Impact of Incidental Findings on Radiology

Bachelor Thesis Industrial Engineering and Management

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Preface

I am delighted to present this thesis, which showcases the culmination of my academic journey in Industrial Engineering and Management at the esteemed University of Twente. This endeavor represents a harmonious collaboration between the University of Twente and the prestigious Leiden University Medical Center (LUMC).

First, I would like to thank Erwin Hans for his consistent support throughout our journey and his constant source of inspiration, his unwavering positivism, seemingly boundless and never-ending. Second, I would like to thank Frouzan Soltani for all the guidance and advice she gave me for all sorts of things. Third, I would like to thank Gayane Sedrakyan for her vital feedback and aid in helping me deliver an improved thesis. Finally, to the person I wouldn't have been able to be here without, Cornelis ten Napel, no words are enough to show you how much I am grateful for your help, all I can say is I will never forget what you have done to me.

I would also like to thank all people who aided me throughout my years at the university, my family, my colleagues, my friends, and all my teachers.

Mohamed El Chiwy

Enschede, July 2023

Management Summary

Motivation & Objective

The increasing demand for the healthcare system to minimize spending and provide the same quality of care (if not better) has forced stakeholders to develop ideas and plans to make their operations more efficient. The Leiden University Medical Center (LUMC) board aims to cut its costs by making projects on hospital broad themes. One of those themes is Diagnostics, with the Radiology department, which our project focuses on, being one of them. The radiology department is a place where innovation is increasing on almost a daily basis, however, this increases the outcomes and therefore the costs. Several factors increase the frequency of imaging tests, including Incidental Findings (IFs). IFs refer to unexpected and unintended findings unrelated to the primary reason for the imaging study (Pham et al., 2014). IFs were also talked about by medical staff in a diverse way, making it more difficult to grasp their frequency and impact. To know the significance of the impact of IFs on radiology is the objective of this research. Reaching such an objective would help us understand the causes of IFs and the influence and costs of IFs on radiology. With such knowledge, we can move forward and start making proposals to mitigate the impact of IFs. Moreover, to specifically see the effects of IFs at the LUMC and as a proof of principle, we examine Breast Cancer (BC) patients at the LUMC to see how IFs impact the rate of imaging testing.

Approach

We start with literature research and interviews with medical experts to gather knowledge about IFs and how it impacts radiology. The aim is to identify the causes of IFs by getting insights into the processes of detecting an IF, the types of IFs, and their frequency and severity. Then, we examine the literature on how IFs impact radiology by knowing the most common follow-ups after detecting an IF and the costs of IFs. We then search for ways to minimize the impact of IFs on radiology. Finally, we research the influence of IFs on BC and transform that into the basis of analyzing the data given by the LUMC to assess the impact IFs have on the medical imaging of BC patients.

Results

In the literature study, we found out that there are six steps involved in detecting IFs in radiology. Based on various studies, we found that the detection rate for IFs ranges from 3% to 40% and is highly influenced by the modality used and the primary diagnosis. In the same studies, we found out that CT and PET scans are the modalities with the most IFs, most PET/CT tests are used to look for metastases, and in most cases, IFs are not clinically significant.

In different studies, we found that IFs significantly impact patients, medical staff, and capacity, which leads to extra costs. We also found three strategies to minimize the rate of IFs, The NLP algorithm, the ACR project, and guidelines for radiologists.

In the data analysis of BC patients in the LUMC, seven relationships between imaging modalities were studied to assess the influence IFs have on those relationships (See Table 1 – Confidential). We first examined if there was a yearly correlation. If there was a yearly correlation, a monthly correlation was examined. If there was a monthly correlation, an analysis of this correlation was examined to see how much it is due to IFs, based on radiologists' reports.

Table 1 Relationships results

Conclusion

Value for Science

This research contributes to the scientific community in various ways. First, it helps advance knowledge regarding IFs, as it gives new insights, challenges existing theories, and analyzes existing literature and data, thereby pushing the boundaries of knowledge. Second, it has a methodological contribution and data analysis approaches, which allow others to build upon or replicate the methods used. Third, it allows the dissemination of findings, as most of this research will be publicly available, allowing other researchers to access, cite, and build upon the work.

Value for Practice

There are two ways in which this research contributes value to practice. First, it offers practical insights, innovative approaches, and recommendations that can be applied in the LUMC. Second, it guides practitioners in making informed choices, developing policies, or implementing changes based on a solid foundation of research evidence.

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1 Introduction

Incidental findings, those unexpected discoveries unrelated to an imaging study's primary goal, have grown to be a prominent topic of discussion in radiology. These incidental findings provide difficulties for radiologists and significantly affect patient treatment and the use of healthcare resources.

This report aims to comprehensively examine the impact of incidental findings on radiology, focusing on their leading causes, the implications for radiological practice, strategies to minimize their impact, and an analysis of data related to incidental findings.

This chapter is organized as follows. Section 1.1 describes the host organization, and Section 1.2 the motivation and problem description of this research. The subsequent sections describe the research goal (1.3), the research questions (1.4), and the intended deliverables (1.5).

1.1 LUMC Description

Leiden University Medical Center (LUMC) is a renowned academic medical center in Leiden, Netherlands. It is known for its innovation, excellence, and healthcare and medical research collaboration. LUMC has three central departments, Patient Care, Research, and Education.

The Medical Center traces its roots back to 1575 when Leiden University, one of Europe's oldest universities, was founded (About Us, n.d.). Throughout its history, LUMC has been at the forefront of medical advancements, pioneering breakthroughs in diverse fields ranging from medical research to patient care.

LUMC is a line organization with decentralized management, which implies that department heads and divisional boards have equal responsibility within the parameters established by the Board of Directors (*Management and organization,* n.d). In Appendix, we show the LUMC organization chart, which shows the board of the LUMC (the project initiator).

1.2 Motivation and Problem Description

LUMC has a major plan to cut their costs, their current spending is 600 million Euros, and they aim to minimize those costs by 54 million euros to spend a max of 546 million euros. Figure 1, breaks down LUMC’s costs (focused on BC). The costs can be broken down into Personnel, Medical Equipment, Infrastructure, Education and Training, Administrative, Research and Development, Operations, and more. One of the sectors that can be optimized to minimize costs is the operations section. Such a section includes various sorts of operations. However, our focus would mostly be on the diagnostics department.

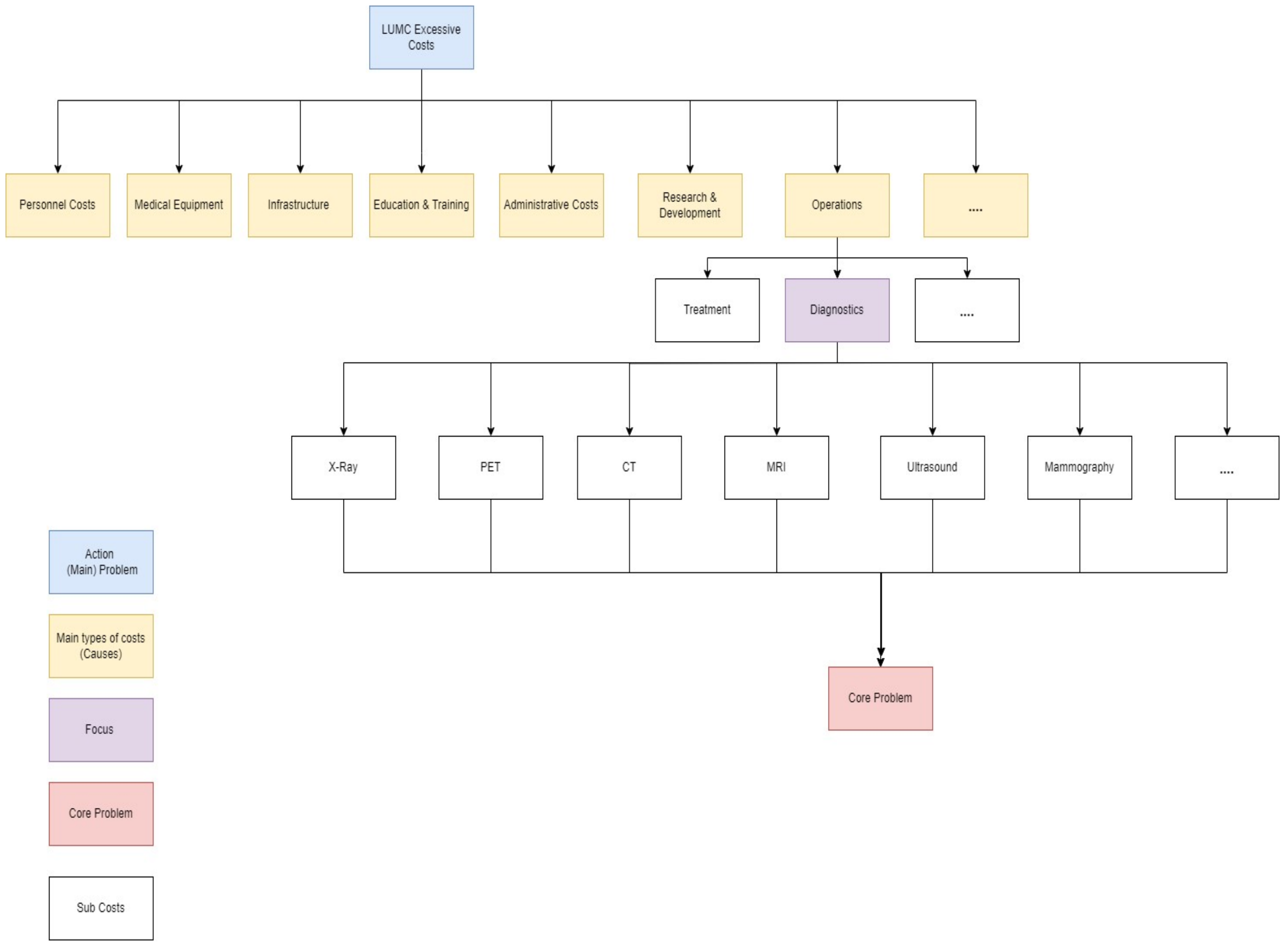


Figure 1 LUMC Costs Breakdown

We focus on the radiology department due to its involvement with BC and the impact incidental findings (IFs) have on it. IFs refer to unexpected and unintended findings unrelated to the primary reason for the imaging study (Pham et al., 2014). These findings can be benign or malignant and may require further evaluation or intervention (Schmidt et al., 2012). Benign findings mean that the finding is non-cancerous, and malignant findings mean that the finding is cancerous and, therefore, clinically significant. Incidental findings can be detected in various imaging modalities, including MRIs, CT scans, X-rays, PET scans, Ultrasounds, Mammographies, and more (See Figure 1). (Schmidt et al., 2012; Lee et al., 2010; Burt et al., 2008).

According to Gerrit Jan Liefers (Researcher, Professor, and surgeon at the LUMC), an IF is when making an image and finding another suspicion in a different part of the body. It could be when doing an MRI and finding a suspicion in the other breast which can lead to a change of care.

The fact that IFs lead to extra costs in the LUMC is why this research is conducted. The research aims to understand better how and why IFs occur (Chapters 2 & 3) to help mitigate their effects (Chapter 4). Moreover, in Chapter 6, we specifically study breast cancer (BC) patients in the LUMC to see how IFs impact them. The reasons BC is chosen and the details about the relation between IFs and BC are shown in Chapter 5.

1.3 Research Goal

The goal of this research is:

To know how significant the impact of incidental findings is on radiology.

1.4 Research Questions and Scope

1. What are the main causes of IFs in Radiology? (CH.2)
   - 1.1. How is an IF detected?
   - 1.2. What are the types of IFs?
   - 1.3. How frequently do IFs occur and what is their severity?
2. How does IF impact Radiology? (CH.3)
   - 2.1. What is the most common follow-up detecting an IF?
   - 2.2. What are the costs of the IFs?
3. How to minimize the impact of IFs on radiology? (CH.4)
4. How do IFs of BC impact the LUMC?
   - 4.1. What are the relations between BC and IFs? (CH.5)
   - 4.2. To what extent do IFs impact the radiology department in the LUMC? (CH.6)

The first, second, and third research questions (including their sub-research questions) are all answered using literature studies.

The first sub-research question of the fourth research question is also answered using literature studies, while the second sub-research question is answered using analysis of the data given by the LUMC about BC patients.

This project has two scopes:

1. To study the impacts of IFs on all types of patients in radiology. (CH.2/3/4)
2. To analyze the impact of IFs on BC patients in the LUMC. (CH.5/6)

Figure 2 shows the idea behind the main goal and why the research questions were chosen. This is done in two ways. First, it introduces the causes of the IFs by showing the detection process, type of discoveries, and frequency. Second, it shows how and why IFs impact radiology, therefore, gives us insights into the costs of IFs. Consequently, with such knowledge, we have a more precise grasp of IFs and can propose ways to minimize their impact on radiology.

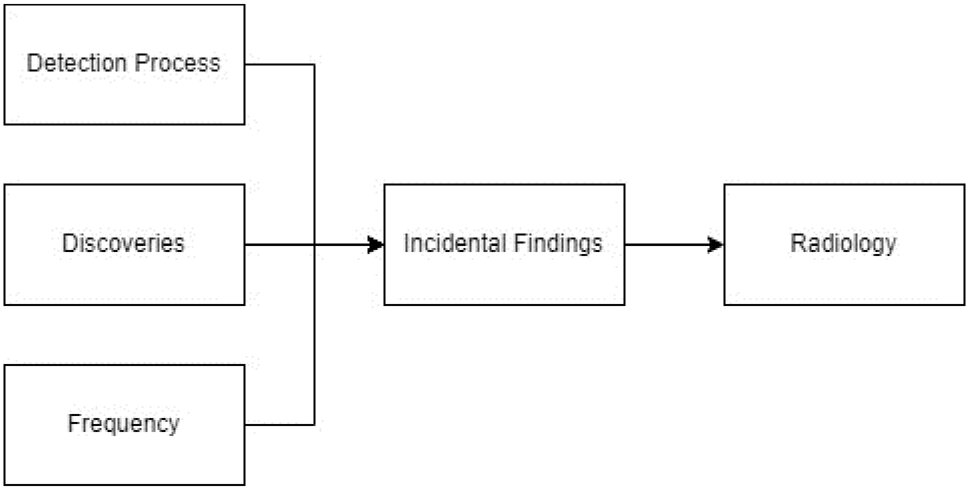


Figure 2 Research goal/question illustration

1.5 Deliverables

This study has one main deliverable:

- An analysis that shows the impact of incidental findings on the BC patients of the LUMC

This study forms the basis for further work, which will focus on:

1. Research that shows whether there was a care change when conducting the extra tests made due to an IF.
2. A tool/algorithm that can be applied to patients other than BC patients.

2 The Causes of Incidental Findings (IFs)

This chapter discusses the causes of IFs. To do so, we first understand the IF detection process (Section 2.1). Second, we comprehend the types of IFs (Section 2.2). Third, we study the frequencies of IFs detection and their severity based on the modality and type of IF (Section 2.3). The last Section (2.4) concludes the findings of this chapter.

2.1 The Process of Detecting Incidental Findings (IFs)

In radiology, examining and interpreting medical images, IFs are frequently found. When evaluating imaging studies like X-rays, CT scans, MRI, ultrasound, and PET scans, radiologists are crucial in spotting these unanticipated abnormalities or lesions. There are six steps involved in detecting IFs in radiology:

1. Image Acquisition: The first process is to acquire imaging results using special radiographic equipment. Different imaging modalities capture images of different body structures and systems. For example, X-rays provide two-dimensional images, while CT scans and MRIs offer detailed cross-sectional views of the body.

2. Image Review: Radiologists thoroughly examine the images after image acquisition to evaluate the main clinical issue or condition for which the imaging scan was requested. They concentrate on assessing the suspected pathology or the targeted location as specified by the referring doctor (Hall et al., 2009).

3. Systematic Examination: The complete imaging scan is then systematically examined by radiologists. Beyond the primary area of interest, they carefully assess the images, searching for any unexpected discoveries or anomalies that might not be connected to the original purpose of the imaging investigation (Rosado-de-Christenson, 2019).

4. Imaging Characteristics: Radiologists pay attention to specific imaging characteristics that may suggest the presence of an IF. These characteristics can include the detected abnormalities in size, shape, density, texture, and enhancement patterns (Eberhardt et al., 2016). By comparing these characteristics to previously known patterns, radiologists can make their assessments.

5. Communication: Once an incidental finding is identified, radiologists communicate their findings to the referring physician or the healthcare team involved in the patient's care. They provide a detailed report that includes information about the primary diagnostic question, any incidental findings encountered, and further evaluation or management recommendations.

6. Follow-up and Management: Based on the radiologist's report, the referring physician evaluates the incidental finding and determines the appropriate course of action. This may involve further diagnostic tests, specialist consultations, monitoring, or the initiation of specific treatments (Kumada et al., 2019).

In summary, the detection of IFs in radiology involves a systematic review of medical images beyond the primary area of interest. In addition to the accuracy of the imaging results, radiologists rely on their knowledge, skill, and experience to spot unexpected abnormalities or lesions. To make sure that IFs are adequately assessed and treated for the patient's benefit, clear communication of the results and appropriate follow-up are essential.

2.2 Types of IFs

IFs in medical imaging can encompass a wide range of abnormalities, conditions, or lesions that are discovered unexpectedly during imaging studies. These findings can vary in their clinical significance, ranging from benign and inconsequential to (malignant) potentially serious or life-threatening. This section shows some of the most common types of IFs.

According to Mollard (2022), we show some common types of IFs in the following subsections.

2.2.1 Atherosclerotic Plaque

Atherosclerotic plaque, or the accumulation of fatty deposits within the artery walls, is a frequent finding on CT scans of many body areas.

2.2.2 Calcifications

Calcifications, which are tiny calcium deposits, are found in many organs, according to CT scans. These calcifications can develop because of several illnesses, including the development of atherosclerotic plaque (linked to coronary artery disease), the development of stones (such as kidney and gallstones), and other closely related conditions.

2.2.3 Cysts

Cysts are sacs filled with fluid that can develop in any organ in the body. Cysts are widespread and frequently seen in organs including the liver and kidneys, but unless they become sizable and put pressure on nearby structures, they usually do not have a significant clinical impact. Cysts are thought of as a regular occurrence and only cause minor concern if they grow exceptionally large or result in difficulties.

2.2.4 Lymph Nodes

Little kidney bean-shaped organs called lymph nodes are a component of the lymphatic system. They are visible in ultrasonography, mammography, CT, and MRI scans.

2.2.5 Tumors

There are two types of tumors: benign (non-cancerous) and malignant (cancerous). Any organ can contain them, and they are most frequently spotted on ultrasound, CT, PET scans, or MRI.

2.2.6 Circulatory System (Blood Vessels)

Coronary Arteries:

Coronary artery calcifications are a common incidental discovery that is noteworthy. The amount of calcium, patient age, gender, and race are among the variables that affect coronary artery disease risk. Higher coronary calcium levels raise the risk of cardiac events and death from coronary artery disease, including heart attacks. Based on their unique risk factors and test results, people who have the disease are assessed for risk, given medication, and encouraged to adjust their lifestyles.

2.2.7 Neurological System

Meningiomas:

Meningiomas are benign tumors that develop from the dura mater covering the brain. While most meningiomas are inconsequential, some can be big enough to enclose the brain. Meningiomas can occasionally be cancerous and need to be surgically removed.

2.2.8 Cardiothoracic (Chest)

1. Lungs:

Pulmonary nodules are the most common incidental finding made in the chest, most of which are benign.

2. Lymph Nodes:

In most cases, enlarged lymph nodes are a reaction to infection. They can, however, also be a sign of malignancy (such as lymphoma or metastases from other cancers) or be connected to inflammatory diseases like sarcoidosis.

3. Thyroid Glands:

Thyroid nodules can be benign or cancerous and can also be found on neck CT scans. All ages, including young patients in good health, are susceptible to them. The size of the nodule and the patient's age determine whether further testing with a thyroid ultrasound is necessary.

4. Breasts:

Occasionally, incidental breast tumors are found and demand further examination using diagnostic mammography. Early diagnosis is essential since incidental breast lesions are more likely to be cancerous. Fortunately, screening mammography is effective in detecting most breast cancers in their preliminary stages.

2.2.9 Abdomen and Pelvis

1. Kidneys:

Renal masses are frequently seen, and many patients have one or more renal cysts. Renal cysts are benign tumors that frequently do not need to be treated right away. Non-contrast CT scans can indicate the presence of potential cysts, but ultrasound confirmation is required to determine that they are cysts and not malignant.

2. Liver:

Most liver lesions are benign cysts and hemangiomas. It is critical to establish the lesion is benign because the liver is a common site for cancer spread.

3. Large Bowel:

Due to the presence of stool, which can reduce vision, conventional imaging frequently has difficulties in examining the bowel. Nevertheless, it is possible to spot masses and polyps.

4. Ovaries:

Ovarian lesions are usually discovered incidentally and make up a sizable fraction of incidental malignant tumors. Ovarian lesions are typically only partially assessed by CT scans, which primarily consider their size. Small accidental cysts usually provide minor risks and can be ignored. However, an ultrasound scan will be necessary for a more complete review of bigger lesions or those that seem potentially solid.

5. Uterus and Cervix:

Uterine fibroids are a common occurrence, typically benign and insignificant, and are frequently found by accident. On the other hand, cervical lesions can be seen directly visually with a speculum exam and pap smear.

It is critical to remember that while these are some of the most frequently observed incidental findings, the clinical importance and care strategy for each discovery can vary. Depending on the specific patient's circumstances and general health, additional diagnostic tests, specialist consultations, or follow-up evaluations may be required to decide the best course of action.

2.3 The Frequency and Severity of Incidental Findings (IFs)

In this section, we analyze 12 articles found using literature research, showcasing the various aspects of IFs. Lumbreras et al.'s (2010) research helped find those 12 articles (Shown in Figure 3).

Those 12 articles were chosen because they cover all the aspects of IFs, as they show the type of modality used, the types of IFs, the frequency of IFs discovered, and the severity of the IFs.

2.3.1 Search Strategy and Eligibility Criteria

The frequency of incidental findings in clinical practice in imaging diagnostics was the initial criterion for papers to be included in the systematic review. Lumbreras et al.'s (2010) used ''The MEDLINE, EMBASE, and Cochrane Library Plus databases using exploded headings under the terms: *incidental finding*, *unexpected finding*, *clinical cascade*, *serendipity* (by using the Boolean operator OR), AND *diagnostic imaging* OR specific modalities such as *computed tomography, MR, ultrasound*, etc.'' to find the studies.

A tool named QUADAS (**Qu**ality **A**ssessment of **D**iagnostic **A**ccuracy **S**tudies) was used to assess the quality of the studies.

QUADAS consists of a group of fourteen elements presented as questions that can be answered with a yes, no, or unclear (Whiting et al., 2003). Articles that fulfilled eight or more elements were chosen, as they were considered applicable and relevant.

For inclusion and exclusion, first, potentially relevant abstracts were included. Second, studies that were not original were excluded. Third, studies with imaging tests not carried out in clinical practice were excluded. Fourth, languages other than English were excluded. Last, studies that did not include the frequency of IFs were excluded. Twelve articles from the remaining studies were chosen based on their informative conclusions.

2.3.2 Review

In Figure 3, the review is shown, where column 1 (orange) shows each article's author(s). Column 2 (yellow) shows the modality used to conduct the test. Column 3 (white) shows the types of IFs detected. Column 4 (green) shows the frequency (percentage) of IFs. Column 5 (purple) shows the severity of the findings.

	Author(s)	Modality Used	Type of IF	IFs	Severity
1.	(Wang et al, 2007)	PET/CT	Any focal extrathyroidal accumulation of FDG	199 (12%) of 1727 patients	181 with adequate follow-up, 59 cases with a suspected second malignancy and 122 sites presumed to be benign.
2.	(Paluska et al, 2007)	CT	Cyst, masses, calcifications, nodes, embolism, thrombosis	289/848 (34%)	Category 1 (12%) required attention before discharge. Category 2 (37%) required follow-up with primary doctor within 1 or 2 weeks, and Category 3 (50%) required no specific follow-up.
3.	(Vierikko et al, 2007)	Chest radiography, spiral CT and high-resolution CT	Non-calcified lung nodules	277/633 (44%)	46 (17%) required further follow up.
4.	(Even-Sapir et al, 2006)	PET/CT	Malignancy	151/2360 (6.4%)	41 (27.2%) unexpected malignancies were found.
5.	(Weber et al, 2006)	MRI	Intracranial abnormalities: tumours, arachnoid cysts, vascular abnormalities	166/2536 (6.5%)	Only a small percentage of the detected abnormalities require urgent medical attention.
6.	(Ishimori et al, 2005)	PET/CT	New primary malignant lesions	79/1912 (4.1%)	22 (27.8%) of the patients had that lesions were pathologically proven to be malignant.
7.	(Majumdar et al, 2005)	Chest radiography	Moderate to severe vertebral fractures	72/459 (16%)	Findings were confirmed in 23 (24%) patients
8.	(Kang et al, 2004)	Ultrasound	Thyroid nodules	198/1475 (13.4%)	Malignancy rate within thyroid incidentalomas was 28.8%.
9.	(Fitzgerald et al, 2003)	Ultrasound, MRI and CT	Pancreatic masses	7/53 (13.2%)	all 7 patients were confirmed to be positively diagnosed.
10.	(Brown et al, 2001)	MRI	Focal enhancing lesions on breast	30/103 (29%)	Cancer at the incidental sites was diagnosed in one of the 30 patients.
11.	(Messersmith et al, 2001)	Abdominal CT	Hiatal hernia, renal cysts, fatty liver, small pericardial effusion, ovarian mass, hepatic mass	145/307 (47%)	Approximately half were rated of "moderate" or "serious" concern.
12.	(Weder et al, 1998)	Whole body FDG-PET	Extrathoracic metastases	19/100 (19%)	N/A

Figure 3 Literature review

2.3.3 Findings

From the analysis of the 12 articles in Figure 3, we derive three conclusions.

1. CT is the modality with the most IFs.

2. Most PET/CT tests are used to look for metastases.
3. In most cases, IFs are not clinically significant.

2.4 Conclusion

This chapter discussed the leading causes of IFs in Radiology. First (Section 2.1), we showed the process of detecting IFs in radiology, which involves several steps, including image acquisition, image review, systematic examination, identification of imaging characteristics, communication of findings, and follow-up and management. Second (Section 2.2), we highlighted the various types of abnormalities or lesions when an IF is detected, such as atherosclerotic plaque, calcifications, cysts, lymph nodes, tumors, circulatory system issues, neurological system findings, cardiothoracic abnormalities, abdominal and pelvic discoveries. Last (Section 2.3), we showed the frequency and severity of IFs, which have been studied through an analysis of 12 articles, which revealed that CT scans result in the most IFs, PET/CT tests are often used to detect metastases, and most IFs are not clinically significant.

3 The Impact of Incidental Findings (IFs) on Radiology

This chapter discusses two topics, the common follow-up tests of IFs (Section 3.1) and the costs of IFs (Section 3.2). Knowing the standard follow-up tests of IFs and the costs of IFs will result in having a more precise understanding of IFs and therefore helps with the aims of the research. In Section 3.3, we conclude the findings of this chapter.

3.1 Common Follow-Up Tests of Incidental Findings (IFs)

In this section, we showcase some of the follow-up tests for BC, Lung Nodules, Kidney Mass, Liver Lesions, and Thyroid Nodules.

The reason we chose those specific types of IFs follow-up tests is because of their high incidental rate.

3.1.1 Follow-up Tests for Breast Cancer (BC)

Diagnostic imaging: To further assess breast abnormalities, diagnostic imaging methods like mammography, ultrasound, PET scans, and MRI are frequently used. These imaging techniques can give precise information like the size, location, and features of the lesion. This can be used to identify the finding's nature and determine whether to conduct further tests. (Le-Petross & Shetty, 2011)

Biopsy: A biopsy could be advised to collect tissue for some investigations. A biopsy can then diagnose the difference between benign and malignant tumors (Aaronson et al., 2019).

Tumor marker testing: When patients with BC are being followed up on, tumor marker testing may be used to track the disease's progression and treatment response (Chu & Ryu, 2016).

3.1.2 Follow-up Tests for Lung Nodules

PET scan: A PET scan may be advised to evaluate the incidental nodule's metabolic activity (Farjah et al., 2021).

Biopsy or tissue sampling: Same reason as mentioned 3.1.1

3.1.3 Follow-up Tests for Kidney Mass

Cross-sectional imaging: Cross-sectional imaging techniques such as CT scans and MRIs are used to evaluate kidney masses. These modalities can give information about the size, location, and characteristics of the mass, helping to differentiate between benign and malignant lesions (Silverman et al., 2008).

Biopsy: Same reason as mentioned in 3.1.1

Laboratory tests: Laboratory tests, including blood tests and urinary cytology, may be performed to assess kidney function.

Genetic testing: Treatment decisions can be guided by genetic testing, which can help identify gene mutations linked to kidney cancer.

3.1.4 Follow-up Tests for Liver Lesion

Contrast-enhanced CT scan: Liver lesions on a normal CT typically are not apparent, and therefore contrast is needed to increase the conspicuity of lesions. (Baron, 2006)

MRI: MRI is another imaging modality that can be used to further evaluate liver lesions (Fowler et al., 2011).

Biopsy: Same reason as mentioned in 3.1.1

3.1.5 Follow-up Tests for Thyroid Nodules

Ultrasonography: One of the main imaging techniques used to assess thyroid nodules is ultrasonography. It gives specific details regarding the nodule's features. (Kang et al., 2004)

Thyroid function tests: Thyroid hormone and thyroid-stimulating hormone laboratory tests (Gregory et al., 2018).

Imaging modalities: Additional imaging modalities such as computed tomography CT, MRI, or PET may be recommended to further evaluate the nodules (Roseland et al., 2022).

3.2 Incidental Findings (IFs) Costs

In this section, we showcase the costs of IFs by examining their impact on:

1. Patients
2. Medical Staff
3. Capacity & Finance

3.2.1 Impact on Patients

IFs in radiology can have negative impacts on patients. Some of the potential negative effects include:

1. Increased anxiety and psychological stress: IFs are always findings that are not expected for both the patient and the radiologist, therefore, when a patient learns about this new finding he/she may encounter a lot of anxiety and psychological stress (Schmidt et al., 2012; Booth et al., 2010).
2. Financial burdens: Additional examinations, intervention, treatment, leaving work, and traveling lead to additional spending, which may be a burden to the patient.
3. Overdiagnosis and/or Overtreatment: IFs may occasionally lead to overdiagnosis, resulting in unnecessary treatments and interventions (O'Sullivan et al., 2018).
4. Quality of life: The need to be actively visiting the hospital for follow-up and checks will disrupt daily activities, cause physical discomfort, or result in limitations on personal and professional life.
5. Personel challenges: When a patient is informed about an IF, he/she will face a decision-making challenge on what to do next.
6. Delay of the start of treatment: A patient might delay a treatment procedure due to a detection of an IF.

3.2.2 Impact on Medical Staff

The impact of incidental findings on medical staff (radiologists and surgeons) can be significant and multifaceted. In this subsection, we display 4 of those effects.

1. Increased workload: IFs most of the time lead to additional tests, therefore, more workload on radiologists.
2. Ethical dilemmas: When encountering an IF, medical staff are likely to face ethical and legal dilemmas, as the decisions of how to proceed are up to them (Sarker, 2020).
3. Stress and Emotions: When IFs are discovered, especially when they are significant, medical staff have to cope with the reactions of the patients which can be challenging
4. Medico-legal concerns: The responsibility to identify and communicate significant IFs accurately is up to the medical staff, as a result, failure to do so can result in legal consequences (Sarker, 2020).

3.2.3 Impact on Capacity and Finance

The monetary costs and capacity of medical care can be significantly impacted by IFs in radiology. In this sub-section, we explain how IFs impact capacity and finance.

Booth and Boyd-Ellison's (2015) research show how IFs influence the costs by radiologists into 5 categories:

1. Researching the finding
2. Research any evidence-based management
3. Going into meetings with relevant personnel to discuss the abnormalities and further costs
4. Further imaging
5. Further consultations

Each category has either a direct or non-direct effect on the time and availability of the medical staff, resources, and facilities, therefore, has an impact on capacity and costs.

3.3 Conclusion

This chapter focused on the impact of IFs on radiology. It covered two main topics, the common follow-up tests (Section 3.1) for IFs and the costs associated with IFs (Section 3.2).

Section 3.1 explored standard follow-up tests for breast abnormalities, lung nodules, kidney masses, liver lesions, and thyroid nodules. We chose those specific types of IFs because of their high incidental rate. Follow-up tests included diagnostic methods such as mammography, ultrasound, MRI, PET scans, biopsy or tissue sampling, tumor marker testing, genetic testing, and laboratory tests.

Section 3.2 examined the costs of IFs by exploring their impact on patients, medical staff, and capacity and finance. The adverse effects on patients included increased anxiety and psychological stress, financial burdens, overdiagnosis and overtreatment, disruption of daily activities, and decision-making challenges. The impact on medical staff involved increased workload, ethical dilemmas, stress and emotions, and medico-legal concerns. Regarding capacity and finance, IFs lead to additional costs in researching the findings, evidence-based management, meetings with relevant personnel, further imaging, and consultations. These costs affect the time, availability of medical staff, and the resources and facilities needed, ultimately impacting medical care's capacity and financial aspects.

4 Minimizing the impact of Incidental Findings (IFs)

IFs have the potential to lead to early detection and improved patient outcomes. Nevertheless, IFs can also negatively impact patients, radiologists, and the healthcare system.

The upcoming three sections highlight three strategies that can minimize the negative impacts of IFs. Section 4.1 shows the American College of Radiology (ACR) project. Section 4.2 shows a natural language processing (NLP) algorithm. Section 4.3 shows some simple strategies that can influence the detection frequency of IFs. The last section (4.4) concludes the findings of this chapter.

4.1 American College of Radiology (ACR) Project

Mayo-Smith's et al. (2017) ACR project has 4 core objectives:

1. "Develop consensus on patient characteristics and imaging features that are required to characterize an incidental finding.
2. Provide guidance to manage such findings in ways that balance the risks and benefits to patients.
3. Recommend reporting terms that reflect the level of confidence regarding a finding.
4. Focus future research by proposing a generalizable management framework across practice settings."

Figure 4 is a flowchart of an example of a guideline that radiologists can use to deal with a specific type of IF (Adrenal Mass).

Each box color gives a specific sort of explanation:

1. Yellow: Clinical data (Features and Size)
2. Green: Advice on what to do next (Sort of imaging, Biopsy)
3. Red: No follow-up needed (Finding is benign)

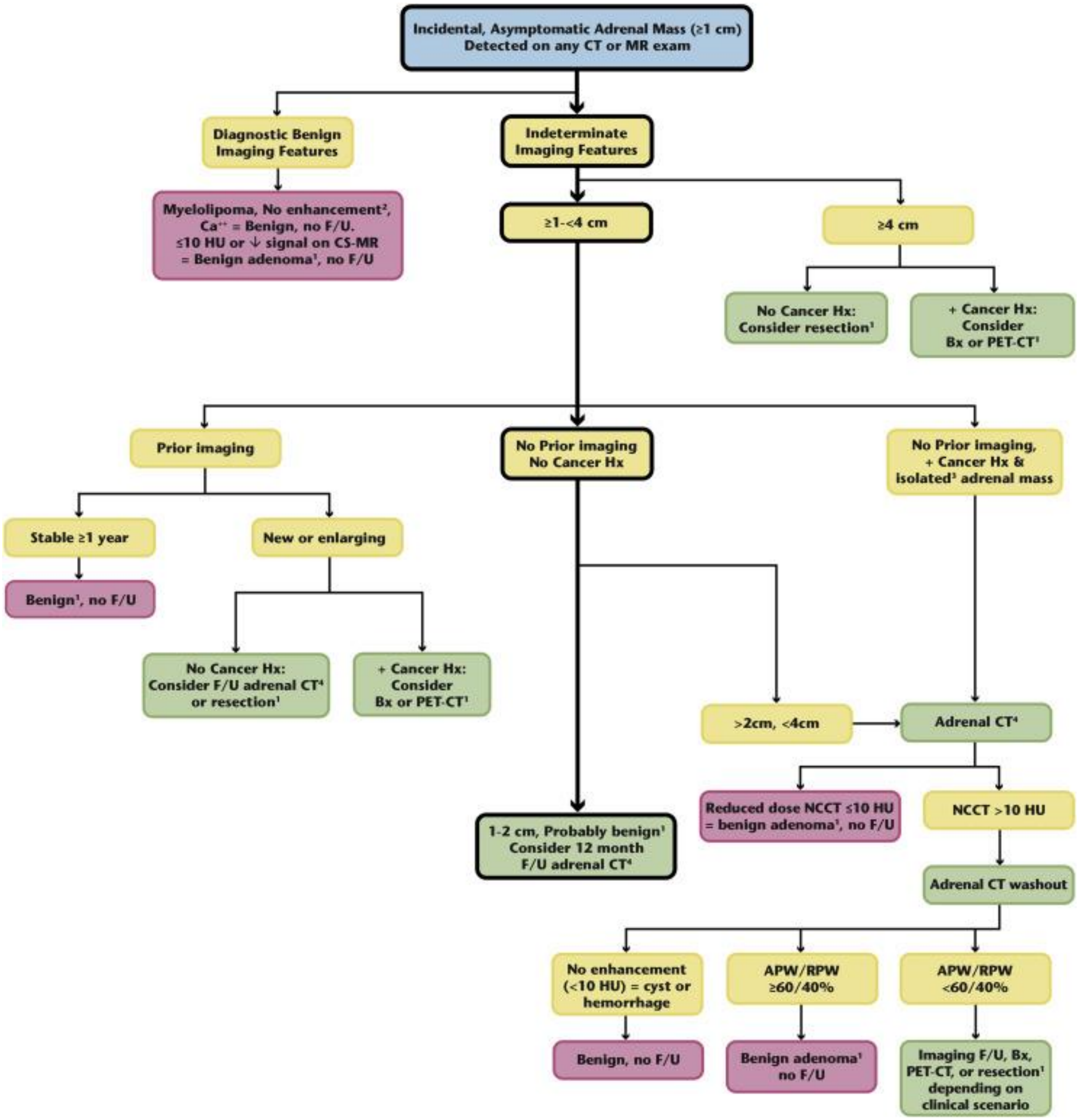


Figure 4 (Mayo-Smith et al., 2017)

Such a project or guideline could be very helpful and can help mitigate the impacts of IFs.

4.2 Natural Language Processing Algorithm

A natural language processing (NLP) algorithm is a technique (used for several reasons) that gives suggestions based on its intake. Such an algorithm is used by various organizations to mitigate the impact of IFs (Dutta et al., 2013; Trivedi et al., 2019).

Trivedi et al. (2019) use an NLP pipeline that splits the notes given by a radiologist into sections and sentences, which are then transferred into elements. Those elements are then binary classified and examined by physicians for incidental findings. To make sure that the algorithm is as accurate as possible, there are three procedures highlighted by Trivedi et al. (2019) that are considered an interactive learning cycle:

1. When possible, the user interface should explain to users why a sentence was predicted to describe an incidental finding and emphasize those sentences that the NLP model indicated as being significant.
2. Sentences that ought to have been highlighted but weren't by the NLP model should be selectable by users. Likewise, they ought to be able to eliminate inaccurate highlights.
3. To make it easier for users to grasp changes between model revisions, user feedback is presented as a list of additions and deletions.

There are also three main challenges for the NLP to be applied. First, applying such a tool will require a lot of capital to use such a program (especially in big organizations like the LUMC). Second, the algorithm will take much time to apply (due to its long learning procedure and application). Third, different physicians will have different notions of what an IF is, therefore, making the algorithm's task more difficult.

The use of the NLP tool, based on application in different organizations, will decrease the time and effort undergone by radiologists to identify IFs and will increase the chance of successfully identifying IFs.

4.3 Strategies that Influence the Detection Rate of IFs

Koplin et al. (2020), give two strategies that can either increase or decrease the frequency of IFs found. Those strategies can be found in Table 2.

Strategies to increase the detection of incidental findings	• Instruct researchers who carry out scans to systematically check for incidental findings. • Explicitly train research-based radiographers to identify and flag (at least some categories of) incidental findings. • Subject all research scans to be reviewed by a qualified radiologist, which may require researchers to obtain diagnostic-quality scans

	alongside research images even if unnecessary to achieve the aims of the study.
Strategies to decrease the detection of incidental findings	• Discourage researchers and research-based radiographers from looking for or speculating on incidental findings irrelevant to the research questions. • Reduce the image field of view to only those areas relevant to the research.

Table 2 (Koplin et al., 2020)

These strategies may be true and indeed result in decreasing the rates of IFs, however, they are not scientifically or medically proven to be reliable.

4.4 Conclusion

This chapter discussed strategies to minimize the negative impacts of IFs in radiology, as IFs can adversely affect patients, radiologists, and the healthcare system.

Section 4.1 highlighted the ACR project, led by Mayo-Smith et al. (2017), which offered guidelines, such as a flowchart for dealing with specific types of IFs, to assist radiologists in managing incidental findings effectively.

Section 4.2 showed another approach, which is the use of NLP algorithms. This approach aims to reduce the time and effort required by radiologists to detect IFs and improve the likelihood of successful identification.

Section 4.3 presented straightforward targeted detection strategies by Koplin et al. (2020) that can influence the detection rate of IFs.

Implementing strategies such as the ACR project, NLP algorithms, and targeted detection strategies may help minimize the negative impacts of incidental findings and improve the management of IFs in radiology.

5 Incidental Findings (IFs) and Breast Cancer (BC)

In this chapter (instead of focusing on all types of diseases and patients, we specifically focus on BC and IFs and how they influence each other.

First (Section 5.1), we discuss the reason behind the selection of BC for the data analysis. Second (Section 5.2), we illustrate how IFs impact BC. Third (Section 5.3), we show the most common IFs based on the imaging modalities. Last (Section 5.4), we conclude the outcomes of this chapter.

5.1 Reasons why Breast Cancer (BC) was chosen for the Data Analysis

1. Their increasing rate in the past 33 years, as shown in Figure 5
2. As a proof of concept for this research.
3. Its significant impact on IFs (section 5.2)
4. The time constraint, limits further analysis of other types of patients.

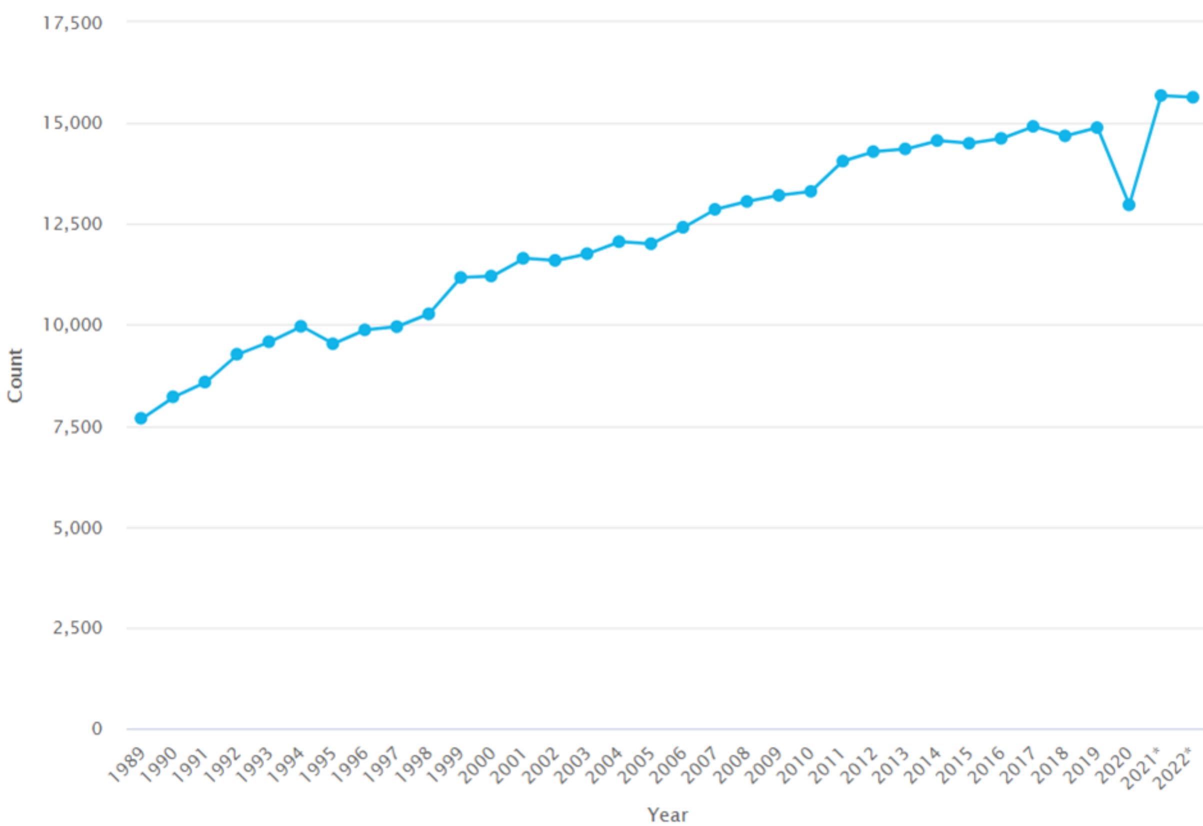


Figure 5 (Incidence by year, *https://nkr-cijfers.iknl.nl/#/viewer/bf2a9265-9b76-431b-8d89-9988076057af*)

5.2 Impact of Incidental Findings (IFs) on Breast Cancer (BC)

IFs of BC patients can have a huge impact on radiology, as it may lead to additional testing, interventions, and follow-ups, resulting in increased costs for patients and healthcare.

In this section, we first show how IFs of BC impact patients, and second we show how it impacts the healthcare system.

5.2.1 Impact on Patients

1. Increased testing: IFs will always lead to further diagnostics, as a result, a patient will have to conduct more tests and spend more time.
2. Psychological impact: IFs in BC patients can cause anxiety and worry about the possibility of having additional diseases or metastases (French et al., 2018).
3. Economic burden: Due to additional evaluations, interventions, and follow-ups the patient may have to spend additional money. Moreover, a patient may have to leave his work and travel more which will impact his finances

5.2.2 Impact on The Healthcare System

Capacity: The increased number of testing, because of an IF, will lead to more time spent by the medical staff and less availability of resources such as imaging modalities (especially mammograms as they focus only on BC), equipment, and facilities. This would result in more implications:

1. Higher costs: Due to additional testing and more time spent by medical staff.
2. Waiting time and delays: To accommodate and evaluate IFs, waiting times will increase as healthcare facilities strive to accommodate the increased demand for services.
3. Workflow and efficiency: Radiologists and oncologists may disrupt their workflow as they encounter an IF as it was probably not in their initial plans

5.3 Incidental Findings (IFs) of Breast Cancer (BC) and Imaging Modalities

Based on the interviews conducted at the LUMC and research studies we specifically chose PET scans, as they are common with BC and lead to many IFs.

5.3.1 Common IFs for PET Scans

When doing PET Scans for BC patients, the 3 parts of the body with the highest chance of detecting an IF are:

1. Thyroids (Adams et al., 2018; Beatty et al., 2009; Liefers, 2023).
2. Lungs (Adams et al., 2018; Beatty et al., 2009).
3. Abdomen (Adams et al., 2018; Beatty et al., 2009).

5.4 Conclusion

This chapter focuses specifically on BC and IFs and explores their influence on each other. Unlike Chapter 2, 3, and 4, which discusses all types of patents, this chapter provides an in-depth analysis of BC patients.

Section 5.1 showed the reasons for choosing BC for the data analysis. The reasons are the increasing rate of BC incidence, serving as a proof of concept for the research, the significant impact of Ifs on BC patients, and time constraints that limit the analysis of other patient types.

Section 5.2 emphasizes the consequences for both patients and the healthcare system. Regarding patients, IFs in BC can lead to increased testing, which leads to psychological distress and economic burdens. For the healthcare system, the increased number of tests and the time spent on IFs result in reduced capacity, higher costs, and longer waiting times.

This chapter also delves into the relationship between IFs and imaging modalities (Section 5.3). Specifically, PET scans are examined due to their relevance between BC and IFs. The most common IFs detected in PET scans are in the thyroid, lungs, and abdomen.

6 Analysis

In this chapter, we show the data analysis done using the data given by the LUMC to search for patterns that indicate the presence of an IF in BC patients. The data contained x imaging tests for y patients.

Section 6.1 shows how the decision tree was made. Section 6.2 shows how the data was approached, which is visualized using a decision tree (Figure 6). Section 6.3 shows how the analysis was conducted using Tableau (Software used for data analysis). Section 6.4 contains the findings and the visualization that is derived from the data analysis. Section 6.5 covers the validation and verification aspects of the findings. Section 6.6 shows the conclusions of this chapter.

6.1 Decision Tree

The decision tree (Figure 6) was inspired by Fan et al. (2011) and Yu et al. (2010) decision trees, as they had the same focus (medical data) and/or explained their application. However, compared to their decision trees, our tree was much more simple.

In Table 33, we show the 5 variables used.

Number	Variable	Type	Value
1	Data Relation	Categorical	Yes/No
2	Modalities Relation	Categorical	Yes/No
3	Yearly Relation	Categorical	Yes/No
4	Monthly Relation	Categorical	Yes/No
5	Radiologists Report Relation	Numerical	[0%,100%]

Table 3 (Model inputs)

Variable 1 was used to determine if there was a relation between the data to be able to derive conclusions from the data. Variable 2 was to confirm if there was a relation between modalities to look for trend relations. Variable 3 was the first indicator to look for trend relations. Variable 4 was used to confirm if the yearly relations were still valid. Variable 5 was the only numerical variable that was used to examine how much of the relation between the modalities was due to IFs.

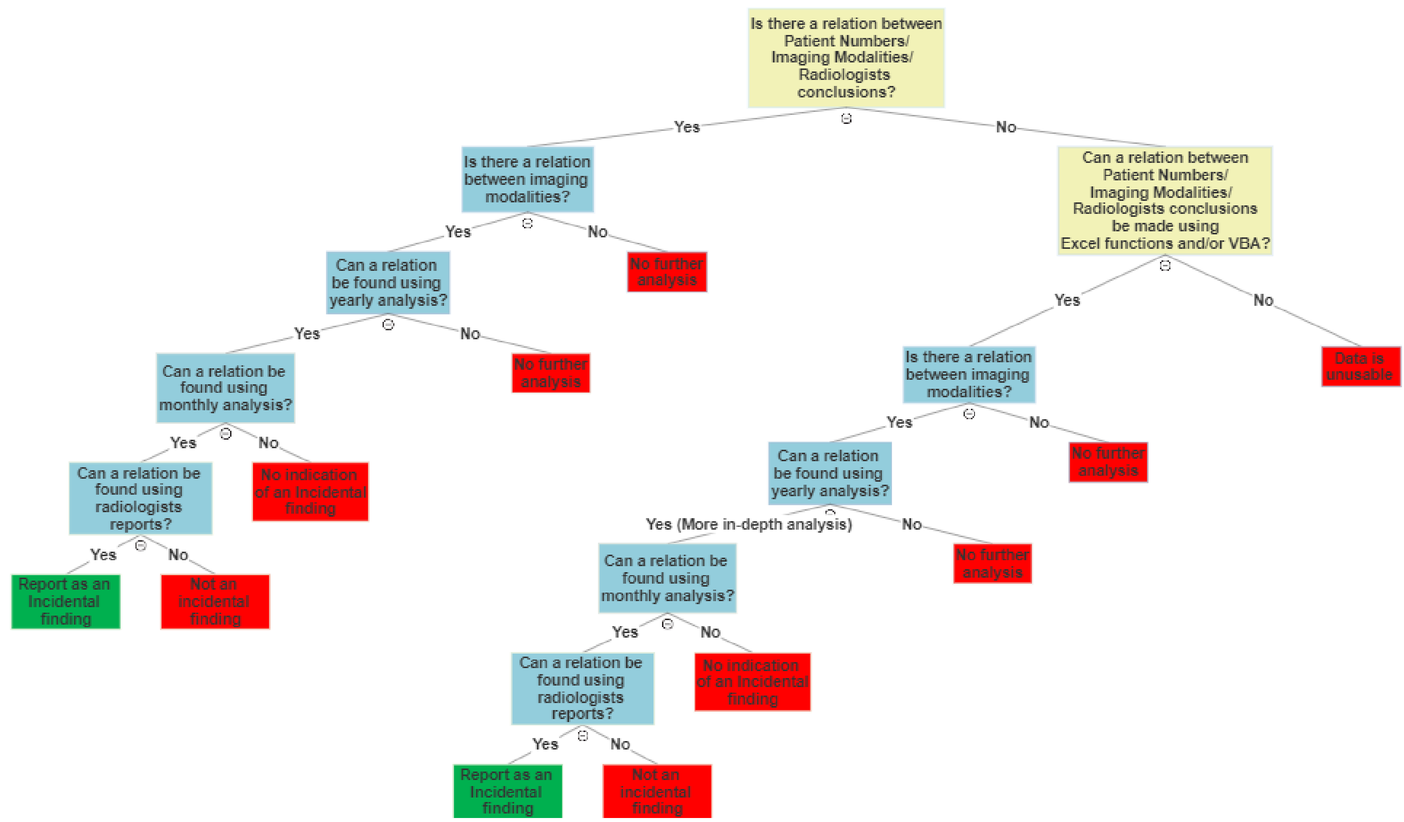


Figure 6 Decision Tree

6.2 Data Approach

In this section, we discuss how the data was approached in 5 steps.

- Step 1: Data preprocessing, to be able to make relations and derivations between the data to start with the analysis.
- Step 2: Look for relations between the types of imaging modalities based on research and conducted interviews
- Step 3: Conduct a yearly analysis of the data to confirm the relations found in Step 2
- Step 4: Get more in-depth to validate the relations found in Step 3
- Step 5: Verify how many of the relations (as a percentage) were due to IFs based on radiologists' reports.

6.2.1 Step 1: Data Preprocessing

6.2.1.1 Methods and Prospects

Data preprocessing is a significant and crucial step whose main objective is to provide final data sets that may be regarded as accurate and helpful for additional data mining techniques (Garcia et al., 2016).

The techniques used before the application of the data analysis and mining are known as data preprocessing. Given that the data will certainly have some problems it will not be suitable to start with data analysis and mining.

In our approach to solving the issues faced with the imperfect data, we used two methods mentioned by Garcia et al. (2016), which are missing values imputation and noise treatment.

The missing value imputation is focused on handling and filling in missing values that are crucial in the data analysis. Luengo et al. (2011) give various approaches to fill missing values, however, our approach is similar to the approach known as imputation of missing values by class of procedures. The procedure we use is based on identifying relationships between attributes to determine missing values.

The noise treatment is focused on resolving the issues faced due to noise data. Noise data can be the input and/or output data used in the analysis process. Therefore noise treatment is used to mitigate the impact of noise data (Garcia et al., 2016). The approach used is known as noise filters, where we removed the null values and data that were not relevant to our research.

6.2.1.2 Data Cleaning and Sorting (Confidential)

6.2.2 Step 2: Relations of Imaging Modalities

Based on some articles studied and the research in section 5.3, imaging modalities that had a relation between them due to an IF were gathered to start with the yearly analysis (step 3).

6.2.3 Step 3: Yearly Analysis

Based on the relations gathered in step 2, a meta-analysis was conducted on all BC patients from 2017 to 2021/2022 (depending on data availability) to find yearly relations between the imaging modalities.

6.2.4 Step 4: Monthly Analysis

In the case that a relationship was found in step 3, a more in-depth analysis was conducted. This analysis was to look for monthly relations instead of yearly relations to confirm if they were indeed related. (Note: there still might be a monthly relation if there was no yearly relation, however, we only look for relations that contain both relations as it has a higher chance of IFs)

6.2.5 Step 5: Verifying the relations

If there was a relationship in step 4, conclusions from the radiologists about 20 patients who conducted both imaging modalities were analyzed to see how much of an impact IFs have on this correlation.

6.3 Approaching Tableau

There were 3 steps to approach Tableau:

1. Upload the Excel file as a database in the software.

2. Add the patient numbers, the modalities, and the dates of incidence.

3. Highlight the modalities which were chosen in section 5.3.

Appendix B shows each of these steps.

6.4 Findings (Confidential)

6.5 Validation and Verification (Confidential)

6.6 Conclusion (Confidential)

7 Conclusion and Discussion

In this research, the objective was to know how significant the impact of IFs is on radiology. First, we showed the impact of IFs and how specifically they impact radiology. Second, we proposed solutions to mitigate the impact of IFs. Last, we covered the relations between BC and IFs and then examined BC patients in the LUMC, showing how IFs influence the rate of Imaging tests.

In the following sections, we discuss this research's scientific and practical values, followed by the limitations and the possibilities of further research.

Value for Science

The scientific community benefits in several ways from this research. First, it pushes the boundaries of knowledge concerning IFs by providing fresh perspectives and analyzing published materials and data. Second, it offers a methodological contribution and data analysis techniques that enable others to expand upon or duplicate the employed procedures. Third, it enables the dissemination of findings because the majority of this study will be made publicly accessible, enabling further scholars to access, reference, and expand on the work.

Value for Practice

In two key areas, this research offers valuable additions to the practice. First, it provides useful information, ideas, and suggestions that are immediately applicable to the LUMC. These conclusions and strategies are the results of careful research and analysis, which guarantees their application to actual situations. Practitioners at LUMC can improve their procedures, boost patient outcomes, and maximize resource use by putting the research's suggestions into practice. Second, by providing practitioners with guidance based on a strong foundation of research evidence, this study helps them make decisions, create useful policies, and implement essential reforms. Practitioners can design their tactics and judgments by relying on the study's results and conclusions.

Limitations

In this research there were some limitations faced, we first introduce those limitations in this section, and then we discuss how to overcome them in the following section.

The first limitation is that the data analysis conducted was only for BC patients. This limitation means that conclusions about IFs are only regarding BC patients. This restricts us from knowing the overall influence of IFs on the LUMC; therefore, we can not quantify how much IFs impact the costs of the LUMC in total.

The second limitation has to do with the making of the decision tree, although the decision tree covers all the steps conducted, it is still limited to the data set we acquired, therefore, this is not a general decision tree that can be applied to all data sets regarding IFs in the LUMC. Additionally, the process of building the decision tree does contain detailed steps and metrics, which makes it more difficult to apply further advancements to it.

The third limitation is the procedures used to conduct the data analysis. The approach used to conduct the data analysis focuses on four aspects :

1. Relations between modalities.
2. Yearly relations between modalities.
3. Monthly relations between modalities.
4. Relations due to IFs between modalities based on radiology reports.

This limitation is mainly due to the second aspect, where we use yearly relations as the start for the data analysis, and we do not conduct further analysis if there were no yearly relations. The problem is that there still might be a monthly relation and/or a relation due to IFs even if there were not any yearly relations. This also applies to the third aspect, that there might be a relation due to IFs even if there were no monthly relation.

Further Research and Recommendations

This research has a significant potential to develop further and become a basis for future analysis and studies.

The first way to develop this research is to address its limitations.

To overcome the first limitation, future analysts and researchers can examine the whole population of radiology instead of BC patients only. The examination of the whole population would be more costly, however, it would give a more precise grasp to the LUMC about how significant the impact of IFs is on the radiology department.

For the second limitation, it is advised that future analysts and researchers base their decision tree on a broader scale that can be applied to the data sets given by the LUMC, and elaborately explain the process of making the steps and metrics of the decision tree. The improved decision tree would be more applicable to different types of data sets.

The third limitation can be addressed by directly looking into radiology reports instead of looking for yearly and monthly relations, which would be much more time-consuming and require more medical experts, however, it will deliver more detailed information about the impact of IFs.

To further develop this research a diversified type of researchers is advised, including data analysts, people with medical backgrounds, and people impacted by IFs. Such diversity will allow future research to reach its maximum potential and deliver more accurate and reliable results.

We also recommend the LUMC to go with a strategy like the NLP algorithm. This recommendation is advised because of three reasons:

1. This approach is already utilized and proven to be effective in various organizations.
2. Artificial intelligence is drastically improving and widely used.
3. LUMC has the expertise and financial capabilities to apply such an approach.

Bibliography

Mollard, B. (2022). Everything you want to know about incidental findings. Retrieved from https://brettmollard.com/incidental-findings

Pham, A.-D., Névéol, A., Lavergne, T., Yasunaga, D., Clément, O., Meyer, G., Morello, R., & Burgun, A. (2014). Natural language processing of radiology reports for the detection of thromboembolic diseases and clinically relevant incidental findings. *BMC Bioinformatics*, *15*(1). https://doi.org/10.1186/1471-2105-15-266

Schmidt, C. O., Hegenscheid, K., Erdmann, P., Kohlmann, T., Langanke, M., Völzke, H., Puls, R., Assel, H., Biffar, R., & Grabe, H. J. (2012). Psychosocial consequences and severity of disclosed incidental findings from whole-body MRI in a general population study. *European Radiology*, *23*(5), 1343–1351. https://doi.org/10.1007/s00330-012-2723-8

Lee, C. I., Tsai, E. B., Sigal, B. M., Plevritis, S. K., Garber, A. M., & Rubin, G. D. (2010). Incidental extracardiac findings at Coronary CT: Clinical and Economic Impact. *American Journal of Roentgenology*, *194*(6), 1531–1538. https://doi.org/10.2214/ajr.09.3587

Burt JR, Iribarren C, Fair JM, et al. Incidental Findings on Cardiac Multidetector Row Computed Tomography Among Healthy Older Adults: Prevalence and Clinical Correlates. *Arch Intern Med.* 2008;168(7):756–761. doi:10.1001/archinte.168.7.756

NKR. (n.d.). *Incidence by year*. NKR Cijfers. https://nkr-cijfers.iknl.nl/#/viewer/bf2a9265-9b76-431b-8d89-9988076057af

Hall, W. B., Sherstin, T. G., Leslie, S. P., Sidharth, S. A., Patricia, R. M., Leonard, P. A., & Shannon, C. S. (2009). The prevalence of clinically relevant incidental findings on chest computed tomographic angiograms ordered to diagnose pulmonary embolism. *Archives of Internal Medicine*, *169*(21), 1961. https://doi.org/10.1001/archinternmed.2009.360

Eberhardt, S. C., Strickland, C. D., & Epstein, K. N. (2016). Radiology of Epiploic appendages: Acute appendagitis, post-infarcted appendages, and imaging natural history. *Abdominal Radiology*, *41*(8), 1653–1665. https://doi.org/10.1007/s00261-016-0757-0

Zaki-Metias, K. M., MacLean, J. J., Satei, A. M., Medvedev, S., Wang, H., Zarour, C. C., & Arpasi, P. J. (2023). The find program: Improving follow-up of incidental imaging findings. *Journal of Digital Imaging*. https://doi.org/10.1007/s10278-023-00780-6

Wang, G., Lau, E. W., Shakher, R., Rischin, D., Ware, R. E., Hong, E., Binns, D. S., Hogg, A., Drummond, E., & Hicks, R. J. (2007). How do oncologists deal with incidental abnormalities on whole-body fluorine-18 fluorodeoxyglucose PET/CT?. *Cancer*, *109*(1), 117–124. https://doi.org/10.1002/cncr.22370

Paluska, T. R., Sise, M. J., Sack, D. I., Sise, C. B., Egan, M. C., & Biondi, M. (2007). Incidental CT findings in trauma patients: incidence and implications for care of the injured. *The Journal of trauma*, *62*(1), 157–161. https://doi.org/10.1097/01.ta.0000249129.63550.cc

Vierikko, T., Järvenpää, R., Autti, T., Oksa, P., Huuskonen, M., Kaleva, S., Laurikka, J., Kajander, S., Paakkola, K., Saarelainen, S., Salomaa, E. R., Tossavainen, A., Tukiainen, P., Uitti, J., & Vehmas, T. (2007). Chest CT screening of asbestos-exposed workers: lung lesions and incidental findings. *The European respiratory journal*, *29*(1), 78–84. https://doi.org/10.1183/09031936.00073606

Even-Sapir, E., Lerman, H., Gutman, M., Lievshitz, G., Zuriel, L., Polliack, A., Inbar, M., & Metser, U. (2006). The presentation of malignant tumours and pre-malignant lesions incidentally found on PET-CT. *European journal of nuclear medicine and molecular imaging*, *33*(5), 541–552. https://doi.org/10.1007/s00259-005-0056-4

Weber, F., & Knopf, H. (2006). Incidental findings in magnetic resonance imaging of the brains of healthy young men. *Journal of the neurological sciences*, *240*(1-2), 81–84. https://doi.org/10.1016/j.jns.2005.09.008

Ishimori, T., Patel, P. V., & Wahl, R. L. (2005). Detection of unexpected additional primary malignancies with PET/CT. *Journal of nuclear medicine : official publication, Society of Nuclear Medicine*, *46*(5), 752–757.

Majumdar, S. R., Kim, N., Colman, I., Chahal, A. M., Raymond, G., Jen, H., Siminoski, K. G., Hanley, D. A., & Rowe, B. H. (2005). Incidental vertebral fractures discovered with chest radiography in the emergency department: prevalence, recognition, and osteoporosis management in a cohort of elderly patients. *Archives of internal medicine*, *165*(8), 905–909. https://doi.org/10.1001/archinte.165.8.905

Kang, H. W., No, J. H., Chung, J. H., Min, Y. K., Lee, M. S., Lee, M. K., Yang, J. H., & Kim, K. W. (2004). Prevalence, clinical and ultrasonographic characteristics of thyroid incidentalomas. *Thyroid : official journal of the American Thyroid Association*, *14*(1), 29–33. https://doi.org/10.1089/105072504322783812

Fitzgerald, T. L., Smith, A. J., Ryan, M., Atri, M., Wright, F. C., Law, C. H., & Hanna, S. S. (2003). Surgical treatment of incidentally identified pancreatic masses. *Canadian journal of surgery. Journal canadien de chirurgie*, *46*(6), 413–418.

Brown, J., Smith, R. C., & Lee, C. H. (2001). Incidental enhancing lesions found on MR imaging of the breast. *AJR. American journal of roentgenology*, *176*(5), 1249–1254. https://doi.org/10.2214/ajr.176.5.1761249

Messersmith, W. A., Brown, D. F., & Barry, M. J. (2001). The prevalence and implications of incidental findings on ED abdominal CT scans. *The American journal of emergency medicine*, *19*(6), 479–481. https://doi.org/10.1053/ajem.2001.27137

Weder, W., Schmid, R. A., Bruchhaus, H., Hillinger, S., von Schulthess, G. K., & Steinert, H. C. (1998). Detection of extrathoracic metastases by positron emission tomography in lung cancer. *The Annals of thoracic surgery*, *66*(3), 886–893. https://doi.org/10.1016/s0003-4975(98)00675-4

Lumbreras, B., Donat, L., & Hernández-Aguado, I. (2010). Incidental findings in imaging diagnostic tests: A systematic review. *The British Journal of Radiology*, *83*(988), 276–289. https://doi.org/10.1259/bjr/98067945

Aaronson, E. L., Quinn, G. R., Wong, C. I., Murray, A. M., Petty, C. R., Einbinder, J., & Schiff, G. D. (2019). Missed diagnosis of cancer in primary care: Insights from malpractice claims data. *Journal of Healthcare Risk Management*, *39*(2), 19–29. https://doi.org/10.1002/jhrm.21385

Farjah, F., Monsell, S. E., Gould, M. K., Smith-Bindman, R., Banegas, M. P., Heagerty, P. J., Keast, E. M., Ramaprasan, A., Schoen, K., Brewer, E. G., Greenlee, R. T., & Buist, D. S. (2021). Association of the intensity of diagnostic evaluation with outcomes in incidentally detected lung nodules. *JAMA Internal Medicine*, *181*(4), 480. https://doi.org/10.1001/jamainternmed.2020.8250

Silverman, S. G., Israel, G. M., Herts, B. R., & Richie, J. P. (2008). Management of the incidental renal mass. *Radiology*, *249*(1), 16–31. https://doi.org/10.1148/radiol.2491070783

Fowler, K. J., Brown, J. J., & Narra, V. R. (2011). Magnetic resonance imaging of focal liver lesions: Approach to imaging diagnosis. *Hepatology*, *54*(6), 2227–2237. https://doi.org/10.1002/hep.24679

Baron, R. (2006). *Characterisation of liver masses*. The Radiology Assistant : Characterisation of liver masses. https://radiologyassistant.nl/abdomen/liver/characterisation-of-liver-masses

Kang, H. W., No, J. H., Chung, J. H., Min, Y. K., Lee, M., Lee, M., … & Kim, K. S. (2004). Prevalence, Clinical and Ultrasonographic Characteristics Of Thyroid Incidentalomas. Thyroid, 1(14), 29-33. https://doi.org/10.1089/105072504322783812

Gregory, A., Bayat, M., Kumar, V., Denis, M., Kim, B., Webb, J. S., … & Alizad, A. (2018). Differentiation Of Benign and Malignant Thyroid Nodules By Using Comb-push Ultrasound Shear Elastography. Academic Radiology, 11(25), 1388-1397. https://doi.org/10.1016/j.acra.2018.02.025

Roseland, M. E., Dewaraja, Y. K., Wong, K. S. (2022). Advanced Imaging and Theranostics In Thyroid Cancer. Current Opinion in Endocrinology, Diabetes &Amp; Obesity, 5(29), 456-465. https://doi.org/10.1097/med.0000000000000740

Sarker, S. K. (2020). Legal &Amp; Ethical Dilemmas In Incidental Findings During Surgery: Review Article. International Journal of Surgery, (75), 107-113. https://doi.org/10.1016/j.ijsu.2020.01.141

Booth, T. C., Boyd-Ellison, J. M. (2015). The Current Impact Of Incidental Findings Found During Neuroimaging On Neurologists' Workloads. PLoS ONE, 2(10), e0118155. https://doi.org/10.1371/journal.pone.0118155

Booth, T. C., Jackson, A., Wardlaw, J. M., Taylor, S. A., Waldman, A. D. (2010). Incidental Findings Found In "Healthy" Volunteers During Imaging Performed For Research: Current Legal and Ethical Implications. BJR, 990(83), 456-465. https://doi.org/10.1259/bjr/15877332

Trivedi, G., Dadashzadeh, E., Handzel, R., Chapman, W., Visweswaran, S., & Hochheiser, H. (2019). Interactive NLP in clinical care: Identifying incidental findings in Radiology reports. *Applied Clinical Informatics*, *10*(04), 655–669. https://doi.org/10.1055/s-0039-1695791

Dutta, S., Long, W. J., Brown, D. F. M., & Reisner, A. T. (2013). Automated Detection Using Natural Language Processing of radiologists' recommendations for additional imaging of incidental findings. *Annals of Emergency Medicine*, *62*(2), 162–169. https://doi.org/10.1016/j.annemergmed.2013.02.001

Koplin, J. J., Turner, M. R., & Savulescu, J. (2020). The duty to look for incidental findings in Imaging Research. *Ethics & Human Research*, *42*(2), 2–12. https://doi.org/10.1002/eahr.500043

O'Sullivan, J. W., Muntinga, T., Grigg, S., & Ioannidis, J. P. (2018). Prevalence and outcomes of incidental imaging findings: Umbrella Review. *BMJ*. https://doi.org/10.1136/bmj.k2387

About Us. Leiden University. (n.d.). https://www.universiteitleiden.nl/en/about-us

Management and organization. LUMC. (n.d.). https://www.lumc.nl/en/about-lumc/het-lumc/management-and-organization/

French, D., Southworth, J., Howell, A., Harvie, M., Stavrinos, P., Watterson, D., … & Evans, D. (2018). Psychological Impact Of Providing Women With Personalised 10-year Breast Cancer Risk Estimates. Br J Cancer, 12(118), 1648-1657. https://doi.org/10.1038/s41416-018-0069-y

Adams, S., Rakheja, R., Bryce, R., Babyn, P. (2018). Incidence and Economic Impact Of Incidental Findings On 18f-fdg Pet/ct Imaging. Can Assoc Radiol J, 1(69), 63-70. https://doi.org/10.1016/j.carj.2017.08.001

Beatty, J., Williams, H. T., Gucwa, A. L., Hughes, M., Vasudeva, V. S., Aldridge, B. A., … & McLoughlin, J. M. (2009). The Predictive Value Of Incidental Pet/ct Findings Suspicious For Breast Cancer In Women With Non-breast Malignancies. The American Journal of Surgery, 4(198), 495-499. https://doi.org/10.1016/j.amjsurg.2009.06.009

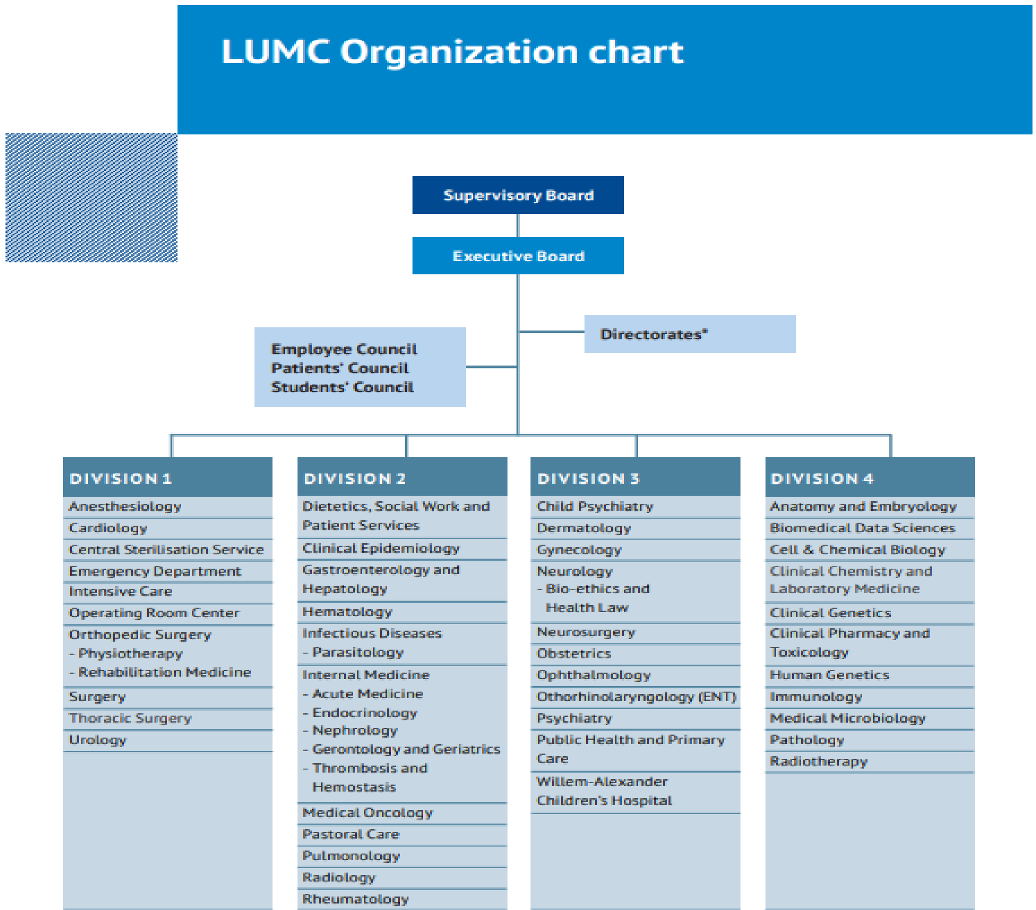
Alduk, A.M., Prutki, M. and Stern-Padovan, R. (2015) 'Incidental extra-mammary findings in breast MRI', *Clinical Radiology*, 70(5), pp. 523–527. doi:10.1016/j.crad.2015.01.003.

Whiting, P., Rutjes, A. W. S., Reitsma, J. B., Bossuyt, P. M., Kleijnen, J. (2003). The Development Of Quadas: a Tool For The Quality Assessment Of Studies Of Diagnostic Accuracy Included In Systematic Reviews. BMC Med Res Methodol, 1(3). https://doi.org/10.1186/1471-2288-3-25

García, S., Ramírez-Gallego, S., Luengo, J., Benítez, J. M., Herrera, F. (2016). Big Data Preprocessing: Methods and Prospects. Big Data Anal, 1(1). https://doi.org/10.1186/s41044-016-0014-0

Luengo, J., García, S., Herrera, F. (2011). On the Choice Of The Best Imputation Methods For Missing Values Considering Three Groups Of Classification Methods. Knowl Inf Syst, 1(32), 77-108. https://doi.org/10.1007/s10115-011-0424-2

Appendix



(https://www.lumc.nl/siteassets/over-het-lumc/het-lumc/bestuur-en-organisatie/bestanden/download-the-lumc-organizational-chart-english.pdf)