for cancer detection. Since the 1980s it has been researched CAD x (computed-aided diagnosis) to develop the capability to distinguish the malignant and benign breast lesions. This algorithm is a second reader mode applied to the images after the human reader performs their interpretation, supporting the human reader to find lesions in the images.

Convolutional neural network (CNN) algorithm is noted by one questioned person. This algorithm is a class of DL algorithm applied to solve computed vision tasks, like image classification and the continuous quantitative analysis through out time of different images, increases the database resources analysis, delivering a more accurate diagnosis.

The inquired group doesn't know the EDPSO algorithm and PSO algorithm for image segmentation, and GAN algorithm for MRI image improvement. These algorithms are understudied to support and improve medical image analysis, decision-making, detection, and classification of lesions.

The Portuguese private and public healthcare expenditure are exceeding the GDP growth rate increasing the motivation for financial savings by Portuguese healthcare institutions. Adding the resistance to change, upgrading the MI technology and equipment correlates with the missing information about the innovative computational technologies applied to MI available at the market. These facts increase the population dissatisfaction with MI healthcare services and the MI technicians and physicians to perform their job.

## 5.3. An interpretation Model

After collecting the key aspects for the non-investment on innovative technologies by the healthcare organizations (causes) and the effects to the patients, MI services human resources and to the MI infrastructure it was built an interpretation model in Figure 2.

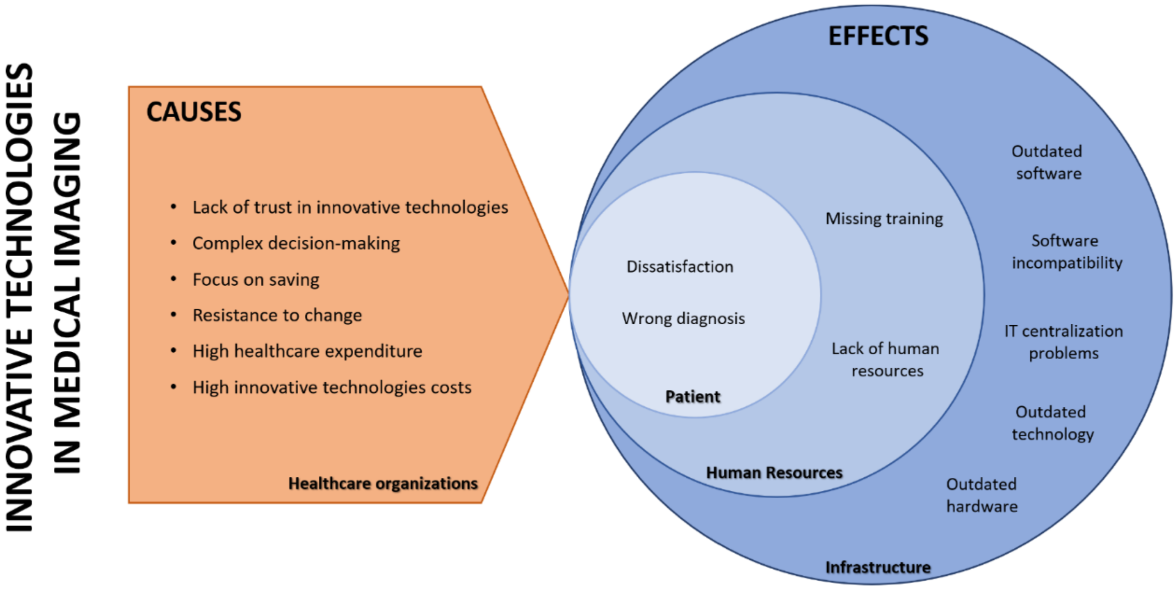


Figure 2 - Interpretation model of the effects caused by the non-investment in innovative technologies in MI.

The construction of the interpretation model in figure 3 was based on the data collected at the quantitative survey, in the literature review performed during this study, and interpretation of the results.

At the present study it was possible to observe the following causes for the lack of investment in innovative computational technologies:

- High innovative technologies costs and the focus on financial savings were the most mentioned causes for the lack of investment by the inquired group, as shown in charts 13 and 14.
    - 41% of the inquired group mentioned the economic barrier as the main barrier, and 61% of the group described the focus on savings by the healthcare institutions;

- The resistance to change by the physicians and lack of trust in innovative technologies by the healthcare organization administration are other causes for the lack of investment. The lack of knowledge on how the innovative technology performs and how it supports the radiologists in their tasks, improving the accuracy of the diagnosis results and fast presentation of the results.
    - 27% of the group mentioned the organizational barrier, and 14% mentioned the human barrier has the barrier for innovative technologies implementation in MI services in Portugal, as shown in chart 12;

    - 19% of the group mentioned resistance to change, 8% mentioned the lack of trust in innovative technologies, and 2% the unfamiliarity of the board of healthcare organizations to the benefits of computational technologies in MI services, as shown in chart 14;

- The complex decision-making results from the complex healthcare management structure and the complex distribution of the annual budgets.
    - 27% of the group mentioned organizational barriers and 8% mentioned project barriers for the incorporation of innovative computational technologies in MI services;
    - 10% of the inquired group mentioned complex decision-making as a reason for the lack of investment, as shown in chart 13;

- The high healthcare expenditure, as mentioned by Deloitte in 2011, increases the motivation for financial saving by the healthcare institutions, as mentioned previously.

This causes effects on the patients, human resources at MI services, and healthcare institutions' infrastructure.

- At the <u>patient</u> level, keeping outdated equipment results in patient dissatisfaction and a possibility for a wrong diagnosis, as mentioned by Figueiredo in 2008.

- The inquired group's level of human resources at MI services mentioned the lack of human resources and missing training as the improvement need at their services, as shown in chart 9.

- At the <u>infrastructure</u> level of healthcare institutions, as shown in chart 7, the hardware and software are both requiring for investment. In chart 8 is possible to observe that 43% of the group mentioned outdated equipment, 27%, software incompatibility by 17%, and IT centralization by 13%. In chart 9, 23% mentioned the updated software has a need at their MI services.

# 6. Conclusion

As mentioned in the present study, since 2009, there has been a visible lack of technology investment in healthcare institutions in Portugal. The inquired group corroborates this affirmation, with 90% of the answers confirming the need to improvements in their MI services.

The main MI techniques with computational technologies application in Portugal are CT, MRI, radiography, mammography, and angiography. These five techniques are as well the most daily used MI techniques by the questioned group. When asked about the computational technology knowledge, the CADe algorithm was the most mentioned by partial of the inquired group. The CADe algorithm is applied to cancer detection in X-ray and CT images.

On the other hand, more than half of the questioned group believes that if the costs weren't so high, there is a possibility of acquiring innovative technology, meaning new equipment and updated software. However, when there are asked to consider the costs of the technology, they are not certain about their acquisition.

To answer the main question of this study, "*What is the gap between innovative healthcare technologies available in the market and the implemented technologies in Medical Imaging areas in Portugal?*" is possible to say that Portuguese medical imaging services need updated equipment and technology improvement, along with more human resources and training. The Portuguese healthcare organizations administration, mainly in the public sector, are motivated primarily to save in costs due to the healthcare organizations' expenditures.

European Fund for Confinement Projects has funds to support the Portuguese healthcare institutions in updating the services and equipment. These programs aim to benefit companies, improve their services, and recover a considerable percentage of investment costs. At the Medical Imaging services, these investments will increase the quality of the services, supporting the patients in detecting malignin lesions and motivating healthcare providers.

## 6.1. Limitations

The present master thesis was performed during the COVID-19 pandemic, increasing the difficulties in establishing contacts with healthcare institutions and respective data collection. To mitigate the situation, most of the contacts were based on LinkedIn (used to establish a connection and, after acceptance, private message), providing a closer contact with the inquired subject and receiving improvement suggestions for survey/study.

## 6.2. Recommendations for future work

For future work, I recommend performing a study with the focus to understand in a couple of hospitals and/or MI clinics which are the computational technologies used and with the institution administration, if applicable, understand the real reason to don't upgrade the technology.

## REFERENCES

Abel, S., & Kolind, S. (2019). Improving parkinsonism diagnosis with machine learning. The Lancet Global Health, 1, 2. https://doi.org/10.1016/S2589-7500(19)30107-4

Agarwal, R., Díaz, O., Hoon, M., Lladó, X., & Martí, R. (2020). Deep learning for mass detection in Full Field Digital Mammograms. Computers in Biology and Medicine, 121, 103774. https://doi.org/10.1016/j.compbiomed.2020.103774

Alexander, A., Jiang, A., Ferreira, C., & Zurkiya, D. (2020). An Intelligent Future for Medical Imaging: A Market Outlook on Artificial Intelligence for Medical Imaging. Journal of the American College of Radiology, 17(1), 165–170. https://doi.org/10.1016/j.jacr.2019.07.019

Bateman, M. G., Durfee, W. K., Iles, T. L., Martin, C. M., Liao, K., Erdman, A. G., & Iaizzo, P. A. (2020). Cardiac patient-specific three-dimensional models as surgical planning tools. Surgery, 167, 259–263. https://doi.org/10.1016/j.surg.2018.11.022

Bi, W. L., Hosny, A., Schabath, M. B., Giger, M. L., Birkbak, N. J., Mehrtash, A., … Hoffmann, U. (2019). Artificial Intelligence in Cancer Imaging: Clinical Challenges and Applications. CA: A Cancer Journal for Clinicians, 69(2), 127–157. https://doi.org/10.3322/caac.21552

Brant, W. (University of V. S. of M., Helms, C., Klein, J., & Vinson, E. (2019). Fundamentals of diagnostic radiology (Fifth edit; S. Zinner & D. Murphy, Eds.). Wolters Kluwer.

Brattain, L. J., Telfer, B. A., Dhyani, M., Grajo, J. R., & Samir, A. E. (2018). Machine learning for medical ultrasound: status, methods, and future opportunities. Abdominal Radiology, 43, 786–799. https://doi.org/10.1007/s00261-018-1517-0

Caballo, M., Pangallo, D. R., Mann, R. M., & Sechopoulos, I. (2020). Deep learning-based segmentation of breast masses in dedicated breast CT imaging: Radiomic feature stability between radiologists and artificial intelligence. Computers in Biology and Medicine, 118, 103629. https://doi.org/10.1016/j.compbiomed.2020.103629

Cabral, M. (Universidade de L., Silva, P., & Mendes, H. (2002). Saúde e Doença em Portugal. In Análise Social. ICS.

Chassagnon, G., Vakalopolou, M., Paragios, N., & Revel, M. (2020). Deep learning: definition and perspectives for thoracic imaging. (2020), 2021–2030. European Radiology.

Chau, K. Y., Lam, M. H. S., Cheung, M. L., Tso, E. K. H., Flint, S. W., Broom, D. R., … Lee, K. Y. (2019). Smart technology for healthcare: Exploring the antecedents of adoption intention of healthcare wearable technology. Health Psychology Research, 7(1). https://doi.org/10.4081/hpr.2019.8099

Coccia, M. (2020). Technology in Society Deep learning technology for improving cancer care in society: New directions in cancer imaging driven by artificial intelligence. Technology in Society, 60, 101198. https://doi.org/10.1016/j.techsoc.2019.101198

Deloitte. (2011). Saúde em análise. Uma visão para o futuro. In Deloitte.

Eira, A. (2010). A Saúde em Portugal: A procura de cuidados de saúde privados (Universidade do Porto). Retrieved from https://repositorio-aberto.up.pt/bitstream/10216/26931/2/A saude em Portugal  A procura privada de cuidados de saude  Ana Eira.pdf

Figueiredo, J. (Universidade do M. (2008). Inovação e Desempenho de Equipamentos Médicos: Estudo Qualitativo em Hospitais Portugueses. Universidade do Minho.

Frockman, J. M. (2019). Artificial Intelligence and Machine Learning. In Journal of Chemical Information and Modeling (Vol. 53).

Gardner, J. (2015). Nanotechnology in medicine and healthcare: Possibilities, progress and problems. South African Journal of Bioethics and Law, 8(2), 50. https://doi.org/10.7196/sajbl.432

Gottapu, R. D., & Dagli, C. H. (2018). DenseNet for Anatomical Brain Segmentation DenseNet for Anatomical Brain Segmentation. Procedia Computer Science, 140, 179–185. https://doi.org/10.1016/j.procs.2018.10.327

Governo de Portugal. (2014). Programa do XXI Governo Constituicional. In Governo Constitucional. https://doi.org/10.1007/s13398-014-0173-7.2

Gupta, R. (2020). ScienceDirect Super-Resolution using GANs for Medical Imaging Super-Resolution using GANs for Medical Imaging. Procedia Computer Science, 173, 28–35. https://doi.org/10.1016/j.procs.2020.06.005

Hwang, E. J., Park, S., Jin, K. N., Kim, J. I., Choi, S. Y., Lee, J. H., … Park, C. M. (2019). Development and Validation of a Deep Learning-Based Automated Detection Algorithm for Major Thoracic Diseases on Chest Radiographs. JAMA Network Open, 2(3), e191095. https://doi.org/10.1001/jamanetworkopen.2019.1095

INE. (2013). Hospitais (N.o) por Localização geográfica (NUTS - 2013) e Modalidade; Anual. Retrieved from Instituto Nacional de Estatística website: https://www.ine.pt/xportal/xmain?xpid=INE&xpgid=ine_indicadores&indOcorrCod=0008110&xlang=pt&contexto=bd&selTab=tab2

Instituto de Informática, I. P. (2021). Projetos cofinanciados por fundos europeus. Retrieved November 2, 2021, from Ministério do Trabalho, Solidariedade e Segurança Social website: https://www.seg-social.pt/projetos-cofinanciados-por-fundos-europeus

Klang, E. (2018). Deep learning and medical imaging. Journal of Thoracic Disease, 10(3), 1325–1328. https://doi.org/10.21037/jtd.2018.02.76

Latif, S., Qadir, J., Farooq, S., & Imran, M. A. (2017). How 5G wireless (and Concomitant Technologies) will revolutionize healthcare? Future Internet, 9(4), 1–24. https://doi.org/10.3390/fi9040093

Lundervold, A. S., & Lundervold, A. (2019). An overview of deep learning in medical imaging focusing on. Zeitschrift Fßr Medizinische Physik, 29(2), 102–127. https://doi.org/10.1016/j.zemedi.2018.11.002

Mamyrbekova, S., Nurgaliyeva, Z., Saktapov, A., Zholdasbekova, A., & Kudaibergenova, A. (2020). Medicine of future: digital technologies in healthcare. E3S Web of Conference 159, 04036, 10.

Maraci, M. A., Bridge, C. P., Napolitano, R., Papageorghiou, A., & Noble, J. A. (2017). A framework for analysis of linear ultrasound videos to detect fetal presentation and heartbeat. Medical Image Analysis, 37, 22–36. https://doi.org/10.1016/j.media.2017.01.003

Mehrotra, R., Ansari, M. A., Agrawal, R., & Anand, R. S. (2020). Machine Learning with Applications A Transfer Learning approach for AI-based classification of brain tumors. Machine Learning with Applications, 2, 100003. https://doi.org/10.1016/j.mlwa.2020.100003

Nunes, R. (2019). Hospitais públicos recorrem ao privado para alugar equipamentos. Diário de Notícias, pp. 1–6. Retrieved from https://www.dn.pt/edicao-do-dia/06-mai-2019/hospitais-publicos-recorrem-ao-privado-para-alugar-equipamento-10854318.html

Obuchowski, N. A., & Bullen, J. A. (2019). Statistical considerations for testing an AI algorithm used for prescreening lung CT images. In Contemporary Clinical Trials Communications (Vol. 16). https://doi.org/10.1016/j.conctc.2019.100434

Oren, O., Gersh, B. J., & Bhatt, D. L. (2020). Artificial intelligence in medical imaging: switching from radiographic pathological data to clinically meaningful endpoints. The Lancet Digital Health, 2(9), e486–e488. https://doi.org/10.1016/S2589-7500(20)30160-6

Paré, G., & Trudel, M. C. (2007). Knowledge barriers to PACS adoption and implementation in hospitals. International Journal of Medical Informatics, 76(1), 22–33. https://doi.org/10.1016/j.ijmedinf.2006.01.004

Pesapane, F., Codari, M., & Sardanelli, F. (2018). Artificial intelligence in medical imaging: threat or opportunity? Radiologists again at the forefront of innovation in medicine. European Radiology Experimental, 2(1). https://doi.org/10.1186/s41747-018-0061-6

Rai, H. M., & Chatterjee, K. (2020). Machine Learning with Applications Detection of brain abnormality by a novel Lu-Net deep neural CNN model from MR images. Machine Learning with Applications, 2, 100004. https://doi.org/10.1016/j.mlwa.2020.100004

SPMS. (2021). Projetos Cofinanciados por Fundos Comunitários. Retrieved November 2, 2021, from Hospital Garcia de Orta EPE website: https://www.hgo.min-saude.pt/2020/09/17/fundos-estruturais-e-de-investimento/

Ting, D. S. W., Liu, Y., Burlina, P., Xu, X., Bressler, N. M., & Wong, T. Y. (2018). AI for medical imaging goes deep. Nature Medicine, 24(5), 539–540. https://doi.org/10.1038/s41591-018-0029-3

Vijay, V., Kavitha, A. R., & Rebecca, S. R. (2016). Automated Brain Tumor Segmentation and Detection in MRI using Enhanced Darwinian Particle Swarm Optimization (EDPSO). Procedia - Procedia Computer Science, 92, 475–480. https://doi.org/10.1016/j.procs.2016.07.370

Webb, A. (2003). Introduction to biomedical imaging (First edit; M. Akay, Ed.). John Wiley & Sons, Inc.

# APPENDIX

## Tecnologia presente nos serviços de Imagiologia Médica em Portugal

O presente questionário tem como objetivo a recolha de dados para o estudo "Avaliação da aplicação de tecnologia inovadora em imagiologia médica em Portugal" - Dissertação de Mestrado em Tecnologias e Sistemas de Informação da Universidade Nova de Lisboa – Information Management School pela aluna Joana Silva.

Este estudo tem como principal objetivo avaliar o gap existente entre as tecnologias inovadoras disponíveis no mercado e as tecnologias atualmente presentes nos serviços de Imagiologia Médica (IM) em Portugal.

Através do presente questionário pretende-se recolher dados de todas as regiões de Portugal, do setor público e privado e de diversas áreas de formação que intervenham e interajam com serviços de Imagiologia Médica em Portugal.

O questionário está dividido em três secções. A primeira secção pretende localizar e caracterizar o sujeito que responde ao questionário, as técnicas e tecnologias com que trabalha e se deteta melhorias no serviço de Imagiologia Médica. Caso a resposta seja afirmativa, na segunda secção é pedido que identifique as melhorias necessárias no serviço de imagiologia médica onde trabalha. Por fim, na terceira secção são apresentados dados de tecnologias inovadoras aplicadas em Imagiologia Médica, em estudo ou disponíveis no mercado, obtidos através da realização da revisão sistemática de literatura realizada no final do ano 2020. Pretende-se com a terceira secção compreender o conhecimento das tecnologias e analisar motivações de implementação de tecnologias inovadoras nos serviços de Imagiologia Médica em Portugal.

O questionário tem um tempo de resposta de cerca de 10 minutos.

Agradeço desde já a sua disponibilidade e apoio na realização desde estudo.

A bibliografia utilizada é disponibilizada no final do questionário.

## Caracterização do sujeito em estudo

### <u>Questões</u>

A que sector pertence a(s) clínica(s) ou hospital(ais) com que colabora?

- Público
- Privado
- Público e Privado
- Parceria público-privado

A que área geográfica pertence o serviço de saúde com que colabora?

- Aveiro
- Angra do Heroísmo
- Beja
- Braga

- Bragança
- Castelo Branco
- Coimbra
- Évora
- Faro
- Funchal
- Guarda
- Horta
- Lamego
- Leiria
- Lisboa
- Ponta Delgada
- Portalegre
- Porto
- Santarém
- Setúbal
- Viana do Castelo
- Viseu
- Região Norte
- Região Centro
- Região Sul
- Arquipélago dos Açores
- Arquipélago da Madeira
- Todo o país

Qual a sua função junto das entidades de Imagiologia Médica?

- Técnico Superior de Diagnóstico e Terapêutica
- Médico
- Fornecedor
- Auxiliar de serviço
- Prestador de serviços

Quais as técnicas de Imagiologia Médica com que trabalha?

- Radiografia
- Tomografia computorizada (CT)
- Angiografia
- Tomografia de emissão de positrões (PET)
- Tomografia computorizada de emissão de fotão (SPECT)
- Ecografia
- Ressonância Magnética
- Ressonância Magnética funcional
- Mamografia

Qual(ais) a(s) técnica(s) de Imagiologia Médica que tem conhecimento da aplicação de tecnologia(s) computacional(ais)?

- Radiografia
- Tomografia computorizada (CT)
- Angiografia
- Tomografia de emissão de positrões (PET)
- Tomografia computorizada de emissão de fotão (SPECT)
- Ecografia
- Ressonância Magnética
- Ressonância Magnética funcional
- Mamografia
- Sem conhecimento

No(s) serviço(s) de Imagiologia Médica com que colabora sente a necessidade de melhorias?

- Sim
- Não

## Melhorias necessárias nos serviços de Imagiologia Médica em Portugal

DEFINIÇÕES:

Tecnologias computacionais: equipamento e sistemas ou aplicações informáticas com capacidade de processar elevada quantidade de informação. No caso de imagiologia médica, os sistemas utilizados têm normalmente como objetivo melhorar a qualidade das imagens recolhidas, diminuir a dimensão dos ficheiros da imagem e facilitar a partilha das imagens entre as partes interessadas (técnicos, utentes e médicos).

Hardware: componente física do equipamento.

Software: conjunto de programas ou aplicações, instruções ou regras que permitem o equipamento funcionar.

## Questões

Nos equipamentos de Imagiologia Medica utilizados no serviço hospitalar ou clínica com que colabora, que tipo de necessidades de melhoria ou defeitos encontra?

- Software
- Hardware
- Software e Hardware

Quais os problemas ou necessidades de melhoria que deteta nos equipamentos de Imagiologia Médica com que trabalha?

- Equipamentos envelhecidos
- Incompatibilidade entre software
- Informação centralizada
- Tecnologia desatualizada
- Adicionar outra opção

No(s) serviço(s) de Imagiologia Médica com que colabora, que requisitos mencionados abaixo considera em falta?

- Formação
- Recursos Humanos
- Software recente
- Equipamento recente de Imagiologia Médica
- Adicionar outra opção

## Tecnologias computacionais em estudo e disponíveis no mercado

Após realizar uma revisão sistemática da literatura das tecnologias computacionais aplicadas ou em estudo em Imagiologia Médica nos últimos cinco anos foi possível recolher os dados apresentados abaixo.

As áreas de Imagiologia Médica mais estudadas e com maior aplicação de tecnologias computacionais são a Tomografia Computorizada, Ultrassonografia e Ressonância Magnética. Por outro lado, as tecnologias computacionais mais estudadas para aplicação em Imagiologia Médica são Inteligência Artificial, Machine Learning e Deep Learning.

Inteligência Artificial consiste numa área da ciência da computação focada na resolução de tarefas que o ser humano executa. Por outras palavras, tem como objetivo replicar o comportamento do cérebro humano na realização de tarefas.

Uma subcategoria da Inteligência Artificial é Machine Learning descrita como um elemento da ciência da computação que tem a capacidade de aprendizagem contínua sem intervenção humana, alavancando algoritmos existentes, desenvolvendo modelos analíticos com a capacidade de reconhecimento de padrões e de realizar previsões baseado em dados.

Por sua vez, Deep Learning é uma subcategoria de Machine Learning que utiliza uma classe específica de algoritmos - redes neuronais - com o objetivo de replicar o funcionamento do cérebro humano e analisar dados continuamente, com uma estrutura lógica semelhante a um ser humano, podendo aprender, apoiar ou tomar decisões.

Abaixo apresentam-se duas tabelas. Na Tabela 1 é apresentado o nível de aplicação e disponibilidade das tecnologias computacionais no mercado. Na Tabela 2 são descritas as várias aplicações das três tecnologias computacionais descritas acima.

Peço que leia com atenção, analise os dados e informações disponibilizadas e responda às quatro questões abaixo de acordo com a sua realidade, sendo uma opcional.

**Tabela 1** – Disponibilidade de tecnologias computacionais em Imagiologia Médica.

| Tecnologias Computacionais | Técnicas de Imagiologia Médica | | | |
|---|---|---|---|---|
| | Radiografia | Tomografia Computacional | Ultrassonografia | Ressonância Magnética |
| **Inteligência Artificial** | Existente[21,32] | Existente[8] | Em investigação[7] | Existente[5] |
| **Machine Learning** | Em investigação[30] | Em investigação[5] | Em investigação[7] | Em investigação[1,5,30] |
| **Deep Learning** | Em investigação[24] | Em investigação[8] | Em investigação[7] | Em investigação[20] |

**Tabela 2** - Aplicação de tecnologias computacionais em Imagiologia Médica.

| Tecnologias Computacionais | Aplicações |
|---|---|
| **Inteligência Artificial** | Sistemas de suporte ao trabalho diário dos profissionais de saúde, melhorando a rapidez de entrega e melhorando a análise das imagens[5] |
| **Machine Learning** | Distinção de lesões mamárias malignas de lesões benignas[5]<br>Classificação ou diagnóstico computacional em ultrassonografia[7]<br>Segmentação de tecidos em ressonância magnética[5]<br>Registo de imagens e reconhecimento de padrões[2] |
| **Deep Learning** | Detetar tumor mamário[8]<br>Detetar anomalias e doenças cerebrais[12,18,28,33]<br>Detetar cancro da próstata[5]<br>Entre outras aplicações de deteção de anomalias[7] |

## Questões

Dentro do hospital ou clínica com que colabora, desconsiderando os custos associados, considera que é possível incorporar algumas das tecnologias descritas acima?

- Sim
- Não
- Talvez

Dentro do hospital ou clínica com que colabora, considera que é possível incorporar algumas das tecnologias descritas acima num curto prazo (aproximadamente 5 anos)?

- Não
- Sim
- Talvez

Quais são as principais barreiras para a incorporação de tecnologias computacionais no hospital ou clínica com que colabora?

- Barreiras de projeto
- Barreira económica
- Barreira técnica
- Barreira organizacional
- Barreira humana
- Outra opção

De acordo com as barreiras para a incorporação mencionadas na questão acima, pode especificar/clarificar de acordo com a sua realidade?

QUESTÃO OPCIONAL: Qual o tipo de tecnologia computacional com que trabalha numa base semanal?

- Convolutional Neural Network (CNN)
- Particle Swarm Optimization (PSO)
- Generative Adversarial Model (GAN)
- Computer-aided detection (CAD)
- Sem conhecimento
- Nenhuma
- Outra opção