An Investigation into the Use of CDS to Improve the Appropriateness of Ordering of Specialist Radiological Examinations

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Declaration

I declare that the work described in this dissertation is, except where otherwise stated, entirely my own work, and has not been submitted as an exercise for a degree at this or any other university.

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Abstract

CTPA scans are the most readily available and most utilised of all specialist radiological imaging techniques in the investigation of PE. Given the non-specific presentation of patients, the yield values are relatively low. Studies found a variation in yields from 10% to 20% in some imaging centres. CTPA examinations are time-consuming and incur a high dose of ionising radiation to patients, as well as the administration of a potentially nephrotoxic contrast.

Literature notes that the utilisation of CDS is more beneficial than no CDS by providing vital information and reducing the requisition of inappropriate examinations. Ideally, a CDS system will incorporate patient-specific data from a central patient record without requiring the ordering physician to fetch the data themselves. The system should encourage best practice and provide feedback and targeted education to system users.

As the frequency of radiology ordering increases, the requirement to limit inappropriate ordering is critical. The study will evaluate the potential of CDS systems in reducing inappropriate ordering of radiology examinations, in particular, CTPA studies

The main objective of the study is to answer the research question *'Has the use of CDS improved the appropriateness of radiology ordering of CTPA examinations for the diagnosis of PE?'* The results will primarily focus on the yield.

An evaluation of 860 individual CTPA examinations was performed over the course of 10 selected months pre and post-CDS. The selected study months span 48 months surrounding the date of CDS implementation – November 2013. The presence of PE was assessed for each individual CTPA examination included in the study. This allowed for the calculation of yield as well as Z-scores to determine a statistical significance value. The findings were sub-divided into all patients, all IP

locations, all ED patient locations as well as regular intervals around November 2013 for a thorough evaluation of findings.

The results provided displayed an overall tortuous variance of yield values over the course of the study. Overall, the yield values were found to decline from 18.09% (n=72) pre-CDS to 16.67% (n=77) post-CDS. This represents a statistically insignificant decrease of 1.42% post-CDS,

Overall, the study provided a thorough knowledge of CDS systems, including their successes, faults and areas for improvement. Recommendations are made and further system evaluations are required to understand fully the potential of CDS system usage. Whilst the findings of the CDS implementation were not found to be statistically significant in this case, it did allow for the inclusion of critical information on CTPA orders at the time of ordering. This allows for a real-time evaluation of requests to determine their suitability based on the pertinent information provided. This high quality data is imperative to patient care.

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Abbreviations

AC	Acceptance Criteria
ACEP	American College of Emergency Physicians
ACR	American College of Radiology
CDS	Clinical Decision Support
COPD	Chronic Obstructive Pulmonary Disease
CPOE	Computerised Physician Order Entry
CT	Computed Tomography
CTPA	Computed Tomography Pulmonary Angiogram
CTPH	Chronic Thromboembolic Pulmonary Hypertension
CXR	Chest X-Ray
DVT	Deep Vein Thrombosis
ED	Emergency Department
ESR	European Society of Radiology
EU	European Union
HIQA	Health Information and Quality Authority
HIS	Hospital Information System
HSE	Health Service Executive
IP	Inpatient
IT	Information Technology
MRI	Magnetic Resonance Imaging
MTBI	Mild Traumatic Brain Injury
NDSC	National Decision Support Company
NM	Nuclear Medicine
OCS	Order Comunication System
OP	Outpatient
PE	Pulmonary Embolism
PERC	Pulmonary Embolism Rule-out Criteria
PTP	Pre-test Probability
RCR	Royal College of Radiologists
RIETE	Registro Informatizado de Enfermedad TromboEmbólica
RIS	Radiology Information System
RSNA	Radiological Society of North America
TTD	Time To Diagnosis
US	Ultrasound
USA	United States of America
VQ	Ventilation-Perfusion
VTE	Venous Thromboembolisation

Glossary

Appropriateness: Measured based on the yield of the exam. Higher yields indicate higher levels of appropriate CTPA ordering. Also based on the provision of suitable and relevant clinical indications provided and adherence to the RCR Guidelines.

CDS: Clinical decision support is an integrated system to aid in decision-making processes by linking observations with knowledge, thus improving healthcare. It is incorporated into CPOE systems.

CPOE: Computerised physician order entry is an electronic system used to place orders. In this case, it refers to radiological ordering, in particular, CTPA examinations.

CTPA: Computed tomography pulmonary angiogram is a type of CT scan performed to look at the pulmonary vascular system. It involves the acquisition of a serious of cross-sectional images using ionising radiation. These are acquired following an intravenous injection of iodinated contrast to enhance the image and to ensure visualisation of filling defects caused by the presence of a pulmonary embolism (PE).

D-dimer: Blood test indicating the presence of an inappropriate blood clot, as found in cases of PE or DVT.

Occlusion: Blockage of a blood vessel.

PE: Pulmonary embolism refers to a thrombus or blockage that causes an occlusion, thus preventing blood flow.

Thrombus: A blood clot.

Wells Score: A clinical prediction rule that risk stratifies a patient for the likelihood of PE. It comprises of a scoring system based on certain clinical indications that

have a pre-determined value. The results can range from 0 (low risk) to 12.5 (high risk)

Yield: Refers to the proportion, as a percentage, of positive PE findings on CTPA examinations.

Chapter 1: Introduction

This chapter provides a brief overview of the dissertation. Topics included will cover the background to the research, research question and objectives, motivation, study scope as well as an overview of the dissertation contents. The author will outline the significance of the research topic, as compared with findings from national and international literature sources.

1.1 Introduction

The focus of this dissertation is to observe the use of clinical decision support (CDS) within radiology ordering systems. A focus will be placed on its use when ordering computed tomography pulmonary angiogram (CTPA) examinations for the diagnosis of pulmonary embolism (PE). The appropriateness of the order is based on the yield. It is assumed that the orders are more appropriate if the yield is found to increase post-CDS. The appropriateness of the order will also be determined by the inclusion of relevant necessary and accurate clinical information, such as Wells Score values on the order form. All terms are outlined within the glossary of terms.

Evidence-based medicine is pertinent to the adherence of best practice guidelines. Many barriers, as discussed in Chapter 2, must be overcome to adopt best-practice guidelines and procedures. CDS is well documented as being imperative to the success of ordering systems. CDS can ensure all necessary clinical information and indications are included on the examination request in order for the radiology department to approve the performance of the examination. It also allows for a reduction in errors and time saving by providing accurate, real-time information as and when required. (Bates et al. 2003, Melnick et al. 2010). den Exter et al. (2014) state that the implementation of any form of CDS is more beneficial than no CDS use.

Throughout the dissertation, the term 'order' is used interchangeably with the term 'request' in the context of radiology or CTPA examinations.

1.2 Background

When compared to other radiological methods of diagnosing PE, such as nuclear medicine perfusion (VQ) examinations, CTPA scans are the most readily available and most utilised of all specialist radiological imaging techniques. Studies have found a variation in yields from 10% to 20% in some imaging centres. The yield refers to the proportion of CTPA examinations found to be positive for the presence of PE. Those at the lower end are indicative of certain overuse of CTPA examinations (den Exter et al. 2014, Drescher et al. 2011).

It is important to monitor and evaluate the effects and outcomes of a CDS implementation. This is carried out to ensure that the implementation of CDS is performing to the best of its abilities (Bates et al. 2003). For the reasons outlined below, it is critical that the performance of CTPA examinations is monitored and controlled.

There are many contraindications to the performance of CTPA examinations. The time-consuming examination incurs a high dose of ionising radiation to patients, as well as the administration of a potentially nephrotoxic contrast. For these reasons alone, the examination may be unsuitable for a small number of patients. The benefits, however, may outweigh the risks involved and prove clinically warranted and necessary for diagnosis (Bokobza et al. 2014, den Exter et al. 2014, Drescher et al. 2011).

As noted already, any CDS is better than no CDS. Ideally, a CDS system will incorporate patient-specific data from a central patient record without requiring the ordering physician to fetch the data themselves. It is important that the process is made as manageable as possible whilst maintaining ultimate appropriateness. The system should encourage best practice and provide feedback

and targeted education to system users. Alternatives should be suggested when the requested examination is not deemed suitable so as to discourage the physician from ordering an inappropriate examination (Bates et al. 2003, Miller et al. 2005).

1.3 Research Question & Objective

The research question is as follows:

'Has the use of CDS improved the appropriateness of radiology ordering of CTPA examinations for the diagnosis of PE?'

For the purpose of this research topic, a focus will be placed on the ordering of computed tomography pulmonary angiogram (CTPA) examinations in the diagnosis of a pulmonary embolism (PE) or emboli (pleural). The research aims to analyse the appropriateness of CTPA orders since the implementation of the clinical decision support (CDS) intervention within the radiology ordering system. The results will primarily focus on the yield. This refers to the number of CTPA examinations that were found to be positive for the presence of PE, as described in Chapter 4. An investigation will also be carried out into the statistical significance of the findings pre and post-CDS implementation. This is further elaborated in Chapter 5.

1.4 Motivation

As the frequency of radiology ordering increases, the requirement to limit inappropriate ordering is critical. The study will evaluate the potential of CDS systems in reducing inappropriate ordering of radiology examinations, in particular, CTPA studies (Carnevale et al. 2015, Moriarity et al. 2015, Sistrom et al. 2009).

The study hospital in question introduced a CDS system into the electronic radiology ordering system in 2011. It had yet to be analysed thoroughly to compare the appropriateness of CTPA ordering pre and post-CDS implementation. This study analyses 10 selected months pre and post-CDS in an attempt to answer the research question, as mentioned in section 1.3. The selected months are outlined below in section 1.5.

It is hoped that by evaluating the CDS system, a greater understanding of its effectiveness will be revealed. The study will determine whether the CDS implementation was successful based on the yield post-CDS, as compared to the yield pre-CDS, and the quality of data provided, as outlined in Chapters 4 and 5.

1.5 Scope

The research was carried out in a single hospital location. This is a busy Dublin teaching hospital comprising of an acute Emergency Department (ED) as well as both Inpatient (IP) and Outpatient (OP) services. Study data will be analysed for the following 10 months surrounding the implementation of CDS (November 2013):

- May 2012 (18 months pre-CDS)
- December 2012 (12 months pre-CDS)
- May 2013 (6 months pre-CDS)
- August 2013 (3 months pre-CDS)
- October 2013 (1 month pre-CDS)
- December 2013 (1 month post-CDS)
- May 2014 (6 months post-CDS)
- December 2014 (12 months post-CDS)
- May 2015 (18 months post-CDS)
- December 2015 (24 months post-CDS)

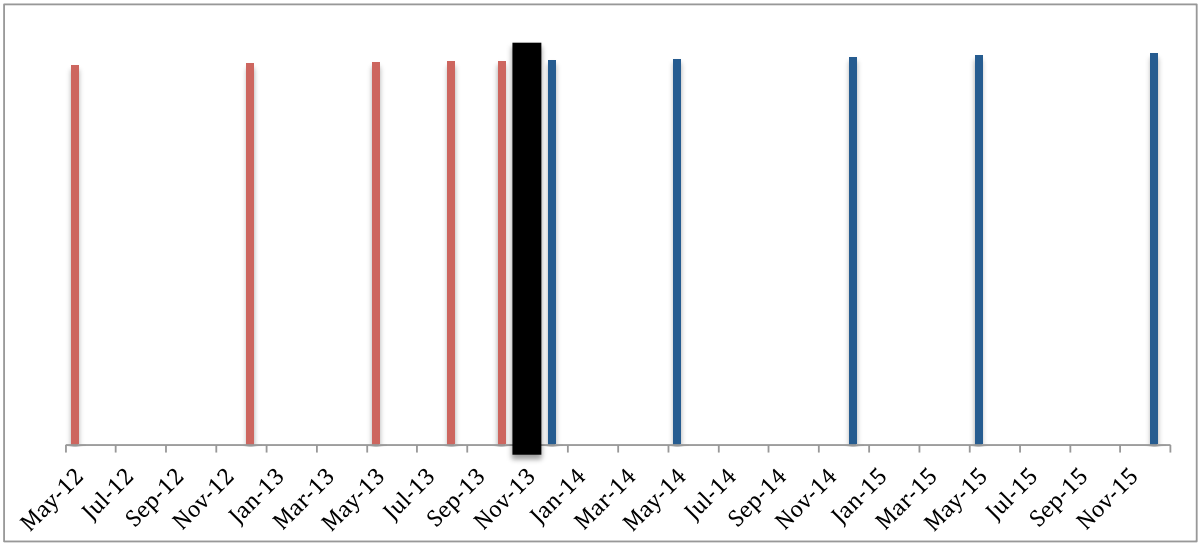

Figure 1.1 Selected CTPA study months for data analysis, with the thick vertical bar indicating the date of CDS implementation (November 2013)

Figure 1.1, above, indicates a well-distributed range of study months around the date of CDS implementation (November 2013). The total study is distributed over the course of 42 months.

Study data is also analysed collectively for the months mentioned above pre & post-CDS implementation. This is also further sub-categorised into ED patient locations and IP patient locations pre & post-CDS.

1.6 Dissertation Overview

The thesis comprises of 6 chapters outlined as follows:

- *Chapter 1: Introduction* – This will provide a brief introduction the objectives and content of the research topic.
- *Chapter 2: Literature Review* – This will provide an extensive background knowledge and understanding of all aspects of the study. It contains up-to-date references and studies surrounding the research topic to provide the

reader with a basis for the research topic. Relevant literature from both national and international sources has been selected.

- *Chapter 3: Methodology* – This section aims to provide an understanding of the research approach taken.
- *Chapter 4: Results* – Results are displayed in both written and graphical form.
- *Chapter 5: Data Analysis and Discussion* – A quantitative analysis of the study is provided in this chapter. A thorough analysis of findings is also discussed in this section. It aims to provide a thorough understanding of the research outcomes.
- *Chapter 6: Conclusion* – The final chapter of the dissertation aims to provide an overview of the research. This will include recommendations and further work.

1.7 Conclusion

By analysing data thoroughly, the study aims to provide an answer to the research question '*Has the use of CDS improved the appropriateness of radiology ordering of CTPA examinations for the diagnosis of PE?*' It will also provide thorough background knowledge on and surrounding the subject including the importance of the investigation. All results are conveyed in a concise graphical format for ease of interpretation. Results are thoroughly evaluated and significance levels are calculated. This will provide a definitive answer as to whether or not a statistical difference in the yield values was seen between CTPA examinations pre and post-CDS implementation, therefore determining the appropriateness of the CDS intervention. Data quality and accuracy will also be observed.

Chapter 2: Literature Review

2.1 Introduction

This chapter will provide an extensive analysis of literature sources surrounding the research topic – the use of clinical decision support (CDS) to improve the appropriateness of specialist radiology ordering. It aims to provide an understanding of the importance of the research topic, as well as proving background information and knowledge. The importance of the topic areas is apparent throughout this chapter, with a focus on CDS, CTPA examinations, PE yield values and radiology ordering systems. Clinical decision support forms the basis of the research. Its use and importance are outlined throughout this chapter, with an emphasis on its use in radiology ordering systems for CTPA examinations to confirm or out-rule the presence of PE. The importance of the research topic is apparent due to an increased demand for imaging services and the requirement of a clinically justified examination. The overall aim is to assess the potential of CDS systems to reduce inappropriate ordering of radiology examinations, in particular, CTPA studies (Carnevale et al. 2015, Moriarity et al. 2015, Sistrom et al. 2009).

Given the authors knowledge of CTPA ordering, as well as CDS and PE, a foundation of search terms formed with the research question in mind. An extensive and thorough search of the literature was carried out. Additional ideas and thoughts were discovered as a result. This aided in the completion of an extensive collection of literature sources. A reflection of the reviewed literature was performed and documented.

By searching PubMed, Science Direct, SpringerLink Web of Science, Trinity College Dublin library sources and other online databases, a comprehensive review of the literature surrounding the topic area was performed. The search keywords included: CTPA; PE; CDS; CPOE; Yield; Wells Score criteria; Geneva score; appropriateness of radiology ordering; diagnosis of PE; D-dimer; PERC; evidence-

based criteria; ACR; RCR; radiology standards; radiology ordering; radiology practice guidelines; ESR; data entry. The literature searches often returned many results. To ensure specificity, combinations of terms were included in the search process. These included: PE Yield; CDS radiology ordering; PE guidelines; diagnosis of PE evidence-based practice. These were culled according to appropriateness to the research topic and to include information-rich resources by a reputable source.

A systematic approach was adopted when searching databases, concentrating on one subsection at a time. Each section was divided into the following groups to categorise the information: CDS; CTPA; PE; Ireland, EU and International standards; other. These topics were pre-selected given a prior knowledge surrounding the research area. Quite often, there was overlapping information between subsections within literature. With a superfluous amount of information sources, it was important to limit the number of pieces chosen for review to just those found to be most appropriate and most relevant and current to the topic at hand. A total number of 79 literature sources comprising of journal articles, official guideline documents, books and other printed and electronically sourced documentation were appropriate for use throughout the dissertation.

This chapter aims to provide the reader with an understanding of the use of clinical decision support (CDS) and its current uses within radiology ordering systems, particularly when ordering specialist radiology studies such as CT and MRI – this is elaborated on later in this chapter. Close attention is directed at the use of CDS in the ordering of computed tomography pulmonary angiogram (CTPA) examinations to diagnose the presence of a pulmonary embolism (PE). Emphasis is placed on the topics of PE, CTPA, CDS, current standards and guidelines. The validity and high quality of the information gathered and its relevance to the research question remains paramount throughout the research.

2.2 PE and Diagnosis

An extensive search of the literature was performed on the topic of Pulmonary Embolism (PE) as well as surrounding subjects relating to PE. These are outlined below and broken down into subsections to describe the importance and relevance to the research questions. With a primary focus on PE, this section will provide a comprehensive review and understanding of the risks involved, urgency of diagnosis, clinical presentation, diagnosis, Wells scoring, D-dimer assay testing, PERC, treatment of PE and CTPA examinations.

Mos et al. (2014) combined the Wells criteria scoring with D-dimer testing and computed tomography pulmonary angiogram (CTPA) examinations in a multi-centre study to identify a simple diagnostic approach when assessing for the presence of acute recurrent PE. By evaluating Wells criteria scoring together with D-dimer assay results, the requirement for CTPA imaging can be safely assessed. It is confirmed that normal Wells criteria scoring, normal D-dimer assays and unlikely clinical suspicion of PE can safely rule out the presence of PE without the need for diagnostic imaging. This was also noted in a large majority of patients with a history of PE. This clearly conveys the importance of providing pertinent information when requesting CTPA studies to assess the appropriateness of the order for the clinical concern in question, thus increasing the yield of CTPA studies (Mos et al. 2014).

2.2.1 Radiology Guidelines

The appropriate use of radiology imaging is pertinent to patients and staff alike. HIQA (2012) have thoroughly and extensively developed national standards that aim to improve the deliverance of healthcare services in Ireland. This was enabled by reviewing national and international standards, engaging in key stakeholder deliberation, and by forming an expert advisory group. The overall aim of these standards is to allow for the best use of available resources. One process of great

importance is the requirement for precise and apparent processes of decision-making and referral pathways (HIQA 2012).

Bairstow et al. (2006) exemplify the importance of defining imaging pathways to ensure the appropriateness of radiological imaging. They discuss the development as well as the deliverance and evaluation of such. The importance of the education of requesting physicians is highlighted as a key area to improving the appropriateness of radiology ordering. As seen in other studies mentioned previously, suggestions are made to further integrate CDS and electronic patient records to achieve greater success (Bairstow et al. 2006).

The RCR guidelines (2012) outline the recommended referral pathway for a patient with a suspected PE. As demonstrated in Appendix B, it describes a CTPA as being indicated whereby clinical suspicion is high, as per clinical judgement. It is also recommended when a patient presents with a positive D-dimer assay result, even though the pre-test probability of PE is low or moderate. The latest version of the RCR guidelines (2012) also recommends the completion of a chest radiograph in all cases to exclude any other chest pathology that may have resulted in the patient's clinical presentation. Recommendations are made to use a locally agreed protocol that should incorporate clinical presentation, pre-test probability scores, D-dimer assay results in an attempt to improve the appropriateness of imaging resources, particularly ionising imaging such as CTPA studies. The guidelines also state that when a patient presents with a well's score of ≤6 requires a D-dimer assay before imaging is carried out (RCR 2012).

2.2.2 PE Treatment

Treatment of PE includes both long-term and short-term actions. These include careful monitoring of patients, the administration of anticoagulant therapy as well as a more invasive procedure of thrombectomy whereby the thrombus is mechanically broken down and removed. Anticoagulants are administered intravenously to prevent and break down the coagulation of blood cells.

Coagulation of blood cells refers to a thrombosis that may fully or partially block a blood vessel, such as a vein or an artery. A course of anticoagulant therapy is recommended for 3 months, or possibly longer if warranted, following the diagnosis of PE (Cohen et al. 2014, den Exter et al. 2014).

2.2.3 Morbidity/Mortality/Risks

Pulmonary Embolism (PE) represents 5-10% of all hospitalised patient deaths annually. It is recognised as being the leading cause of preventable death for in-patients. The non-specific nature of the clinical presentation of a PE guarantees a challenging diagnosis process for medical staff. A yield of just 15-30% of suspected cases are confirmed as positive for the presence of a PE (Posadas-Martínez et al. 2014, Singh et al. 2012). den Exter et al. (2014) provide evidence that an acute PE is present in 0.1-0.2% of adults annually – proving fatal for roughly 10% of whom within 30 days. Approximately 300,000 deaths occur annually due to PE in Europe – many of which fail to be diagnosed (Cohen et al. 2014).

Given such high fatality rates and preventability, the requirement of accurate diagnosis of PE is of paramount importance within healthcare. The diagnosis is arduous and labour intensive, involving the collection of multiple clinical risk calculations, specialist examinations and resources of high demand (Cohen et al. 2014, Posadas-Martínez et al. 2014). Many complications exist in the presence of PE. One such complication, albeit uncommon, is chronic thromboembolic pulmonary hypertension (CTPH). This disorder often manifests in the years following the occurrence of PE and has a fatality rate of 20% within 5 years. Other non-fatal complications, such as post-thrombotic syndrome, can have adverse effects on a patient's quality of life (Cohen et al. 2014).

Size of embolus, cardiopulmonary reserve, and degree of occlusion on pulmonary circulation contribute towards the clinical severity of PE on a particular patient. These must also be used in conjunction with clinical risk scales to assess the probability of mortality. Treatment and diagnosis at early stages is of paramount

importance to counteract the risk of premature mortality as a result of PE (Cohen et al. 2014).

2.2.4 Clinical Presentation of PE

The heterogeneous presentation of PE is often non-specific and therefore difficult to diagnose or predict based on clinical presentation alone. The presenting symptoms can often be suspicious for a multitude of cardiothoracic disorders. The yield of positive PE diagnoses is resultantly small in this cohort of patients (den Exter et al. 2014). 30% of all PE diagnoses are without known cause (Cohen et al. 2014). The United States sees in excess of 10 million presentations of potential PE assessments annually (Bokobza et al. 2014). This places an enormous strain on the healthcare systems globally as a demand for services is increased (Bokobza et al. 2014, Cohen et al. 2014, den Exter et al. 2014).

Five common presentations, as outlined by Cohen et al. (2014), of PE are outlined below:

1. Sudden death: A 1-day survival rate of 64% and a 7-day survival rate of 59% exist following PE. This is significantly higher in patients who are 1-day post deep vein thrombosis (DVT) at 97%. DVT consists of a blockage caused by a blood thrombus in a vein, usually from a peripheral vein such as those found in the lower limbs.
2. Typical presentation: Dyspnoea, pleuritic chest pain, tachypnoea, tachycardia, and syncope are common symptoms of PE. 90% patients present with at least one or a combination of these symptoms. Studies have found PE cases also show signs of DVT when compared to unconfirmed PE cases.
3. Atypical presentation: Several studies found atypical presentations such as a cough, pleuritic and retrosternal chest pain, wheezing, and haemoptysis were present in up to 59% of PE cases. Cyanosis found in 11% of cases and fever in 7% of cases.

4. Incidental findings upon CT scanning: Due to the increased sensitivity of scanning techniques coupled with the increased usage of such, more incidental findings of PE are presenting. These are mostly non-significant and non-life threatening. They are usually diagnosed when cardiothoracic or oncology patients present for routine thoracic imaging without suspicion for PE.
5. Asymptomatic presentation following DVT diagnosis: The international Registro Informatizado de Enfermedad TromboEmbólica (RIETE) registry assessed 2375 proximal lower-limb DVT patients and revealed that 35% also had asymptomatic PE.

As the differentiation between diagnosing PE or other cardiothoracic complications is extremely difficult, an increased demand is being placed on clinical assessment rules and risk scores in combination with a physician's own professional judgement. It is suggested that clinical decision rules are introduced to assist in diagnosis, thus improving the standardisation in the diagnostic approach within hospitals and relieving the pressure on valuable resources (den Exter et al. 2014).

2.2.5 Diagnosis

It is well known and much feared by physicians that the clinical presentation of acute PE could be nonspecific and heterogeneous in nature. Thus making it more difficult to establish a clinical diagnosis (den Exter et al. 2014).

The timing of PE diagnosis and treatment is critical to patient care and recovery (Bokobza et al. 2014). Bach et al. (2016) analysed factors relating to time delays between Emergency Department (ED) admission and PE diagnosis. 241 PE symptomatic patients were chosen for the study. Tachycardia and a high embolus concern resulted in the shortest time to diagnosis (TTD). The greatest delays were seen mostly with older patients who presented with low embolus concern and underlying chronic obstructive pulmonary disease (COPD) (Bach et al. 2016).

Depending on the pre-test probability (PTP) of PE, it is recommended that validated risk assessment and pre-defined criteria (for example, the Wells criteria – see next section) are included in the assessment of a patient with suspected PE (Bokobza et al. 2014, Cohen et al. 2014, den Exter et al. 2014, Moores et al. 2004). As mentioned previously, clinical judgement must contribute to the decision-making processes. It has been shown that the presence of DVT coupled with a clinician's suspicion that PE is the most likely diagnosis, mostly results in a positive PE finding (Wells et al. 2000).

Symptoms suggestive of PE may be investigated through the use of easily accessible and non-invasive methods. These include a chest x-ray (CXR), lab testing for arterial blood gases, ultrasonography of peripheral veins to assess for DVT, D-dimer assay, as well as pre-test probability (PTP) and nuclear medicine ventilation–perfusion (VQ) scintigraphy studies. However, the results may lack specificity and sensitivity for PE and these tests can be time consuming (Cohen et al. 2014). In keeping with time constraints, guidelines recommend that anticoagulation therapy commences upon suspicion of PE, regardless of a diagnostic conclusion at the time (Cohen et al. 2014, den Exter et al. 2014). Overutilisation of these resources is apparent due to the risk of missing a diagnosis. This is further discussed in section 2.5.2.

Clinical probability scores are paramount for deriving clinical conclusions and planning treatment. Many common algorithms are used in medical practice to interpret symptoms. These can often provide peace of mind that they reach a reasonable conclusion based on well-established diagnostic algorithms. The most popular diagnostic algorithm for PE is the Wells Score (Cohen et al. 2014, Posadas-Martínez et al. 2014). RCR (2012) guidelines also recommend utilising the Wells Score criteria in the in the diagnosis of PE. Its main use, in combination with a D-dimer assay result, is to prevent unnecessary radiological imaging in the diagnosis of PE, primarily the performance of CTPA examinations. Posadas-Martínez et al. (2014) also found that ultrasound (US) of the lower limbs to rule out deep vein thrombosis (DVT) resulted in a 15% decrease in the use of CTPA. A powerful point

was made that the Wells Score in isolation cannot be used to rule out the presence PE (Posadas-Martínez et al. 2014).

2.2.5.1 Wells Criteria

A review by Posadas-Martínez et al. (2014) found that the specificity of the Wells Score was 81% together with a negative predictive value of 43%. Wells criteria are easily applicable and allow for a simple risk stratification of probable PE patients (Moores et al. 2004).

The Royal College of Radiologists (RCR) guidelines (2012) outline how to calculate the Wells Score as follows:

- DVT Symptoms – 3 points
- Unlikelihood of differential diagnosis – 3 points
- Tachycardia (heart rate >100 beats per minute) – 1.5 points
- Prolonged immobilisation or recent surgery – 1.5 points
- History of DVT or PE – 1.5 point
- Haemoptysis (coughing of blood from below the level of the larynx) – 1 point
- Malignancy – 1 point

According to clinical prediction rules, the literature states that patients with a Wells Score of ≤4 are unlikely to have a PE. Patients who have a Wells Score of >4 are likely to have a PE present. It is also worth noting that the Wells Score is best applied to hospitalised patients and Emergency Department (ED) patients. It may also be used in a primary care setting however when a patient is suspected to have a PE, an urgent transfer to secondary care is essential given the acuity and the potential risk of immediate death. (Cohen et al. 2014, den Exter et al. 2014).

2.2.5.2 D-dimer Assay

D-dimer assays are frequently used in the diagnostic workup of PE due to their high sensitivity in detecting the presence of an acute venous thromboembolisation. The test involves obtaining a blood sample from the patient. The laboratory receives and evaluates the blood sample. Results return to the referring physician either electronically or as a hard copy on paper, ideally before a diagnostic decision made. Studies have suggested that patients who present with a high PTP are not suitable for D-dimer testing, in which case a CTPA should follow as standard given the patient's already high clinical probability. Additionally, false negative D-dimer assays can be present in approximately 9.3% of patients with a high PDP. D-dimer testing is recommended following a normal PTP. When a normal D-dimer assay is coupled with a normal PDP, CTPA is not recommended (Cohen et al. 2014).

Low specificity of D-dimer testing is a great disadvantage. The following, amongst others, may raise D-dimer results: infection and inflammation; recent surgery; recent trauma; renal deficiencies; oncological or malignant causes; cardiovascular disease; stroke; pregnancy. Many of these are already included in the criteria for Wells Score calculation (den Exter et al. 2014).

Efforts are continuous to increase the specificity of D-dimer testing. However, this currently requires further testing for validation purposes. Such efforts include determining thresholds according to age as D-dimer results increase with age. Studies have shown that a combination of age-related D-dimer thresholds and clinical suspicion can result in a definitive exclusion of PE (den Exter et al. 2014). As a result of this, PTP should always be performed before acting on D-dimer results (Posadas-Martínez et al. 2014).

2.2.5.3 PERC

The PE rule-out criteria (PERC) rule is a clinical decision rule used to assess patients with a low PTP. It can be used to avoid unnecessary radiological imaging for these patients. However, its adoption is limited, particularly in Europe whereby PE rates are high (Bokobza et al. 2014). Whilst not discouraging its use, the RCR (2012) does not currently recommend its use either. It is not known whether it is being used in Ireland at present.

Hugli et al. (2011) conducted an extensive study that argues against the safe use of the PERC rule to exclude the presence of PE when used in isolation of additional testing. Additional testing includes D-dimer testing and CTPA examinations. The PERC rule includes the following criteria. A patient is described as PERC negative if they meet all the following criteria, as outlined in Table 2.1, below (Hugli et al. 2011).

Table 2.1 PERC Rule (Hugli et al. 2011)

Age < 50 years
Pulse rate< 100 bpm
Blood saturations > 94%
No unilateral lower limb oedema
No haemoptysis
No recent surgery or trauma (within 4 weeks)
No prior DVT (deep vein thrombosis) or PE
No oral hormone use

Stojanovska et al. (2015) conducted a study in the ED environment to compare the modified Wells criteria with PERC in determining their effect on yield. The modified Wells (mWells) score is the Wells Score combined with D-dimer values. The study found that there was a higher yield of PE positive patients when the

PERC criteria were used, compared to the use of mWells criteria alone. A higher yield of 10% was seen when PERC was used, compared to an 8% yield when mWells criteria was used. The study concluded that the use of the PERC decision rule was an overall safer method of justifying CTPA examinations for the investigation of PE (Stojanovska et al. 2015). Bokobza et al. (2014) echo these findings in their study looking at the negative predictive values following the application of PERC in patients who underwent CTPA imaging. It found that radiological imaging 15% of patients could have been avoided if PERC were applied. It also found that 0.5% of patients were positive for the presence of PE whereby D-dimer results and PERC were normal, thus implying a 95% confidence interval (Bokobza et al. 2014). Here it remains evident that justification based on clinical judgement is maintained, as outlined in the previous section.

Conclusively, the use of PERC is well documented throughout literature as a valuable and reliable CDS system diagnostic tool. A combination of PERC, PTP and clinical judgement has the potential to reduce inappropriate CTPA ordering, thus improving yield (Bokobza et al. 2014, Hugli et al. 2011, Stojanovska et al. 2015).

2.2.6 Conclusion

There are many methods of diagnosing PE. As outlined earlier tin this section, CTPA is the most utilised examination due to its availability and accuracy. Given such high fatality rates and preventability, the requirement of accurate diagnosis of PE is of paramount importance within healthcare. The diagnosis is arduous and labour intensive, involving the collection of multiple clinical risk calculations, specialist examinations and resources of high demand (Cohen et al. 2014, den Exter et al. 2014, Posadas-Martínez et al. 2014). The requirement for accurate diagnosis is pertinent, this includes the provision of CDS system aids.

2.3 Appropriateness of Radiology Ordering

This section aims to outline the importance of complete, accurate and concise radiological ordering by providing all the necessary clinical information and indications for the exam at hand. Literature sources were explored to investigate what is being done elsewhere to ensure appropriate ordering is taking place.

2.3.1 American College of Radiology (ACR)

The American college of radiology (ACR), in conjunction with the national decision support company (NDSC) has developed a web application named ACR Select consisting of ACR approved appropriateness criteria (AC) for radiological imaging. This was initialised in July 2012 to ensure the appropriate use of radiological imaging for individual patients by incorporating relevant clinical information contained within medical records and CPOE systems. It provides referring physicians access to ACR approved guidelines at the point of data entry in a well structured, easy to follow format (Moriarity et al. 2015, NDSC 2012).

2.3.2 European Society of Radiology (ESR)

The European Society of Radiology (ESR) has collaborated with the national decision support company (NDSC) to create a CDS system for European referral guidelines, namely the ESR iGUIDE. Up to date guidelines and recommendations, based on best practice and evidence-based criteria, are incorporated into the ESR iGUIDE knowledgebase. A prime advantage of ESR iGUIDE utilisation is the guarantee that patients receive optimum healthcare and referring physicians have an assurance that they are providing the patient with such, in a user-friendly manner at the point of care. The ESR appointed a team of radiologists in 2014 to review and adapt the ACR appropriateness criteria for use in Europe according to strict practice standards (ESR 2014).

Blackmore et al. (2011) exemplify the utilisation of CDS within radiological imaging orders to potentially improve the appropriateness of radiology ordering. An

example is made of the USA whereby a recent mandate initiative is in place to include CDS systems within radiology ordering systems. The use of targeted CDS to specific examinations resulted in an overall reduction in the volume of orders and a higher yield of appropriate orders. Thus reducing the number of unnecessary examinations performed (Blackmore et al. 2011, Huber et al. 2015, Prevedello et al. 2013).

A statute enacted by United States of America (USA) congress has mandated the use of CDS within CPOE systems for specialised radiological imaging in USA hospitals (Huber et al. 2015, Keen 2014). The aim of which is to reduce inappropriate radiology ordering, thus easing the burden on valuable resources and limiting unnecessary exposure to ionising radiation to patients. It is also in place to allow for and encourage the use of government-approved, best-practice guidelines as outlined by the American college of radiologists (ACR). Overall it is expected that the quality of patient care will be optimised. The mandate will commence in the US on the 1st of January 2017. Resulting from the creation of CDS as a national healthcare policy in the US, the creation of industry standards is now sought for CPOE of radiology imaging procedures (Keen 2014).

A European survey found that the reinforcement of standards and guidelines as well as educational initiatives were pertinent to their adherence. Overall, there was a strong widespread agreement that guidelines are to be integrated into CDS systems so as to improve radiology ordering systems. It was also suggested that audits were carried out to analyse the use and availability of practice guidelines (Remedios et al. 2014b).

2.3.3 Conclusion

The provision of appropriate radiology ordering is critical to radiology staff and patients. It will ensure a timely and justified examination is carried out. It can determine the urgency of the examination. Guidelines, well-defined standards and

appropriateness criteria are effective methods of ensuring appropriate radiological ordering.

2.4 CDS in CPOE

According to Osheroff, CDS is defined as:

> "Providing clinicians or patients with clinical knowledge and patient-related information, intelligently filtered, or presented at appropriate times, to enhance patient care" (2005)

There are many definitions of CDS within the literature. They share a commonality in that the purpose of CDS is to aid in decision-making processes by linking observations with knowledge, thus improving healthcare (Hayward 2004). Berner (2007) defines CDS as:

> "Computer systems designed to impact clinical decision making about individual patients at the point in time that these decisions are made" (2007, p.3)

Evidence-based medicine is at the forefront of modern healthcare, however the practice of such can often prove difficult. The reasons for this are multi-factorial. There lies an overall aim to overcoming barriers and ensuring the best care for patients, best use of services and improving clinical outcomes. It is widely accepted that clinical decision support (CDS) interventions can allow this to happen by providing relevant accurate information as required and reducing errors (Bates et al. 2003, Melnick et al. 2010). It is believed that the use of CDS, irrespective of which CDS exactly, is more beneficial than the use of no CDS at all (den Exter et al. 2014). Considering the long-standing existence of CDS systems, there remains a relatively small number of sites whereby CDS is in use (Demner-Fushman et al. 2009). For example in Switzerland, Carli-Ghabarou et al. (2013) found that despite a national enforcement, rates of implementation varied.

CDS systems comprise of computer software that encompasses a knowledgebase of specific criteria, scenarios and rules. The functionality of CDS systems is to aid and interact with users in clinical decision-making processes by presenting actionable patient-specific recommendations and prompts in a timely manner (Carli-Ghabarou et al. 2013, Demner-Fushman et al. 2009, Marcos et al. 2013, Melnick et al. 2010, Zafar et al. 2012). With a focus on radiological ordering, implementation of CDS systems occurs within computerised physician order entry (CPOE) systems to ensure the correct procedure be requested for the specified clinical indications. It serves an educational purpose by presenting relevant real-time information and actionable recommendations to system users. The results of implementing CDS for radiological requests will be to reduce the number of redundant imaging procedures performed (Zafar et al. 2012).

CPOE is an extremely useful tool when placing and storing electronic requests for imaging within a radiology department. It works by prompting the input of pre-defined data via a computerised software tool, ideally linked by an order communication system (OCS) within the hospital information system (HIS). Free-text entry fields, tick-box multiple-choice questions and pre-filled data from a patient's medical record form part of the order completion process (Zafar et al. 2012). It is well established that the integration of clinical data from hospital information systems and other systems e.g. laboratory systems and radiology systems, is essential to improve CDS systems (HSE 2015, Huber et al. 2015, Ip et al. 2012, Marcos et al. 2013, Schuh et al. 2015, Sistrom et al. 2009).

2.4.1 Benefits of CDS

The deliverance of high quality healthcare is dependant on evidence-based practice. However, in many areas of medicine knowledge base has out passed clinical practice. One reason for such is the dismissal of guidelines by physicians, coupled with a resistance to change (Bates et al. 2003). On average, it can take 5 years for guidelines to become common practice (Lomas et al. 1993).

Kaplan et al. (2001) carried out a systematic review of CDS system application within healthcare. CDS had been available for clinical systems for more than 25 years at the time yet utilisation was relatively low. Literature surrounding the area was inconclusive as to the value of incorporating CDS into clinical systems. Literature has shown that there was a limited evaluation of CDS systems in the past. However, a systematic review also found that CDS had the potential to improve patient care, assist in more informed decision-making processes and improve diagnoses and treatment plans. Recommendations were to perform more in-depth evaluations of CDS systems to analyse their potential and encourage adoption thus improving clinical performance (Kaplan 2001).

It was recognised almost 20 years ago that cost savings for healthcare are possible through utilisation of CDS. CDS was also found to benefit the efficiency of physicians in decision-making processes (Stiell and Wells 1999).

CDS, when used in radiological ordering systems, is advantageous in many ways. Coupled with the creation of European standards, ESR iGUIDE aims to target areas of concern in the area of diagnostic imaging. Those included were: appropriate use of radiological diagnostic resources; encouraging the use of continuously updated referral guidelines; workflow assimilation; ease of use of systems; education for referrers by providing relevant guidelines and recommendations for specific procedure types, based on a patient's clinical presentation and/or clinical history (ESR 2014).

Remedios et al. (2014) studied the use and availability of radiological imaging referral guidelines in the European Union (EU). During the study, Finland and Italy were alone in responding to confirm the assimilation of their imaging guidelines with their CDS systems for the radiological ordering of specialised examinations. However, other countries suggested they were supportive of the aforementioned assimilation and were planning on the future adoption of such. Of a total 138 organisations, responses were received from 32% (n=44). Recommendations were made towards the adoption of CDS for organisations. These included: Encouragement towards the use of and availability of guidelines; clearly defined

European standards for uniformity and direction; advancement of CDS and integration with current and future CPOE systems; encouragement of education for radiologists, radiographer and referrers; auditing capabilities externally and internally within organisations (Remedios et al. 2014a).

Dunne et al. (2015) observed the yield of CTPA studies on the presence of acute pulmonary embolism (PE) following the implementation of CDS by means of an approved decision rule. By comparing the number of positive CTPA versus negative CTPA studies for the presence of PE, with and without the use of CDS. The study found a reduction rate of 12.3% in the number of CTPA scans performed to evaluate the presence of PE. This was both an initial finding as well as a maintained finding throughout the 32-month period of the study. The yield post-CDS implementation amounted to 16.3%. The findings were consistent and encouraging for the value of CDS use within radiological ordering (Dunne et al. 2015).

A local, recent example of CDS use in the diagnosis of PE began in January 2009 whereby St. James's Hospital, Dublin incorporated evidence-based CDS into their CPOE system when requesting CTPA studies. This was in an effort to reduce the fast-growing pace at which CTPA orders were being placed, with an aim to significantly reducing unnecessary requests. Customised CDS software used automatically generates a risk score based on the information provided. The risk score is a valuable indicator of the likelihood of PE and imaging recommendations are provided depending on the overall score. Pre-implementation, the yield of CTPA examinations positive for the presence of PE was 11%. Post-implementation, the yield of CTPA studies increased to 17%. In addition to this, CDS recommendations lead to 20% of CTPA exams being cancelled as unnecessary or not clinically advisable based on information provided. Also, the overall number of CTPA exams performed was found to be 14% less than pre-CDS implementation. Utilisation of CDS in this case was widely accepted by all disciplines of medicine with an early recognition of the positive results for all involved – clinicians, radiology staff and most importantly, patients (Cerner 2011, Keen 2010). It was

also found that 100% of patients who had normal D-dimer assays were negative for the presence of PE. Cancellation of requests occurred whereby normal D-dimer values and low-risk Wells criteria-based scores suggested an overall low-risk score for the presence of PE. This accounted for 35% of CTPA requests following CDS implementation. This study was encouraging for the use of CDS systems to reduce the number of inappropriate radiological examinations performed by allowing for a more interactive and intelligent ordering system (RSNA 2010). They offer guidance in a clinical setting and with successful implementation they allow for the prevention of errors (Saxena et al. 2011).

2.4.2 Implementation of CDS

Literature has remained consistent over the last two decades in portraying CDS as a beneficial tool in reducing errors, saving time and assisting compliance with clinical guidelines (Haynes and Wilczynski 2010, Huber et al. 2015, Kaplan 2001, Lehnert and Bree 2010, Marcos et al. 2013, Rosenthal et al. 2006, Zafar et al. 2012).

A smooth integration of CDS is essential for the adoption of systems. Ensuring interoperability standards and evoking end-user satisfaction can achieve this. Sophisticated CDS systems comprise of storage and management platforms, an alerting mechanism to identify risk, and assistance in decision-making processes by interacting with other hospital systems and information platforms allowing for ease of access to pertinent information when required (Marcos et al. 2013).

Bates et al. (2003) outline 10 main recommendations towards the implementation of successful CDS systems:

1. Speed – Efficiency of systems is admirable and all users welcome timesaving interventions.
2. Timely access to relevant information – By anticipating the needs of users, time management is greatly improved by providing real-time relevant

information as and when required.

3. Efficient workflow – Ergonomic workflow with minimum alerts and notifications ensures user satisfaction with systems and allows for the merging of knowledge with practice.
4. Usability of systems – Ease of use is pertinent to end-users and ensures continued use.
5. Providing alternatives – By offering suggestions to alternatives when requested examinations or procedures are not recommended avoids gaming of systems. End-users are resistant to stopping, therefore by providing an alternative investigation based on best practice guidelines, physicians display a higher level of job satisfaction.
6. Changing direction rather than prematurely terminating an action – Offering alternatives or providing additional information or suggestions can prove beneficial rather than creating a boundary, providing an alternative route.
7. Maintaining simplicity – The presence of brief guidelines or instructions is critical to the likelihood of a user reading and following them. This often requires the modification of guidelines to include precise relevant information.
8. Requesting additional information – The inclusion of additional information is often necessary. Such information may require the physician to perform a calculation or a clinical assessment that may prove to be time-consuming and laborious. It is important to only seek additional information when necessary.
9. Monitor system performance and act accordingly – The selection of alerts provided to users must be stringent. This may require an initial evaluation of alert responses with an aim to reducing dismissal rates.
10. Maintenance of systems – Systems must ensure that up-to-date and relevant information is included in the knowledgebase. Optimisation of system is improved by performing regular thorough analysis and evaluation of system performance.

There are risks involved when implementing CDS systems. One such risk is for users to learn to game the system. This is the case whereby users can input certain data fields to ensure the procedure type desired is performed. This is done through learning what the system is expecting to return certain procedure types. Also, CDS requires the valuable input of several stakeholders to ensure the best product is delivered (Huber et al. 2015).

Miller et al. (2014) outline further recommendations when implementing CDS. Time-consuming notifications and reminders are frustrating to the user and tend to leave users dissatisfied with the system. The system must be seen to be helpful, a valuable asset as opposed to a hindrance. A limit of 1 minute is recommended for the time spent interacting with the CDS system to minimise frustration and encourage use (Miller et al. 2014).

Implementation of evidence-based CDS has been seen to increase the yield of CTPA studies for PE. A comparison was carried out to assess the appropriateness of CTPA ordering to diagnose PE in the Emergency Department (ED). Post implementation a 20.1% reduction in the use of CTPA studies was seen. Diagnostic yield of positive CTPA studies for evidence of PE increased by 69%. These results are of great value and greatly encourage the adoption of CDS within CPOE systems. These results further confirm that the use of CDS is of great value to patient care and departmental workflow. The study makes recommendations for further analysis to be carried out and other areas of CDS implementation in other areas given the encouraging results received (Raja et al. 2012).

As found in other studies, recommendations are made for further evaluation of the effect of CDS implementation in clinical systems. This is imperative to the improvement of functionality and to ensure general compliance. It is not well understood to what extent users are gaming the system. This must be minimised in order to improve outcomes of CDS use. Resistance to change can prove problematic and therefore disruption must be minimised and ease of use maximised to ensure adoption of CDS systems (Huber et al. 2015, Rosenthal et al. 2006).

Overall, the move towards evidence-based practice is strongly encouraged through CDS implementation. The optimisation of CDS systems is critical to adoption and performance, thus improving patient care and end-user satisfaction (Bates et al. 2003, Jiménez et al. 2015). For a successful CDS system integration, it requires expert knowledge and familiarity. Systems must also be subject to regular review, maintenance and development to preserve a high standard of care for patients and healthcare users alike (Schuh et al. 2015).

2.4.3 Clinical Acceptance of CDS within CPOE

Several studies have explored and verified the benefits of incorporating CDS into clinical systems. CDS has the opportunity to revolutionise the behaviour of ordering physicians when used to its full potential. Lehnert and Bree (2010) found that the yield of specialist radiology studies – computed tomography (CT) and magnetic resonance imaging (MRI), performed increased when CDS was implemented into the radiology ordering system. Evidence-based guidelines were used to form CDS rules. Results were mirrored by an earlier study carried out by Melnick et al. (2010) who found that an active CDS system had a positive impact on ordering behaviours. This further reduces the divide between knowledge translation and clinical practice (Haynes and Wilczynski 2010, Lehnert and Bree 2010, Melnick et al. 2010).

Ip et al. (2012) performed a ten-year analysis of clinical acceptance of CDS integration with computerised physician order entry (CPOE) systems for radiology ordering. Acceptance rates were high as a result of optimising physician workflow and providing real time decision support. Integrating CDS with CPOE systems was also found to reduce inappropriate imaging (Ip et al. 2012).

By providing evidence-based CDS, Ip et al. (2015) found a reduction in the number of unnecessary CT brain examinations performed for patients presenting with mild traumatic brain injury (MTBI), as recommended by the American College of Emergency Physicians (ACEP). The study safely concluded that a reduction in

inappropriate imaging could be achieved without delaying diagnoses or warranting follow-up imaging (Ip et al. 2015).

A recent study carried out by Moriarity et al. (2015) observed the effects of CDS on specialised radiological imaging ordering for Inpatients. CDS in this case was based on the standards set out by the American college of radiology (ACR) appropriateness criteria (AC). Nuclear medicine (NM), CT and MRI requests were assessed and assigned an AC score using drop-down menu selections from requesting physicians. This saw an increase in the score values and therefore the appropriateness of orders placed for these specialties, thus validating the inclusion of CDS when requesting specialist radiological examinations. CDS enables users to choose the best examination for the clinical indications given. Successful implementation of CDS allows for adherence to imaging guidelines and improve acceptance by users (Bowen et al. 2011, Ip et al. 2012, Keen 2014, Lehnert and Bree 2010, Levy et al. 2006, Moriarity et al. 2015, Rosenthal et al. 2006, Solberg et al. 2010).

Nazarenko et al. (2015) explain how physicians are faced with an overload of information and a rapidly growing knowledgebase containing new information, revolutionary practices and guidelines – so much so that it proves difficult to keep up-to-date on all aspects of current medical best practice guidelines and protocols. The assistance of CDS, as seen previously, can ensure that current best-practice guidelines are adhered to. A systematic review found, on average, 34% of recommendations were followed whereby CDS was not in place (Nazarenko et al. 2015).

2.4.4 Demand for Radiology Services

CTPA studies, along with all other CT examinations, are prime examples of specialised imaging. Other specialised imaging modalities include MRI, NM, and PET imaging (Keen 2014). These specialised imaging modalities remain increasingly in demand, especially within Emergency Departments (ED) departments.

Carnevale et al. (2015) assessed the inclusion of CDS on orders for CT and MRI from ED. While there was no alteration in the total order numbers, the yield of orders placed for high-risk patients increased. Resultantly, the study found a reduction in re-admittance rates to ED as well as a reduction in the number of orders placed for both medium-risk and low-risk patients (Carnevale et al. 2015).

The use of CDS in specialised imaging areas of CT, MRI and ultrasound (US) in a large academic American hospital was analysed to determine the effect of such on the quantity of out-patient orders placed in these areas over a 7-year period. Initially there was a substantial decrease in the number of orders placed for specialist imaging. Overall, there was a slight decrease in the annual growth rate of radiology orders from CT, MRI, and US. CT fell from 12% to 1%, MRI from 12% down to 7%, and US from 9% to 4%. This was despite an annual attendance increase of 5% at Outpatient clinics during the study period (Sistrom et al. 2009).

2.4.5 Conclusion

Given the positive effect on radiological ordering patterns, adoption of CDS enhanced CPOE systems is encouraged (Cerner 2011, Keen 2010, Rosenthal et al. 2006, Roshanov et al. 2011).

However reliant and often extremely valuable, CDS cannot be used in isolation for decision-making purposes in clinical settings. Clinical judgement is highly valuable and so CDS should be treated merely as an aid when available (Remedios et al. 2014a). CDS is not expected to cover all clinical scenarios (Raja et al. 2014). Rather it is a potentially functional tool to provide guidance for users. It is best used and more widely accepted when integrated into current radiology information systems (RIS), electronic ordering systems and hospital information systems (HIS). It is not intended to commandeer the role of a radiologist, radiographer or physician alike (Remedios et al. 2014a).

2.5 CTPA for PE Diagnosis

CTPA studies are radiological examinations performed in a CT scanner to assess the pulmonary vasculature using an angiography technique. They incur a substantial dose of ionising radiation, which is potentially harmful to body tissues and cellular structures. It also involves the intravenous administration of a nephrotoxic, iodinated contrast agent. Contraindications exist for these reasons. Justification of radiation exposure and nephrotoxic contrast must be stringent to avoid a potentially undue harm to the patient. It is also a costly examination both financially and resourcefully as the demand on services increases annually. They are diagnostic in the evaluation of the pulmonary vasculature. The administration of contrast agents and timely acquisition of image slices can diagnose a filling defect due to the presence of a thrombus, namely a pulmonary embolism. They are commonly performed to diagnose the presence of PE. They are considered the study of choice as they provide an accurate and timely diagnosis. CTPA studies are widely available and suitable for the majority of patients. It is also possible to diagnosis other unsuspected chest pathologies when present using this procedure (den Exter et al. 2014, Lucassen et al. 2013, Moriarity et al. 2015, Weiss et al. 2006)

A study carried out in the United States of America (USA) found that 86.7% of physicians believed PE were best diagnosed by performing a CTPA. In 71.4% of patients suspected of PE, a CTPA was the first test requested by physicians (Weiss et al. 2006).

Advances in image quality, scanning techniques and prevalence of multi-detector CT scanners have resulted in an increased capability of CTPA studies to diagnose non-clinically significant small sub-segmental pulmonary emboli. These are not thought to be of clinical concern to physicians or patients alike and do not require treatment (den Exter et al. 2014, Lucassen et al. 2013).

Lucassen et al. (2013) found a 10% rate of false negative CTPA scans for the presence of PE. There lies a strong argument for the requirement of industry gold

standards surrounding the diagnosis and treatment of PE. There remains an uncertainty as to the number of false positives on CTPA examinations due to a lack of imaging standards. This may result in the unnecessary administration of anticoagulant therapy (Lucassen et al. 2013).

2.5.1 Contraindications to CT

There are many contraindications to the performance of CTPA examinations. The time consuming examination incurs a high dose of ionising radiation to patients, as well as the administration of potentially nephrotoxic contrast. For these reasons alone the examination may be unsuitable for a small number of patients but may be clinically warranted and necessary for diagnosis (Bokobza et al. 2014, den Exter et al. 2014, Drescher et al. 2011).

Due to the constant increase in requests for imaging, including CTPA examinations, radiology departments have a requirement to become more stringent on the validation of the requests being processed. There is an increased demand on referring physicians to justify the examination by including specific evidence-based criteria before an examination will be carried out. CTPA studies are invasive, potentially nephrotoxic for renally impaired patients, ensue a high dose of ionising radiation and are often time-consuming procedures in a high demand area of radiology – particularly when inappropriately requested and performed. For this reason, it is pertinent that CDS is implemented to ensure the appropriateness of CTPA requests (Brenner and Hall 2007, Broder and Warshauer 2006, Corwin et al. 2009, Fesmire et al. 2011, Lee et al. 2010, Mitchell et al. 2012)

2.5.2 Overutilisation of Resources

Over the last twenty years, the performance of CTPA studies has seen a steady increase. This is due to the concern that a diagnosis may be missed if a CTPA study is not performed, coupled with the heterogeneous presentation and non-specific

nature of symptoms of PE diagnoses. This coupled with the potentially life-threatening risk of a PE has led to more CTPA examinations being approved and performed. This has created an increased burden on resources. Higher costs ensue, longer lengths of stay for patients occurs, longer waiting times for other CT scans for other patients, as well as an exorbitant use of ionising radiation to a progressively larger population. These consequences have adverse effects on the heath system as a whole and ensue a great burden on requesting physicians to limit ordering of these examinations without missing a potentially positive finding (Bokobza et al. 2014, den Exter et al. 2014, Drescher et al. 2011).

When compared to other radiological methods of diagnosing PE such as nuclear medicine VQ examinations, CTPA scans are the most readily available and most utilised of all specialist radiological imaging techniques. Studies have found a variation in yields from 10% to 20% in some imaging centres. The yield refers to the proportion of CTPA examinations found to be positive for the presence of PE. Those at the lower end are indicative of certain overuse of CTPA examinations (den Exter et al. 2014, Drescher et al. 2011).

An increased use of CDS systems is seen in support of evidence-based decision-making (Robertson et al. 2010). However, the effect of CDS on imaging utilisation requires further investigation (Carnevale et al. 2015, Shiffman and Wright 2012). Acceptance of CDS systems will result from providers assuming risk for the care of patients by enforcing the use of evidence-based criteria into clinical practice (Zafar et al. 2012).

A substantial growth rate of 80% is observed between the years 2000 and 2009 by Medicare, an American social insurance programme, in the use of medical diagnostic imaging. Hence an increased demand for radiology imaging services (Ip et al. 2013, Moriarity et al. 2015). A growing concern as to the unnecessary and inappropriate use of diagnostic imaging examinations is apparent as studies have found approximately 30-40% of radiology imaging examinations may be invaluable for diagnoses. A medical management program was enabled for radiology by integrating CPOE systems with CDS. As a result, there was a significant reduction in

the number of high-cost specialised diagnostic radiology orders placed over the years (Ip et al. 2013).

2.5.3 Overdiagnosis

As mentioned previously, there are often insignificant small pulmonary emboli found of CTPA scans that do not require treatment (Bokobza et al. 2014, den Exter et al. 2014, Lucassen et al. 2013). The instances of this have increased as the sensitivity of CT examinations has also increased. This has lead to instances of incidental as well as insignificant PE findings (Cohen et al. 2014, den Exter et al. 2014). Studies have found that instances of insignificant PE diagnoses have increased by 100% since the advancements in CT technology and scanning techniques (den Exter et al. 2014).

2.5.4 Conclusion

As mentioned earlier in this section, CTPA is believed to be the examination of choice when diagnosing PE. This is largely due to their availability and diagnostic accuracy. (den Exter et al. 2014, Lucassen et al. 2013, Moriarity et al. 2015, Weiss et al. 2006) There lies a requirement for all requesting physicians to be educated as to when to request these examinations as the low yield values would suggest that they are often requested at times when another examination could provide a diagnosis instead. The volume of unnecessary and inappropriate use of radiological imaging is concerning. It is believed that integrating CDS and CPOE can reduce a significant proportion of these instances from occurring (Ip et al. 2013).

2.6 Conclusion

A balance must exist between the demand for imaging and the need for imaging. CTPA examinations are in high demand, in what is commonly an already demanding department of CT. Further investigation into the optimisation of radiology ordering systems and education is required to ensure an overall appropriateness of ordering.

Chapter 3: Methodology

3.1 Introduction

The purpose of this chapter is to outline the research design to include how data was collected, where it was collected from and how it was interpreted. It will also discuss the methods used to store and display the data collected and how it was summarised in a manageable format. The author will describe in detail the implementation of CDS for CTPA examinations. A description of the system used for the study is provided later in this chapter to outline exactly how it operates. A reflection on the radiology ordering system as well as the CDS system is provided in Chapter 6.

The study focus is based on the use of CDS to improve the appropriateness of the ordering of specialist radiological examinations. An example is made of CTPA examinations, as described in Chapter 2. Thus, the research aims to answer the question '*Has the use of CDS improved the appropriateness of radiology ordering of CTPA examinations for the diagnosis of PE?*' Based on an extensive review of the literature, a hypothesis was formed. This suspects that the implementation of CDS will result in an increased yield of PE post-CDS. This chapter will describe how this will be tested. Chapter 4 provides the results, thus outlining the truth of this hypothesis.

The research design's primary focus is to evaluate the yield of CTPA examinations both pre and post-CDS implementation. The yield of the study will help to determine the appropriateness of the CTPA completion. It is worth noting that the studies are defined as appropriate if the clinical indications and clinical judgement are suspecting the presence of PE. This is mostly due to the high clinical concern and mortality rate relating to PE coupled with the non-specific presentation of ambiguous symptoms (den Exter et al. 2014, RCR 2012, Remedios et al. 2014a, Wells et al. 2000). This data is sub-categorised into IP patient locations, ED patient

locations, and individual month figures. Other data, as mentioned in Chapter 1, will include the statistical significance between data collected pre-CDS and post-CDS as well as consultant-based yields to evaluate if CDS had a notable influence on consultant team ordering patterns. A detail of this data is provided in Chapters 4 and 5.

3.2 Study Location

The selected study site is a large Dublin-based teaching hospital comprising of an acute ED as well as providing full-time Inpatient and Outpatient services, therefore consisting of a wide diversity of patients. This site was chosen as it had implemented CDS for CTPA ordering some time ago, however an extensive evaluation had not yet been performed. The chosen site also provided a wide selection of patients for research purposes. The size of the hospital ensured a large number of study samples for a thorough analysis. Access to study information was readily available for the author. For these reasons, it was considered an ideal study location.

3.3 Methodology

A research proposal was drafted outlining the research topic. Upon approval, an extensive and thorough review of the literature was performed. Throughout the research process, a total number of 148 pieces of literature were reviewed surrounding the research topic. Only literature of a high quality and relevance was chosen to form the literature review section of this report. Investigation was required to determine the exact date of CDS implementation from the hospital involved in the research. This then allowed for progression to the selection of specific data months. Given the short timeframe available to conduct the research, it was deemed appropriate to select 5 months worth of data pre-CDS implementation and 5 months post-CDS implementation, with an average of 86

examinations performed per month. This allowed for a large number of studies to undergo a rigorous evaluation of data.

Information was gathered from CTPA orders. This included the following, where available:

- Clinical indications – only a limited number of characters were available therefore some of the clinical indication fields were incomplete. For this reason, this detail was not analysed.
- Procedure type – limited to CTPA procedure orders.
- Patient Age – This was not used during data analysis. It was not deemed a requirement as per the RCR Guidelines (RCR 2012)
- Order location – Inpatient, Outpatient or Emergency Department.
- Attending consultant – each consultant was assigned a code, e.g. C2 for consultant number 2.
- Order Date – this was not used, as it did not provide a valuable source of analytical data.
- Wells Score – values as entered on CTPA orders, only available in orders placed post-CDS implementation.
- D-dimer – values as entered on CTPA orders, only available in orders placed post-CDS implementation.
- Result – Presence of PE, either positive (1) or negative (0)

Coding values, as listed above were used for ease of interpretation. CTPA studies were also assigned a code value to identify them to the author. This did not contain patient specific information that could be used to identify the patient for data protection purposes. This included the study month and year and a number, e.g. MAY12-1 for the first CTPA observed from May 2012. As the examinations were not listed in chronological order, this was not necessarily the first CTPA exam performed in May 2012. This ensured a lack of tractability of studies therefore protecting identifiable study details. CTPA examinations were listed by study location within Excel spreadsheets by individual month and thereafter, collectively.

Access to radiology reports was then required to determine the result of the presence of PE. This was recorded on the spreadsheet as indicated, above. This was performed using the same radiology information system (RIS) that study data was obtained from.

3.4 Study Population

The implementation of mandatory completion of questions relating to Wells Score and D-dimer results on all orders for CTPA studies took place on Tuesday, 5th November 2013. From this date forward, requesting physicians were asked if the patients Wells Score was above 4 and were obliged to select either yes or no. Following this, the physician must complete a separate free-text field to note the patients Wells Score. If the Wells Score is below 4, they are asked to enter a D-dimer value also. The system will only ask for D-dimer value when the requesting physician has answered no to the question "Is the patients *Wells Score* greater than 4?" The entry of the Wells Score and D-dimer values are free text fields. As a result, these fields may be inaccurate or invalid. Any prompt questions unanswered resulted in an on-screen pop-up alert asking the physician to complete the form before the order could be saved.

In total, 860 CTPA examinations were evaluated over 10 individual months surrounding the implementation of CDS. 46.28% (n=398) of these were pre-CDS and 53.72% (n=462) were post-CDS examinations. The total study number was deemed appropriate to perform a thorough evaluation. It was believed to be a good reflection of the total population. The 10 chosen months were deemed well distributed around the CDS implementation month of November 2013.

The months selected were: May 2012 (18 months pre-CDS); December 2012 (12 months pre-CDS); May 2013 (6 months pre-CDS); August 2013 (3 months pre-CDS); October 2013 (1 month pre-CDS); December 2013 (1 month post-CDS); May 2014 (6 months post-CDS); December 2014 (12 months post-CDS); May 2015 (18 months post-CDS); December 2015 (24 months post-CDS). Pre & post-CDS yields

were analysed overall as well as divided into ED patient locations and IP patient locations. These categories were chosen for data analysis purposes. This was also to allow for analysis of yields from specific locations to determine a possible problem area. If problem areas are indicated, education could be suggested in these areas.

Over the course of the study, 0.81% (n=7) of CTPA orders originated from an OP location. Due to these low figures, patients originating from Outpatient patient locations were not analysed individually. It should be noted that these patients were included in the overall study number (n=860) and were included in the 'all patient' analysis, as outlined in Chapter 4. Incomplete studies that were also reported on as non-diagnostic and grossly incomplete were not included in the study.

3.4.1 Selection of Study Months

A well-distributed sample was selected by choosing 5 months either side of November 2013 when the CDS was implemented. For an immediate pre & post comparison to be made, the months directly before and after were selected – October 2013 and December 2013 respectively. Other months were selected with the intention of directly comparing them pre & post-CDS implementation as the allowed for the same time period either side of November 2013 – 6 months pre & post, 12 months pre & post; 18 months pre & post. The final 2 months were selected at random to avoid bias.

3.5 Data Processing

This section will outline the processes of how the data was collected, where it was collected from and how it was evaluated afterwards. The evaluated CDS is a selection of questions deemed necessary for the justification of a CTPA examination to be performed. A screenshot of the radiology ordering system

outlining the questions asked as part of the CDS for CTPA studies is provided in Appendix C.

The CDS questions of interest, contained on the CTPA order form analysed, include 'Please provide the patients current *Wells Score*?' and 'Is the patients Wells Score greater than 4?'. Each answer field, except for yes/no response questions, are free-text fields. Each free text field has a rule whereby it is mandatory to enter data before the system allows the user to save the order. This is not the case for the D-dimer value entry field. As the system does not retrieve D-dimer value information from the lab system, the onus is on the requesting physician to provide accurate data. It is difficult to verify this data, as it requires users to access a separate system. This is both time-consuming and laborious. The same is true for other blood result values included on the order form, such as creatinine values. These are important for the radiographer or radiologist to obtain prior to the administration of iodinated nephrotoxic contrast to avoid kidney damage. For the purpose of this report creatinine values were not analysed as they are not considered necessary according to the RCR Guidelines (RCR 2012). It is also worth noting that the current CDS system does not provide feedback on values entered or information/education on why the information requested is necessary to order completion. This could improve the accuracy of the data entered and possibly reduce the number of inappropriate orders placed. As the RCR guidelines are used as a primary referral guideline source, a copy of the RCR guideline surrounding CTPA examinations was sought. A request was also made to reproduce this information in this research project. Information on this communication and the RCR guideline itself (CC04) is found in Appendix A and B respectively.

3.5.1 Data Collection

Study data was collected directly from the radiology information system (RIS). This limited system contains radiology records in isolation of all other hospital systems. It does not communicate with any other hospital information systems for CDS

purposes. Patient details were anonymised for confidentiality. CTPA study information was entered into an Excel document for analysis. The Excel document consisted of separate sheets for each study month's CTPA examinations. The following information was available for each CTPA examination: Patient location (IP/OP/ED) and result (1/0). These coding values were used to easily analyse data values within Excel, as outlined in Table 3.1, below. Additionally, all examinations ordered post-CDS implementation included Wells Score and D-dimer values. These were less easy to interpret as they included a large range of values. However, an analysis was performed on these figures.

Table 3.1 Microsoft Excel data input spreadsheet – legend of values given

Legend				
Patient Location			**Result**	
IP	3.5.1.1.1 Inpatient		**1**	PE Positive
OP	Outpatient		**0**	PE Negative
ED	Emergency Department			

The study also observes the quality of the data as entered into the CDS system. It observes the number of times the Wells Score was not included yet the CTPA was performed. The study also evaluates the number of instances whereby the Wells Score was <4 and a CTPA was completed. The study observes the number of instances whereby the Wells was <4 and the D-dimer value was not entered, although requested. Finally, the accuracy of D-dimer values entered is observed. Following the inspection of D-dimer results entered into the CDS, their validity was felt to be questionable. Therefore, after D-dimer results were extracted from the lab system for all CTPA studies in one post-CDS month. These results are provided in Chapter 5. Due to restrictions of the radiology ordering system, the author was unable to evaluate cancelled exams. The author was also unable to evaluate the number of instances whereby an order was not completed, i.e. whereby an order had been initiated and was subsequently discarded. This information would be useful to evaluate if it was as a result of CDS information. However, as the system does not provide feedback, this is unlikely.

3.5.2 Data Analysis

Chapter 4 provides yield figures relating to each of the 10 months, as observed individually. A further analysis was performed to analyse the yield: 18 months pre & post implementation (May 2012, May 2015); 12 months pre & post implementation (Dec 2012, Dec 2014); 6 months pre & post implementation (May 2013, May 2014); 1 month pre & post implementation (Oct 2013, Dec 2013); IP pre & post implementation; ED pre & post implementation; All patients pre & post implementation. The entirety of data collected was inputted into Excel spreadsheets to allow for a thorough analysis. The following will provide information on the yield of CTPA studies month by month, overall pre & post implementation of CDS as well as broken down into ED and IP locations pre & post implementation of CDS. The proportion of CTPA examinations that were positive for the presence of PE was found and recorded for each CTPA instance. This was also done per patient location and per consultant, as described earlier in this chapter, to determine a variety of yield values.

3.5.3 Statistical Analysis

Statistical analysis was carried out to determine the significance of the CDS implementation. Direct comparisons were performed for study months at regular intervals surrounding the CDS intervention month of November 2013 – 1 month pre & post-CDS; 6 months pre & post-CDS; 12 months pre & post-CDS; 18 months pre & post-CDS. Z-score tests were carried out on these months as well as all 10 months together pre & post-CDS intervention. These were also sub categorised into ED patient locations and IP patient locations. Z-scores were used to determine the significance in the difference between the two populations, i.e. the yield pre and post implementation of CDS. Details pertaining to statistical findings are outlined in Chapters 4 and 5.

The P-value is the calculated probability that the difference in results of two studies is not just by chance. This value relates to the probability of finding that

the null hypothesis is true. The null hypothesis states that no difference between the pre and post-CDS implementation yields exists, i.e. that the yield values will remain unchanged. In an effort to disprove the null hypothesis, therefore proving the study hypothesis, the P-values were found for time periods as previously outlined in this chapter. Conventionally, P-values less than 0.05 are considered statistically significant. For this reason, a significance level of 0.05 was used (Luijkx and Goel 2016).

The Z-score is the number of standard deviations from the data point the average is. It is used to determine the reliability of the findings by comparing results from a normal population source (Luijkx and Morgan 2016).

This statistical analysis tool was chosen as the sample size was large and the population variance was known. A recommended online tool was used to calculate P-values and Z-scores (Stangroom 2016).

3.6 Conclusion

In summary, the presence of PE was assessed for each individual CTPA examination included in the study. This allowed for the calculation of yield as well as Z-scores. These values are used to evaluate the significance of the difference in values pre and post CDS-implementation for all patients as well as all Inpatient patient locations and Emergency Department patient locations. Ultimately, this is hoped to answer the research question, *'Has the use of CDS improved the appropriateness of radiology ordering of CTPA examinations for the diagnosis of PE?'*

Chapter 4: Results

4.1 Introduction

This chapter intends to provide an answer to the research question *'Has the use of CDS improved the appropriateness of radiology ordering of CTPA examinations for the diagnosis of PE?'* For the purpose of this study, the appropriateness will be determined by evaluating yield values. An increase in yield values post-CDS will exemplify an increase in the appropriateness of CTPA ordering. An analysis of data was carried out for 10 pre-determined months pre and post implementation of CDS, as outlined in Chapter 3. Initially the yield of CTPA examinations was observed for each study month and records were kept for later evaluation. An average yield was calculated for 5 months pre-CDS and 5 months post-CDS. All yield values collected were also subdivided into Inpatient locations and Emergency Department locations to provide a more in-depth analysis, as outlined in Chapter 3. A record was kept of the number of CTPA studies performed for each month as well as the number of PE findings per individual examination. Data representation is in both graphical and chart form for ease of interpretation. Statistical analysis was performed thereafter. This calculation of P-values was performed to represent the significance of CDS implementation when comparing two population proportions (pre-CDS and post-CDS implementation). This is expanded on in Chapter 5.

Whilst analysing the data provided to the CDS by those ordering CTPA examinations, the given D-dimer values raised suspicion as to the accuracy of data entered. In many cases D-dimer values were not entered when required (when the Wells Score was below 4) and at times the D-dimer value entered matched the Wells Score exactly. The unlikelihood of these values matching is high and so suspicion was raised. A month whereby D-dimer values were provided was selected at random. The month chosen was May 2015. D-dimer values as entered

on order forms were stringently compared to those as provided by the laboratory system. All discrepancies were recorded. Details are provided later in this chapter.

Chapter 3 provides details of all data recorded from each CTPA study throughout the course of the study. However, the focus of the research is to evaluate the yield of CTPA examinations since the implementation of CDS within the radiology ordering system. For this reason, yield will be the primary focus of this chapter. Other details pertaining to total study numbers per month are discussed in lesser detail. The yields both pre and post-CDS implementation were evaluated in detail. Several approaches were taken when evaluating the results, as previously mentioned. These are outlined throughout this chapter in more detail.

4.2 Study Findings

Table 4.1 overleaf, portrays the overall study findings in terms of numbers of CTPA examinations performed and yields. As mentioned in Chapter 3, the study data is divided into Inpatient and Emergency Department figures to provide a more thorough evaluation and possibly target problem areas. This data is also further subdivided by attending consultant to determine if there is a worthy difference seen when comparing the yields pre and post-CDS implementation for each consultant team. Further details surrounding consultant-based yields can be found later in Chapter 5 and Appendix D. The yield values assist in determining the appropriateness of CTPA ordering. By improving the appropriateness of CTPA ordering, it is hoped that the yield of positive PE findings will also increase.

The following measures of yield will partially determine the appropriateness of CTPA ordering. Other factors of appropriateness include the inclusion of relevant information, e.g. Wells criteria score values, D-dimer values when required and appropriate clinical indications. For the purpose of this project, only the Wells criteria scores and D-dimer values are observed as not all clinical indications were available for review. As mentioned in Chapter 3, study data from only 10 months was used as it provided a large number of studies (n=860) and given the time

constraints, it was neither necessary nor possible to further evaluate. Additionally, observations were only made of Wells Score values and D-dimer values, as these are the only measurable CDS system values of interest. Details pertaining to the validity of data entry yield per consultant and statistical findings are discussed in Chapter 5.

Table 4.1 CTPA study yield findings for all patients, IP and ED patient locations

	Overall			4.2.1.1.1 Inpatients			Emergency Department		
Month	**Number of CTPA Exams**	**Number of PE Findings**	**Overall Yield**	**Number of IP CTPA Exams**	**Number of IP PE Findings**	**IP Yield**	**Number of ED CTPA Exams**	**Number of ED PE Findings**	**ED Yield**
May 2012	71	16	22.54%	26	5	19.23%	44	11	25.00%
Dec 2012	49	11	22.45%	28	7	25.00%	21	4	19.05%
May 2012	94	10	10.64%	30	7	23.33%	63	3	4.76%
Aug 2013	91	15	16.48%	39	6	15.38%	51	8	15.69%
Oct 2013	93	20	21.51%	40	11	27.50%	51	8	15.69%
Subtotal (pre-CDS)	**398**	**72**	**18.09%**	**163**	**36**	**22.09%**	**230**	**34**	**14.78%**
NOVEMBER 2013 - CDS IMPLEMENTATION									
Dec 2013	105	24	22.86%	62	15	24.19%	43	9	20.93%
May 2013	80	15	18.75%	45	11	24.44%	34	4	11.76%
Dec 2014	100	9	9.00%	44	4	9.09%	56	5	8.93%
May 2015	84	16	19.05%	27	2	7.41%	56	14	25.00%
Dec 2015	93	13	13.98%	50	8	16.00%	43	5	11.63%
Subtotal (post-CDS)	**462**	**77**	**16.67%**	**228**	**40**	**17.54%**	**232**	**37**	**15.95%**
Total	**860**	**149**	**17.33%**	**391**	**76**	**19.44%**	**462**	**71**	**15.37%**

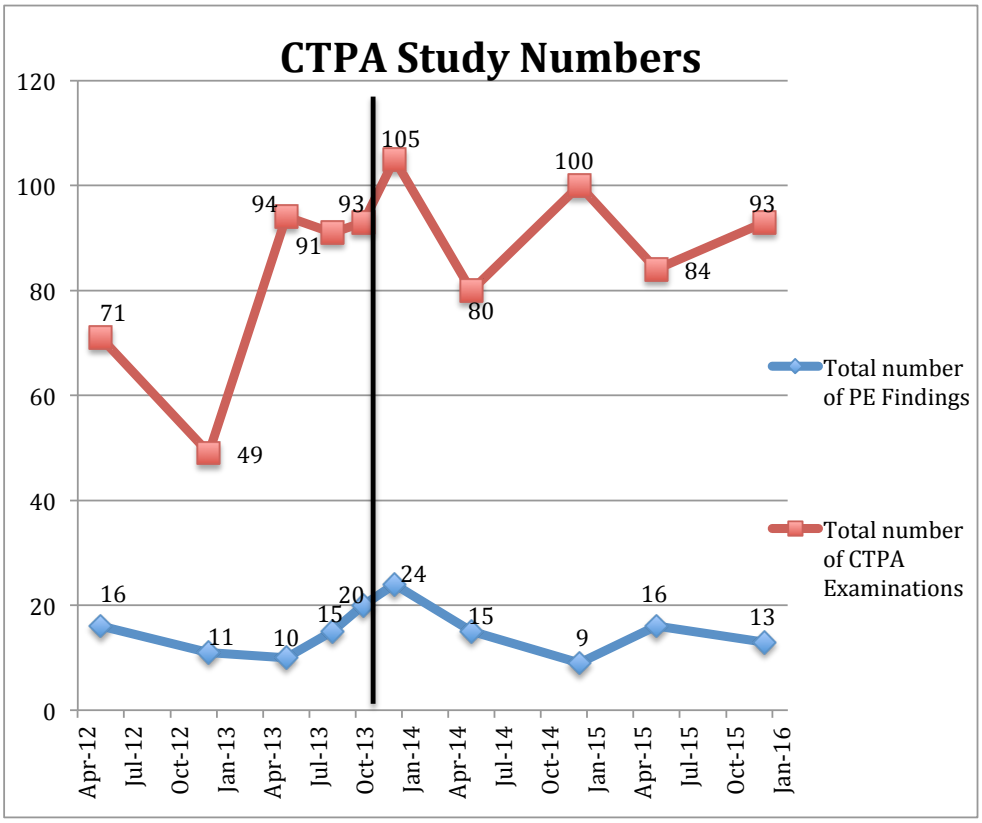

Figure 4.1 Number of CTPA examinations (incl. number of positive PE findings), with the vertical bar indicating the date of CDS implementation (November 2013)

Figure 4.1, above, graphs the total CTPA study details. Details included are: total number of scans performed per study month; total number of positive PE findings. The variation in these findings is clearly portrayed as a torturous wave with variants ranging from 49 studies performed (December 2012) to 105 studies performed (December 2013). The following will outline each month as represented in Figure 4.1 and Table 4.1.

May 2012 represents 18 months pre-CDS implementation. The yield of positive PE findings was 22.54% during this month, as shown in Figure 4.1 and Table 4.1. The total number of CTPA examinations performed in May 2012 was relatively low (n=71). With the overall yield subdivided into Inpatient locations and Emergency

Department locations, it revealed that the Inpatient yields were lower than Emergency Department yields, at 19.23% and 25% respectively.

December 2012 represents 12 months pre-CDS implementation. The yield of positive PE findings was 22.45% during this month. The total number of CTPA examinations performed in December 2012 was the lowest of all observed (n=49). The yield from Inpatient locations and Emergency Department locations varied somewhat at 25% and 19.05% respectively.

May 2013 represents 6 months pre-CDS implementation. The yield of positive PE findings was 10.64% during this month. The total number of CTPA examinations performed in May 2013 was 94. The yield from Inpatient locations and Emergency Department locations varied greatly at 23.33% and 4.76% respectively. This was the largest variance between these two patient classes seen during the entirety of the research study.

August 2013 represents 3 months pre-CDS implementation. The yield of positive PE findings was 16.48% during this month. The total number of CTPA examinations performed in August 2013 was 91. The yield from Inpatient locations and Emergency Department locations was comparable at 15.38% and 15.69% respectively.

October 2013 represents 1 month pre-CDS implementation. The yield of positive PE findings was 21.51% during this month. The total number of CTPA examinations performed in October 2013 was 93. The yield from Inpatient locations and Emergency Department locations varied greatly at 27.5% and 15.69% respectively.

December 2013 represents 1 month post-CDS implementation. The yield of positive PE findings was 22.86% during this month. During the course of the research, the month of December 2013 had the highest overall yield. The total number of CTPA examinations performed in December 2013 was 105. This was notably the largest number of CTPA studies performed during a single month during the study. The yield from Inpatient locations and Emergency Department locations varied slightly at 24.19% and 20.93% respectively.

May 2014 represents 6 months post-CDS implementation. The yield of positive PE findings was 18.75% during this month. The total number of CTPA examinations performed in May 2014 was 80. The yield from Inpatient locations and Emergency Department locations varied significantly at 24.44% and 11.76% respectively.

December 2014 represents 12 months post-CDS implementation. The yield of positive PE findings was 9% during this month. This was the lowest yield for a single month during the entirety of the research study. The total number of CTPA examinations performed in December 2014 was 100. The yield from Inpatient locations and Emergency Department locations varied slightly at 9.09% and 8.93% respectively.

May 2015 represents 18 months post-CDS implementation. The yield of positive PE findings was 19.05% during this month. The total number of CTPA examinations performed in May 2015 was 84. The yield from Inpatient locations and Emergency Department locations varied significantly at 7.41% and 25% respectively.

December 2015 represents 24 months post-CDS implementation. The yield of positive PE findings was 13.98% during this month. The total number of CTPA examinations performed in December 2015 was 93. The yield from Inpatient locations and Emergency Department locations varied slightly at 16% and 11.63% respectively.

4.3 Overall Findings

A great variance is observed in overall yield values throughout the course of the study. Figure 4.2, overleaf, demonstrates the tortuous path of yield variance from May 2012 to December 2015. The lowest (i.e. worst) yield was seen 12 months post-CDS in December 2014 (9%). The highest was seen 1 month post-CDS in December 2013 (22.86%). This is also noted in Table 4.1, earlier in this chapter. The square points on the line represent the study months observed. The vertical black line represents the date of CDS implementation – November 2013. The

overall yield pre-CDS was found to be 18.09% (n=72) and the overall yield post-CDS was 16.67% (n=77). This represents a statistically insignificant decrease of 1.42% post-CDS, as outlined in Chapter 5.

It is worth noting that while the overall number of positive findings increased post-CDS, so too did the total number of CTPA examinations performed (n=462) as compared to pre-CDS implementation figures (n=398). This represents a total increase of 64 CTPA examinations performed post-CDS, which is equivalent to a total increase of 16.33% post-CDS.

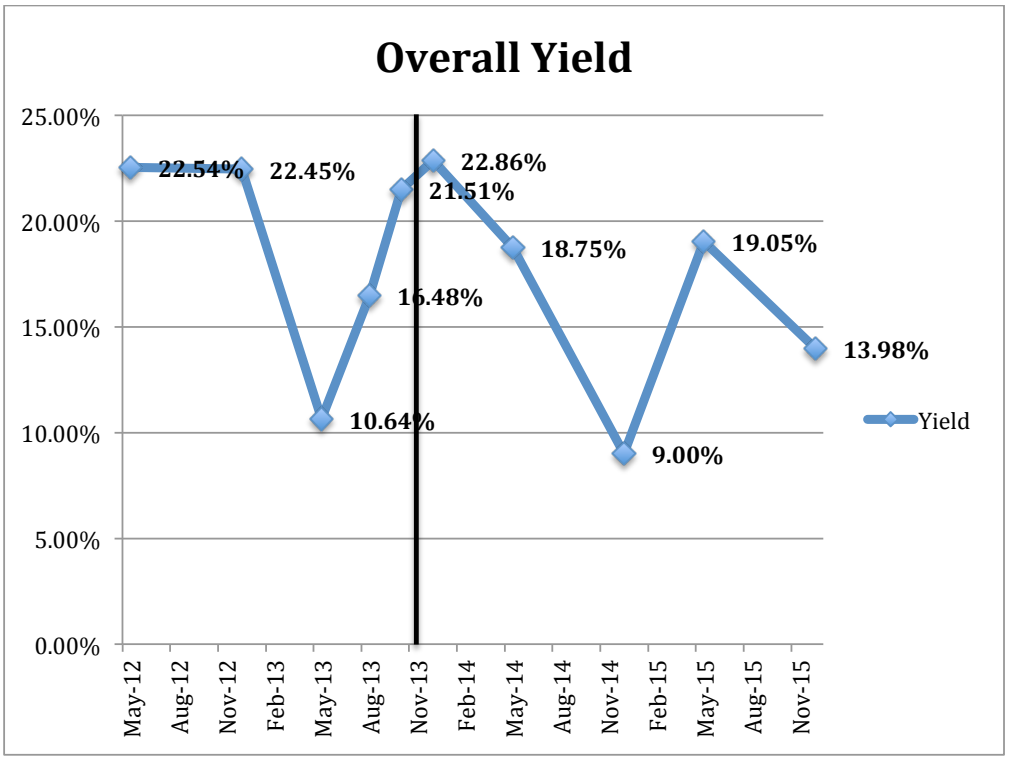

Figure 4.2 Overall yield range, with the vertical bar indicating the date of CDS implementation (November 2013)

4.4 Overall Inpatient Findings

Overall, there was a great variance observed in Inpatient yield values. Figure 4.3, overleaf, demonstrates a drastic variability of yield values from May 2012 to

December 2015. The lowest yield value for Inpatients was seen in May 2015 (7.41%) and the highest (i.e. best) yield was seen prior to the intervention, in October 2013 (27.5%). The square points on the line represent the study months observed. The vertical black line represents the date of CDS implementation – November 2013. Table 4.1 earlier in this chapter outlines the study numbers for Inpatients throughout the study. The Inpatient yield pre-CDS was found to be 22.09% (n=36) and the Inpatient yield post-CDS was 17.54% (n=40). This represents a statistically significant decrease of 4.55% post-CDS, as outlined in Chapter 5.

It is worth noting that while the overall number of positive findings increased post-CDS, so too did the total number of CTPA examinations performed (n=163) as compared to pre-CDS implementation figures (n=228). This represents a total increase of 65 CTPA examinations performed post-CDS. Considering the total number of Inpatients, this is a relatively large increase in the proportion of studies performed post-CDS (39.88%).

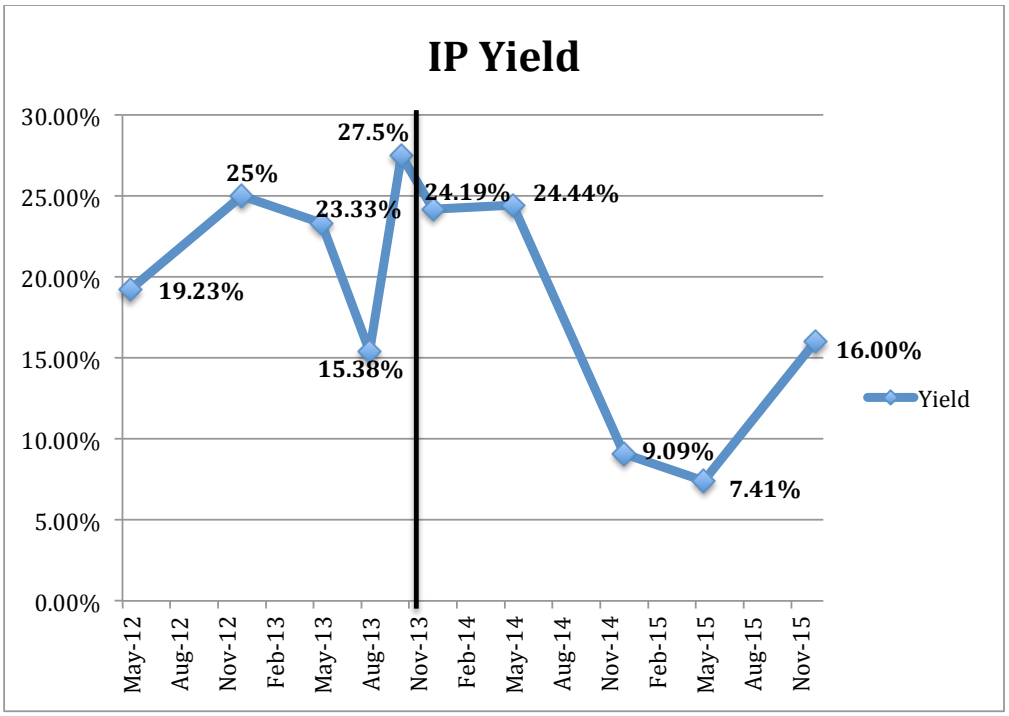

Figure 4.3 Inpatient **yield range**, with the vertical bar indicating the date of CDS implementation (November 2013)

4.5 Overall Emergency Department Findings

Overall, there was a great variance observed in Emergency Department yield values. Figure 4.4, overleaf, demonstrates the tortuous variability of Emergency Department yield from May 2012 to December 2015. The lowest yield value was observed in May 2013 (4.76%) and the highest yield was observed in two months – May 2012 and May 2015 (25%). The yield value seen in May 2013 was the lowest recorded throughout the entirety of the study (4.76%). The square points on the line represent the study months observed. The vertical black line represents the date of CDS implementation – November 2013. Earlier in this chapter, Table 4.1 demonstrates the average yield values from the study months both pre-CDS and post-CDS. The Emergency Department yield pre-CDS was found to be 14.78% (n=34) and the Emergency Department yield post-CDS was 15.95% (n=37). It portrays a statistically insignificant increase of 1.17%. The significance of such is discussed in Chapter 5.

Albeit statistically insignificant, the Emergency Department is the only location whereby an increase in yield was noted post-CDS implementation. The detail of such is expanded on in Chapter 5. It is worth noting that while the overall number of positive findings increased post-CDS, so too did the total number of CTPA examinations performed (n=232) as compared to pre-CDS implementation figures (n=230). This represents a minor increase of 2 CTPA examinations performed post-CDS. This is significantly lower than the total increase in study numbers seen overall (n=64) and from Inpatient locations (n=65). Considering the total number of Emergency Department patients, there is a relatively small increase in the proportion of studies performed post-CDS (0.87%), compared to pre-CDS patient numbers.

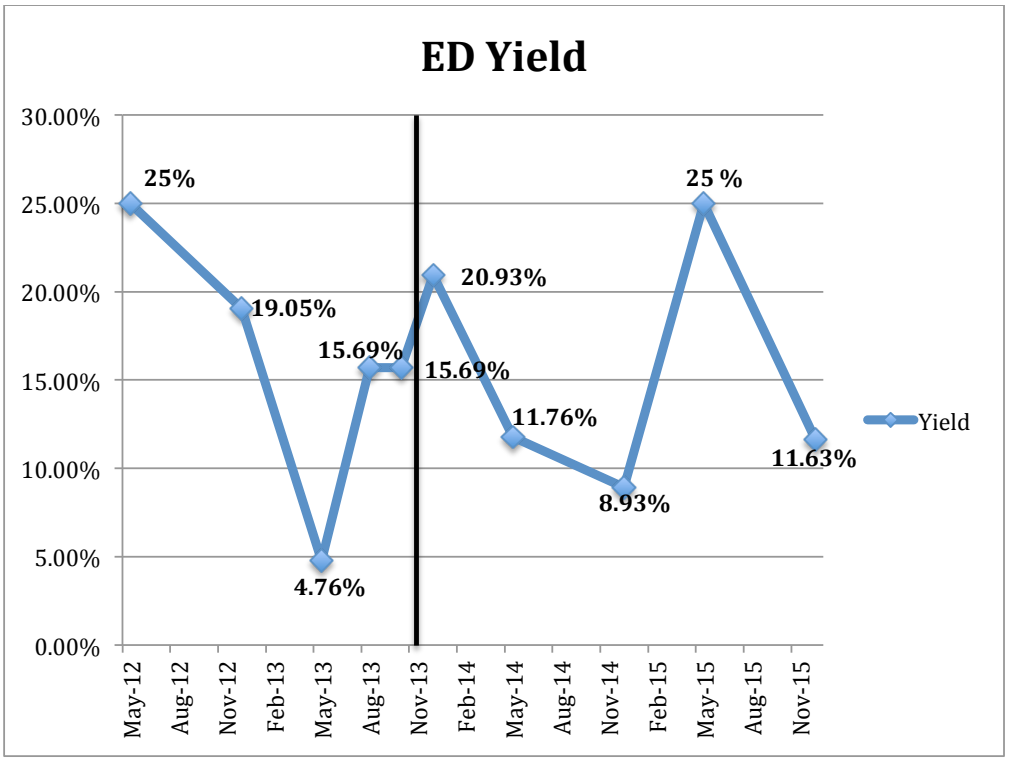

Figure 4.4 Emergency Department yield range, with the vertical bar indicating the date of CDS implementation (November 2013)

4.6 Overall Study Yields

The study yields from all locations observed throughout the study are outlined in Figure 4.5, overleaf. Once again, the vertical black line represents the date of CDS implementation – November 2013. Representation of data includes each of the 10 study months observed throughout the study. This includes overall study yield (all patients), Inpatient study yield and Emergency Department yield. The drastic variance between the areas listed is apparent on a month-to-month basis, as also seen for each patient location individually in sections 4.12, 4.13 and 4.14.

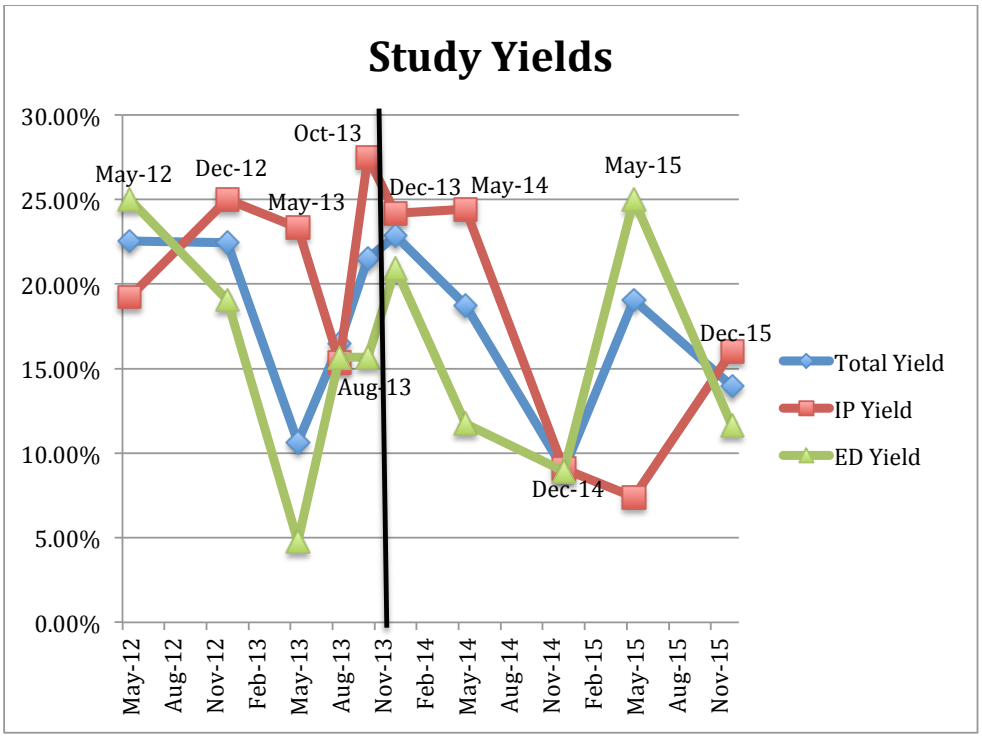

Figure 4.5. Total study yields (all patients, Inpatients, Emergency Department patients), with the vertical bar indicating the date of CDS implementation (November 2013)

4.7 Analysis by Consultant

All CTPA examinations throughout the course of the study were divided into referring consultant in table form. This was divided into pre and post-CDS implementation for comparison in yield, where available. The findings were not included in the discussion as with 80 consultant teams analysed, any statistics by consultant would likely be statistically insignificant.

Appendix D provides the numbers of CTPA orders as well as positive PE findings throughout the course of the study as per each attending consultant. The columns are divided into pre-CDS and post-CDS findings. All Emergency Department patients are assigned a generic ED consultant, this account for 53.72% (n=462) of all studies (n=860).

4.8 Conclusion

The results provided have displayed an overall tortuous variance of yield values over the course of the study. An initial minor increase in overall and Emergency Department yield is noted immediately following implementation of CDS when comparing 1 month pre-CDS and 1 month post-CDS. This is not the case for Inpatient yield when observing the same study dates. A thorough evaluation of the given results is provided in Chapter 5.

Chapter 5: Data Analysis and Discussion

5.1 Introduction

The objective of this study is to analyse the use of CDS within radiology ordering systems. The focus was on CTPA exam ordering and the appropriateness of such for diagnosing PE. Overall, the main objective was to answer the research question:

"Has the use of CDS improved the appropriateness of radiology ordering of CTPA examinations for the diagnosis of PE?"

This chapter aims to discuss the findings relating to the research question as well as outlining the statistical methods used. Statistical analysis of data collected occurred by means of determining P-values and Z-scores pre and post implementation of CDS. More detail is provided in the following section of this chapter, 5.2.

The yield gradually increased in the months prior to implementation of the Wells Score and D-dimer questions. It is possible that this is a result of the increased demand for clinicians to include this information in the clinical indications field as radiologists and performing radiographers were continuing to seek this information before it became mandatory on the order entry form.

The Emergency Department (ED) accounts for the majority of CTPA orders throughout the course of the study (53.72%), when compared to Inpatients (45.47%) and Outpatients (0.81%). However, the overall yield from ED was found to be the lowest (14.78% pre-CDS and 15.95% post-CDS) when compared to that of all patients (18.09% pre-CDS and 16.67% post-CDS), all Inpatients (22.09% pre-CDS and 17.54% post-CDS) and all Outpatients (28.57%). These figures, including the raw data, are available in Table 4.1. This remains the case (on average) over the course of the study – with the exception of some outliers as seen in certain

months, as outlined in Chapter 4. CTPA orders are infrequently seen for Outpatients. During the entirety of the study, a total number of 7 orders were placed for Outpatients – 2 of which were for a routine follow-up appointment and the other 5 were patients who were seen in clinics and had CTPA examinations performed as urgent cases. 2 of the urgent Outpatient department (OPD) patients were found to be positive for the presence of PE. This accounts for 28.57% (n=2) of all Outpatients (n=7). As the total number of Outpatients (OP) was relatively low, they were not included in the analysis as a separate entity. They are, however, included in the total patient figures.

5.2 Statistical Analysis

The Z-score test, as outlined in Chapter 3, proved most appropriate statistical analysis tool as it allows for an analysis of two distinct populations (CTPA patients pre and post-CDS). Z-score tests are used to measure the standard deviation of a sample, i.e. if 2 populations (pre and post-CDS implementation CTPA studies) differ significantly on a single characteristic (presence of PE).

To perform this calculation, a sample of patients both pre and post-CDS were selected from a chosen population (patients who underwent CTPA examinations in certain months surrounding the implementation of CDS). The presence of PE was the categorical characteristic chosen for comparison. It allows for the calculation of the significance between these 2 populations, as mentioned above, based on the yield of CTPA results for the presence of PE.

The following equation is used to find the Z-score for 2 population proportions:

$$Z = \frac{(\hat{p}_1 - \hat{p}_2) - 0}{\sqrt{\hat{p}(1-\hat{p})\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$$

The following is a description of each component of the z-score calculation formula:

- **$p\hat{}_1$** The yield proportion of the first population (pre-CDS)
- **$p\hat{}_2$** The yield proportion of the second population (post-CDS)
- **$p\hat{}$** The total yield proportion of both populations (pre and post-CDS)
- **n_1** Total number of CTPA examinations for the first population (pre-CDS)
- **n_2** Total number of CTPA examinations for the second population (post-CDS)
- **0** Testing using the null hypothesis – that there is no difference between the two populations

As outlined in Chapter 3, Z-score test calculations compare two population proportions with individual samples. This hypothesis test will prove the significance between two proportions. The following steps are followed to determine the best statistical analytical process and carry out the most suitable calculation:

1. State hypothesis – Null hypothesis used in this case. As outlined in Chapter 3, a null hypothesis was chosen to disprove that the proportion of yield difference pre and post-CDS implementation will differ.
2. Formulate an analysis plan to accept or reject null hypothesis – Significance level of 0.05 is used in this case. Two-proportion Z-score test is the test method used in this case also. These are conventionally used, as described in Chapter 3. By using a significance level of 0.05, all equated P-values <0.05 are considered statistically significant. Equated P-values >0.05 are not considered statistically significant. P-values <0.05 suggest that the sample provides enough evidence to reject the null hypothesis for the population.
3. Analyse all data to find test statistic and P-value – Performed by calculating pooled sample proportion, standard error, test statistic and ultimately the P-value, as described in Chapter 3.

4. Interpretation of results – P-value compared to significance levels in order to out-rule a null hypothesis. Null hypotheses are rejected whereby the P-value is less than the significance level.

Using the results, as outlined in Chapter 4 and earlier in Chapter 5, a calculation of P-values determines the significance of the difference in yield pre and post-CDS implementation at pre-determined intervals. The following were analysed: All patients pre and post-CDS; Emergency Department patients pre and post-CDS; Inpatients pre and post-CDS; All patients 1 month pre and post-CDS; All patients 6 months pre and post-CDS; All patients 12 months pre and post-CDS; All patients 18 months pre and post-CDS.

5.2.1 All patients pre and post-CDS

The following results relate to all CTPA examinations observed pre-CDS compared to all CTPA examinations observed post-CDS. The Z-score is 0.5501. The P-value is 0.58232. The result is not significant at $p < 0.05$. The proportion of positive PE findings for all patients pre-CDS is 0.181. The proportion of all patients post-CDS is 0.167. The yield post-CDS was found to be lower, however it was not significantly lower than pre-CDS. Based on the data analysed, CDS in this case was not found to have a significant effect on the yield nor the appropriateness of CTPA ordering. The findings of the research are disappointing. It was hoped that by implementing CDS, the yield would be significantly higher thereafter. Not only was the difference insignificant, the yield was found to be even lower post-CDS in the months selected for analysis.

As demonstrated in Table 4.1 and Figure 4.2, the yield varies dramatically over the course of the study. It is seen to rise rapidly preceding the implementation of CDS on CTPA orders. The earliest study figures show relatively high yields of 22.54% and 22.45% in May 2012 and December 2012 respectively. In May 2013 it was dramatically lower at 10.65%, August 2013 the yield was 16.48%, and just three months later in October 2013 it was higher again at 21.51%. This saw a torturous

reduction of 11.8% rise of 10.86% over the course of 12 months prior to CDS implementation – December 2012 to November 2013. In May 2014, 6 months following implementation of CDS, the yield is seen to reduce slightly to 18.75%. 7 months later, in December 2014 the yield reaches an all-time low of just 9%. It then rises again and is not seen to reach a level any lower than 13.98% for the remainder of the study. This would suggest that surrounding the time of implementation (November 2013) there was a greater focus on the appropriateness of CTPA orders.

Improving the appropriateness of CTPA orders was the main focus of such implementation. It is possible that the higher yield values surrounding November 2013 are as a result of closer monitoring of CTPA orders and more strict criteria being applied in the approval of CTPA studies, as per radiological guidelines. Throughout the course of the study, the highest yield of 22.86% was seen in December 2013 – the month following implementation. Overall the yield was shown to decrease insignificantly by 1.42%, as conveyed in Figure 13 Chapter 4. This is suggestive of an ineffective CDS system.

5.2.2 Inpatients pre and post-CDS

The following results relate to all Inpatient CTPA examinations observed pre-CDS compared to all Inpatient CTPA examinations observed post-CDS. The Z-score is 2.0271. The P-value is 0.04236. The result is significant at $p < 0.05$. The proportion of positive PE findings for all Inpatients pre-CDS is 0.265. The proportion of all Inpatients post-CDS is 0.175. The yield post-CDS was found to be significantly lower than pre-CDS. Based on the data analysed, CDS in this case was found to have a significant negative effect on the yield and therefore the appropriateness of CTPA ordering. The yield was found to have significantly reduced as a result.

As demonstrated in Table 4.1 and Figure 4.3, the highest yield (27.5%) was seen in October 2013 for Inpatient CTPA examinations. This was the month preceding implementation of CDS. It is closely followed by 12 months pre-CDS

implementation (December 2012) whereby the Inpatient yield was 25%. Immediately following implementation of CDS yield values remained steady at 24.19% in December 2013 and 24.44% in May 2014. This result is encouraging for the value of CDS within CTPA ordering. This may be due to the Hawthorne effect whereby participants are aware of observation and so act more favourably (McCarney et al. 2007). Months later, in both December 2014 and May 2015 the yield values were disappointing at 9.09% and 7.41% respectively. Yield values increase thereafter to 16% by December 2015.

Inpatient orders account for 45.47% (n=391) of all CTPA orders throughout the course of the study. Overall, Inpatient yield declines by 4.55% post-implementation of CDS. This, as mentioned earlier, is a significant decrease in yield values. These figures are disappointing and require further evaluation to investigate their validity.

5.2.3 Emergency Department patients pre and post-CDS

The following results relate to all Emergency Department CTPA examinations observed pre-CDS compared to all Emergency Department CTPA examinations observed post-CDS. The Z-score is -0.3474. The P-value is 0.72634. The result is not significant at $p < 0.05$. The proportion of positive PE findings for all Emergency Department patients pre-CDS is 0.148. The proportion of all Emergency Department patients post-CDS is 0.159. Based on the analysed data, CDS in this case was not found to have a significant effect on the yield.

As demonstrated in Table 4.1 and Figure 4.4, and as with overall yield values, the Emergency Department yield values vary dramatically over the course of the study. The highest yield (25%) is seen in May 2015 – 18 months following implementation of CDS. The lowest yield from ED is seen in May 2013 at 4.76%.

As conveyed in Chapter 4, the Emergency Department yield was seen to increase overall, albeit insignificant, by 1.17%. However, the ED yield values are low when

compared to overall yield values. This suggests that learning initiatives from the implementation of CDS may be slightly improving the appropriateness of CTPA ordering. During the course of this study, 53.72% of CTPA studies (n=462) originated from ED. Targeted education to a single area would prove beneficial and effective. This is further discussed later in this chapter.

5.2.4 All patients 1 month pre and post-CDS (Oct 2013, Dec 2013)

The following results relate to CTPA examinations observed 1 month pre-CDS compared to CTPA examinations observed 1 month post-CDS. The Z-score is -0.2283. The P-value is 0.8181. The result is not significant at $p < 0.05$. The proportion of positive PE findings for all patients 1 month pre-CDS is 0.215. The proportion of all patients 1 month post-CDS is 0.229. Based on these figures, CDS in this case was not found to have a significant effect on the yield nor the appropriateness of CTPA ordering.

5.2.5 6 months pre and post (May 2013, May 2014)

The following results relate to CTPA examinations observed 6 months pre-CDS compared to CTPA examinations observed 6 months post-CDS. The Z-score is -1.5203. The P-value is 0.12852. The result is not significant at $p < 0.05$. The proportion of positive PE findings for all patients 6 months pre-CDS is 0.106. The proportion of all patients 6 months post-CDS is 0.188. Based on these figures, CDS in this case was not found to have a significant effect on the yield nor the appropriateness of CTPA ordering.

5.2.6 12 months pre and post-CDS (Dec 2012, Dec 2014)

The following results relate to CTPA examinations observed 12 months pre-CDS compared to CTPA examinations observed 12 months post-CDS. The Z-score is

2.2464. The P-value is 0.02382. The result is significant at p <0.05. The proportion of positive PE findings for all patients 12 months pre-CDS is 0.224. The proportion of all patients 12 months post-CDS is 0.09. In this case, CDS was found to have a significantly negative effect on the yield of CTPA studies.

5.2.7 18 months pre and post (May 2012, May 2015)

The following results relate to CTPA examinations observed 18 months pre-CDS compared to CTPA examinations observed 18 months post-CDS. The Z-score is 0.5345. The P-value is 0.59612. The result is not significant at p <0.05. The proportion of positive PE findings for all patients 18 months pre-CDS is 0.225. The proportion of all patients 18 months post-CDS is 0.19. Based on these figures, CDS in this case was not found to have a significant effect on the yield nor the appropriateness of CTPA ordering.

5.3 Completeness and Accuracy of Data Entered

In an attempt to understand how those ordering CTPA examinations use the CDS system, the completeness and accuracy of the D-dimer field for a randomly selected month (May 2015) was analysed. Completeness refers to the presence of a D-dimer value in the log of the CDS system interaction. Accuracy in this case refers to whether the D-dimer value entered into the CTPA CDS matches the value in the hospital's laboratory system. This involved searching the lab system for recent (usually same day) D-dimer test results for each patient for whom a CTPA had been ordered. Table 5.1, overleaf, provides the results.

An interesting observation was made during this analysis – in many cases the D-dimer value provided to the CDS was a whole number, whereas D-dimes are usually given with two decimal places. On further inspection, it transpired that these D-dimer values were a replica of the entered Wells Score. The frequency of this occurrence is shown in Table 5.1.

32.14% (n=27) of patients in the month of May 2015 had D-dimer results completed on the order form. Only 22.22% (n=6) of these orders had the correct value entered. 51.85% (n=14) of requests had the same value entered in the D-dimer score field as the Wells Score field. One major downfall of the CDS system used in this study is that D-dimer fields can be left empty without warning or a prompt to enter a value. It is believed that if this were the case, more D-dimer values would have been provided when requested.

Table 5.1 Completeness and Accuracy of D-dimer values as entered (May 2015)

May 2015	
Total number of CTPA orders	84
Number of CTPA orders containing Wells score	94.05% (n=79)
Orders with D-dimer value entered	32.14% (n=27)
Orders with accurate D-dimer value entered	22.22% (n=6)
Orders with matching Wells Scores and D-dimer value	16.67% (n=14)
Number of CTPA orders whereby Wells Score <4	15.48% (n=13)
Number of CTPA orders missing D-dimer value when requested (Wells Score <4)	15.38% (n=2)
Proportion of accurate D-dimer values entered	22.22%

41.67% (n=30) of all CTPA examinations post-CDS whereby the Wells Score was less than 4 (n=72) did not include a D-dimer value when prompted to do so. This only includes empty fields or non-numerical values. It does not include erroneous entries.

It was also found that 8.23% (n=38) of all CTPA orders (n=462) did not contain a Wells Score value. This is a mandatory field. Some of the values entered included a single punctuation, such as a full stop or a backslash, or simply 'na'. These CTPA examinations were still performed however it is unknown if the Wells Score was communicated otherwise and not recorded on the order form. Across all CTPA examination orders post-CDS (n=462), the Wells score and the D-dimer value were found to be suspiciously matching in value 15.15% of the time (n=70)

5.3.1 Data Entry

The accuracy of data can be questioned when manually entered. Gupta et al. (2014) carried out a study that observed the accuracy of physician-entered clinical decision support (CDS) data when ordering radiology studies. They focused on the entry of D-dimer results when ordering CTPA studies. The values entered were directly compared to those from the laboratory results system. More than 90% of values manually entered by physicians were found to be accurate when compared with lab results. It is well noted that inaccurate entry of D-dimer values can result in the inappropriate use or non-use of CTPA examinations. Furthermore, recommendations are made to reduce erroneous data entry by auto-filling the data fields directly from the lab system. This is ultimately achieved by integrating the electronic patient record with ordering systems and CDS (Gupta et al. 2014).

This, however, is not the case in this research project. It is possible that the method of data collection was arduous or that the instructions were not clear enough to the requesting physician, as it was an extension of the Wells Score question and not a D-dimer question on its own. Instructions should be as clear and easy to follow as reasonably possible to ensure accurate data entry.

5.4 Conclusion

There were no positive signs of statistically significant changes in yield since the implementation of CDS. This would suggest that the introduction of CDS in this case did not have a significant effect on the appropriateness of CTPA ordering, concerning the yield. It is suggested that the CDS is reviewed and further monitored with possible changes made if possible to improve the quality of the data provided.

However, there are positives to note in that the Wells Score is now included on most of the requests for CTPA examinations as a result of the CDS initiative. This is a positive step towards a more appropriate order, given the compliance as suggested by the RCR guidelines.

It is noted that the yield gradually increased in the months prior to implementation of CDS. It is possible that this is a result of the increased demand for clinicians to include this information in the clinical indications field as radiologists and performing radiographers were continuing to seek this information before it became mandatory on the order entry form. It may also be as a result of the Hawthorn effect. McCambridge et al. describe the Hawthorne effect as:

> "Awareness of being observed or having behaviour assessed engenders beliefs about researcher expectations. Conformity and social desirability considerations then lead behaviour to change in line with these expectations" (2014, p.268)

This would purport that behavioural changes were made to ensure relevant data was provided, prior to the impending CDS implementation. This was most likely the case as the intervention possibly resulted due to pertinent Wells Score data regularly being omitted from CTPA requests. This would avoid any delays in

patient care and scheduling. Unfortunately, this is not possible to accurately assess.

Of the data gathered, it is difficult to truly establish the accuracy as a whole. The Wells Score is not possible to measure without clinically assessing the patient. For this reason, the validity of the data is questionable. Additionally, as previously mentioned, the validity of the D-dimer results was questioned. These were easily measured and found to be inaccurate in 22.22% of cases, see Table 5.1 for further details.

Chapter 6: Conclusion

It was found that literature has remained consistent over the last two decades in portraying CDS as a beneficial tool in reducing errors, saving time and assisting compliance with clinical guidelines (Haynes and Wilczynski 2010, Huber et al. 2015, Kaplan 2001, Lehnert and Bree 2010, Marcos et al. 2013, Rosenthal et al. 2006, Zafar et al. 2012).

It transpired that the use of CDS, irrespective of which CDS exactly, is more beneficial than the use of no CDS at all (den Exter et al. 2014). From observing the use of CDS throughout the study, it is apparent that this may still be the case, irrespective of the difference in yield pre and post-CDS and the statistically insignificant results found. The CDS has a duty of allowing for the provision of critical data from the requesting physician. In this case the system requested the Wells Score value. This value is important to note before commencing a CTPA examination, as per the RCR (2012) guidelines. CDS implementation ensured that this value was sought for each CTPA requested. For this reason alone it was successful in improving the appropriateness of CTPA orders.

Note is made of the risks involved in CDS implementation. One such risk is for users to learn to game the system. This is the case whereby users can input certain data fields to ensure the procedure type desired is performed. This is done through learning what the system is expecting to return certain procedure types. Also, CDS requires the valuable input of several stakeholders to ensure the best product is delivered (Huber et al. 2015). Additionally, a resistance to change can prove problematic and therefore disruption must be minimised and ease of use maximised to ensure adoption of CDS systems (Huber et al. 2015, Rosenthal et al. 2006).

However reliant and often extremely valuable, CDS cannot be used in isolation for decision-making purposes in clinical settings. Clinical judgement is highly valuable and so CDS should be treated merely as an aid when available (Remedios et al.

2014a). CDS is not expected to cover all clinical scenarios (Raja et al. 2014). Rather it is a potentially functional tool to provide guidance for users. It is best used and more widely accepted when integrated into current radiology information systems (RIS), electronic ordering systems and hospital information systems (HIS). It is not intended to commandeer the role of a radiologist, radiographer or physician alike (Remedios et al. 2014a).

Patient records and CTPA examination orders were assessed for a total of 10 months surrounding the implementation of CDS relating to Wells Score and D-dimer results. A total of 860 CTPA examination records were assessed for the presence of PE between May 2012 and December 2015. 5 months of CTPA examinations were assessed pre-implementation and 5 months post-implementation. On average, the yield pre-CDS implementation was 22.09%. The yield post-CDS implementation was slightly decreased at 16.67%. Overall, the total yield of positive CTPA studies for the presence of PE saw a statistically insignificant decrease of 5.42% post implementation of CDS, as outlined in Chapter 5.

The results provided have displayed an overall tortuous variance of yield values over the course of the study. An initial minor increase in overall and Emergency Department yield is noted immediately following implementation of CDS when comparing 1 month pre-CDS and 1 month post-CDS. This is not the case for Inpatient yield when observing the same study dates. A thorough evaluation of the given results is provided in Chapter 5.

6.1 Limitations of the Study

The study provided the author with an opportunity to highlight the strengths and weaknesses of the current CDS initiative in place for CTPA ordering. A major downfall of the system evaluated is the lack of feedback or education provided. It does not offer a tool to calculate the Wells score, nor does it provide a reason for requesting such information. It does mention that a chest x-ray must be performed initially to rule out an alternative diagnosis to explain the patient's

symptoms before a CTPA will be performed. This is the only actionable recommendation made by the system. As it is merely a side-note, it is possible for system users to dismiss it and proceed with the order. Guidelines and recommendations should be made clear and concise and require the user to actively accept them.

Validity of data was questionable throughout the course of the study. Of the data gathered, it is difficult to truly establish the accuracy as a whole. The Wells Score is not possible to measure without clinically assessing the patient. For this reason, the validity of the data is questionable. Additionally, as mentioned previously, the validity of the D-dimer results was questioned. These were easily measured and found to be inaccurate 22.22% of the time, see Table 5.1 for further details.

Other limitations included a lack of access to full data sets for each CTPA order. For example, only a limited amount of the clinical indications field was included on the data sheets. This could have proven beneficial in the gathering of data for a more in-depth look at the ordering system as a whole. It was also not possible to assess any cancelled orders. It would also prove beneficial to establish if a request had been initialised but was subsequently terminated based on the CDS intervention indicating to the requesting physician that the examination is not indicated.

6.2 Dissemination of Findings

A dissemination of findings will be presented to the hospital that participated in the research. It is hoped that recommendations will be taken on board and it will motivate the radiology department to partake in more rigorous monitoring of systems, particularly those newly implemented It is also hoped that an expansion of CDS will be seen across the department for other specialist examination ordering. The study was encouraged by the radiology team in the hospital and will hopefully encourage future work.

6.3 Recommendations

Kawamoto et al. (2005) carried out a systematic review to reveal key features to improve the success of CDS systems. From the findings, the following actionable recommendations were made:

- Include CDS in clinician workflow automatically, as found in 75% of CDS interventions observed. All other CDS systems were unsuccessful when users were forced to seek the advice of the CDS manually.
- Provide real time CDS, as and when required. These were more effective than systems that did not provide direction at the point of care.
- Offer actionable alternatives and/or recommendations.
- Requirement for system user to record the reason why the advice was not followed. These systems were found to be more successful.
- Ensure a computer-based system. These were found to be considerably more effective than a manual process.
- The improvement of ordering patterns was found to be apparent when CDS is incorporated into CPOE systems, thus allowing best-practice guidelines to be followed (Sanders and Miller 2001). It is also well established throughout the study that the integration of clinical data from hospital information systems and other systems e.g. laboratory systems and radiology systems, is essential to improve CDS systems (HSE 2015, Huber et al. 2015, Ip et al. 2012, Marcos et al. 2013, Schuh et al. 2015, Sistrom et al. 2009).

Miller et al. (2014) outline further recommendations when implementing CDS systems. Time-consuming notifications and reminders are frustrating to the user and tend to leave users dissatisfied with the system. The system must be seen to be helpful, a valuable asset as apposed to a hindrance. A limit of 1 minute is recommended for the time spent interacting with the CDS system to minimise frustration and encourage use (Miller et al. 2014).

Recommendations are made for more stringent monitoring of CDS systems whereby physician initiative is required – as is the case in the CDS system involved in this research project due to the lack of direction provided as well as a requirement for the physician to gather and enter all data required manually. This must be done regularly to ensure the system is providing assistance and performing the task of supporting clinical decisions as required.

The optimisation of CDS systems can prove arduous, particularly when initially implemented as a new system. Systematic reviews should be performed to ensure it is serving its intended purpose (Kawamoto et al. 2005). In the case of this research project, it is the first time a thorough evaluation of the implemented CDDS system was carried out. Based on the recommendations outlined above, the system analysed in this research project is substandard. A more automatic and actionable approach should be taken to improve the standard of the CDS. Recommendations are made to introduce an automatic provision of D-dimer results from the laboratory system as well as providing actionable recommendations and alternatives for physicians. This would reduce erroneous and null entries, when available, to improve the accuracy of the data provided and making the system more user-friendly. It is also recommended that targeted education be introduced into the CDS system to improve learning and cooperation with guidelines and standards, thus improving the quality of care to patients. Further evaluation of system features should be carried out to identify further areas of improvement. Given the time constraints of this study, it was not possible to analyse any additional features.

6.4 Reflection on the study

The study provided a thorough knowledge of CDS systems, including their successes, faults and areas for improvement. Relating to the study in question, it is important that the results are reflected upon across a wider scale. This includes the radiology department, management teams as well as the CT department to

ensure a strategic plan is devised for further improvements to be made. Whilst the findings of the CDS implementation were not found to be statistically significant in this case, it did allow for the inclusion of critical information on CTPA orders at the time of ordering. This allows for a real-time evaluation of requests to determine their suitability based on the pertinent information provided. This high quality data is imperative to patient care.

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Appendices

Appendix A: Communication with Royal College of Radiologists

The Royal College of Radiologists

Permission request

Date: 11th January 2016

Your name: Sarah Moore

Name of organisation: Trinity College Dublin

Your telephone number: (00353)861061726

Your email address: smoore2@tcd.ie

Title of RCR publication: iRefer Guidelines: Making the best use of clinical radiology - Version 7.0.2

Date of RCR publication: January 2012

Publication code (if known):

Page(s) (please make clear if you are extracting information or wish permission to reproduce in its entirety): Just section CC04 Suspected Pulmonary Embolism (PE), including all information regarding this section – all complete info, investigation details, dose details, recommendation [grade] details and comment information details.

Information about how you would like to reproduce the material: I wish to include it in my appendices for a research thesis at MSc Level in part completion of the MSc Health Informatics (Trinity College Dublin). My research is looking at the use of clinical decision support when requesting CTPA studies in the diagnosis of suspected PE's. The title of such will be "Has CDS improved the appropriateness of CTPA ordering when investigating suspected pulmonary embolisms?"

If the material is to appear in another title/publication please list the following:

Publisher:

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The Royal College of Radiologists

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Many thanks,

Sarah Moore

Clinical Radiology
The Royal College of Radiologists

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T. +44(0)20 7405 1282 enquiries@rcr.ac.uk
www.rcr.ac.uk

Ms Moore
Trinity College Dublin
12 June 2016

Dear Ms Moore

Re: Request for permission to reproduce CCO4 from *iRefer: making the best use of clinical radiology,* Seventh edition

Further to your recent email requesting permission to reproduce CCO4 of *iRefer: making the best use of clinical radiology*, Seventh edition in your MSc thesis, permission is granted for you to reproduce the un-referenced text which belongs to the RCR subject to the following conditions:

1. The Royal College of Radiologists must be rightfully acknowledged as the source of the material (such as 'Reproduced with permission from The Royal College of Radiologists')
The Royal College of Radiologists. *iRefer: making the best use of clinical radiology, Seventh edition.* London: The Royal College of Radiologists, 2012.
2. Our materials must not reproduced by a third party.
3. As the document may be updated from time to time, it is your responsibility to ensure that your material is updated and older material withdrawn.

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Kind regards

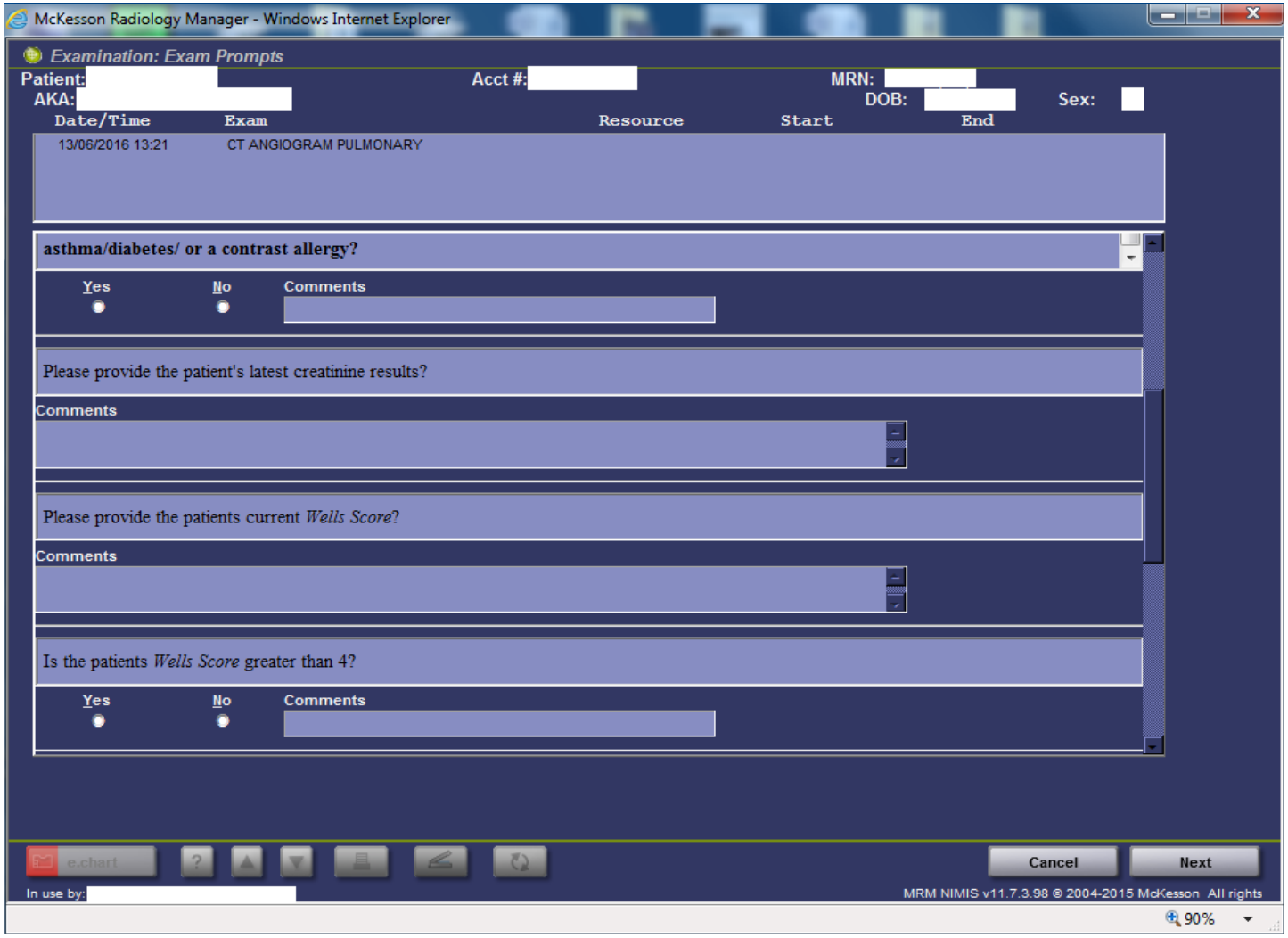
Holly Benson
Publications and Website Officer
The Royal College of Radiologists

Appendix B: RCR Guideline CC04

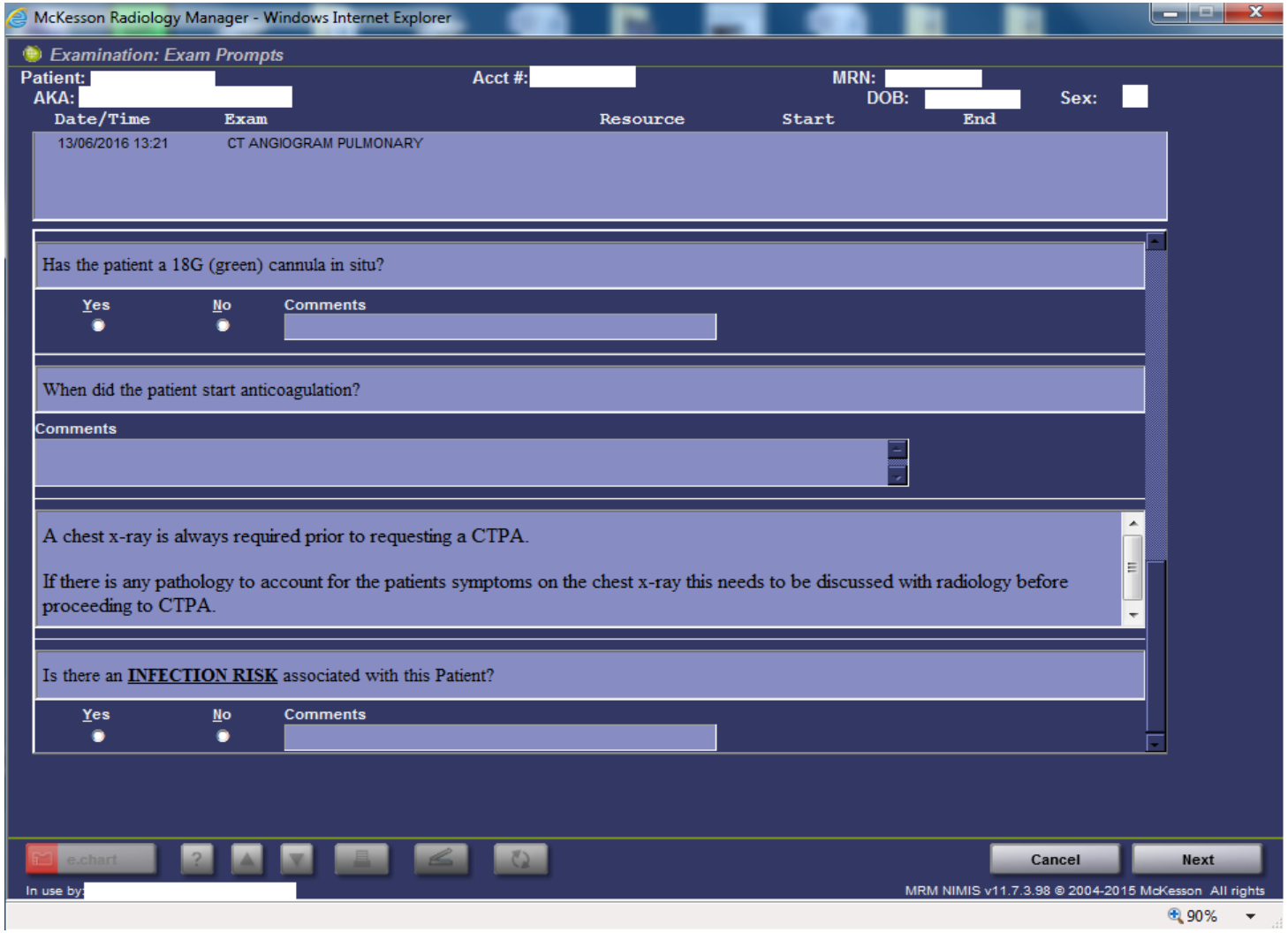
CC04: Suspected pulmonary embolism (PE) **Wells' criteria:** • Symptoms of DVT: 3 pt • No alternate diagnosis: 3 pt • Heart rate >100/min: 1.5 pt • Immobilisation or surgery: 1.5 pt • Previous DVT or PE: 1.5 pt • Haemoptysis: 1 pt • Malignancy: 1 pt Score of ≤6 need D-dimer first				*To diagnose or to exclude thromboembolic disease, it is helpful to use an agreed protocol combining clinical features, pre-test probability and results of D-dimer assay in order to utilise imaging appropriately.* *In patients with high clinical suspicion but indeterminate CTPA or VQ scan, US/CT/MRI venography may help to diagnose thromboembolic disease. Choice of technique will depend upon local expertise and radiation risk. Routine CT venography with CTPA does not change the outcome.*
	CXR	0	Indicated [B]	CXR should be the preliminary investigation to demonstrate consolidation and pleural effusion, but a normal CXR does not exclude a pulmonary embolus.
	CT pulmonary angiography (CTPA)	0 0 0	Indicated [A]	Investigation of choice in patients with high clinical suspicion or those with moderate to low pre-test probability but positive D-dimer assay particularly in

				those with existing pulmonary abnormalities on CXR. Allows diagnosis of alternative causes of chest pain, assessment of right ventricle and main pulmonary artery.
CC04	NM (ventilation–perfusion scintigraphy)	0 0	Indicated [B]	VQ scintigraphy is an alternative to CTPA in patients without pre-existing pulmonary disease and with normal CXR. In view of the lower radiation dose, VQ scintigraphy should be considered as first choice in young patients, particularly during pregnancy. A normal perfusion scintigram excludes clinically significant pulmonary emboli. VQ scintigraphy is also helpful in patients with suspected chronic pulmonary thromboembolism.
	MRA	None	Indicated only in specific circumstances [B]	MR pulmonary angiography may be considered when CTPA is contraindicated, and when ventilation–perfusion scintigraphy is unlikely to be helpful in the presence of an abnormal CXR.

Appendix C: Screenshot of CDS




McKesson Radiology Manager - Windows Internet Explorer
Patient: DUCK, DAFFY
Acct #: 6144154(BH)
MRN: 88888(BH)
AKA: DUCK, DAFFY R90001234
DOB: 07/02/1955
Sex: M
Date/Time
Exam
Resource
Start
End
16/06/2016 09:35
CT ANGIOGRAM PULMONARY
Please provide the patients current Wells Score?
Comments
Is the patients Wells Score greater than 4?
Yes
No
Comments
•IF WELLS SCORE IS 4 OR BELOW, PLEASE PROVODE D-DIMER RESULTS IN THE COMMENTS BOX ABOVE.
Has the patient a 18G (green) cannula in situ?
Yes
No
Comments
When did the patient start anticoagulation?
Comments
A chest x-ray is always required prior to requesting a CTPA.
If there is any pathology to account for the patients symptoms on the chest x-ray this needs to be discussed with radiology before proceeding to CTPA.
Is there an INFECTION RISK associated with this Patient?
Yes
No
Comments
Cancel
Next
In use by: MOORE, SARAH, A/PACS MGR
MRM NIMIS v11.7.3.98 © 2004-2015 McKesson All rights reserved
80%


McKesson Radiology Manager - Windows Internet Explorer
Examination: Exam Prompts
Patient:
Acct #:
MRN:
AKA:
DOB:
Sex:
Date/Time
Exam
Resource
Start
End
13/06/2016 13:21
CT ANGIOGRAM PULMONARY
Has the patient a 18G (green) cannula in situ?
Yes
No
Comments
When did the patient start anticoagulation?
Comments
A chest x-ray is always required prior to requesting a CTPA.
If there is any pathology to account for the patients symptoms on the chest x-ray this needs to be discussed with radiology before proceeding to CTPA.
Is there an INFECTION RISK associated with this Patient?
Yes
No
Comments
e.chart
Cancel
Next
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90%

Appendix D: Consultant Yield Values Pre and Post-CDS

	Pre-CDS			Post-CDS		
Consultant	**No. of CTPAs performed**	**PE Findings**	**Yield**	**No. of CTPAs performed**	**PE Findings**	**Yield**
C1	2	1	50%	3	1	33%
C2	2	1	50%	0		
C3	0			2	0	0%
C4	2	0	0%	2	0	0%
C5	3	0	0%	6	1	17%
C6	9	2	22%	7	1	14%
C7	0			1	0	0%
C8	2	2	100%	3	0	0%
C9	0			2	0	0%
C10	2	1	50%	4	1	25%
C11	5	2	40%	2	0	0%
C12	0			1	1	100%
C13	0			1	0	0%
C14	0			2	1	50%
C15	0			1	0	0%
C16	0			3	0	0%
C17	2	1	50%	1	1	100%
C18	2	0	0%	1	0	0%
C19	0			8	1	13%
C20	2	1	50%	0		
C21	232	34	15%	236	37	16%
C22	0			3	3	100%
C23	2	0	0%	1	0	0%
C24	6	2	33%	8	0	0%
C25	9	1	11%	9	2	22%
C26	4	2	50%	0		
C27	3	1	33%	6	1	17%
C28	0			2	1	50%
C29	0			1	0	0%
C30	2	0	0%	3	0	0%
C31	0			2	0	0%
C32	0			4	0	0%
C33	5	1	20%	4	0	0%
C34	1	0	0%	3	0	0%
C35	0			1	0	0%
C36	5	1	20%	2	0	0%
C37	0			1	0	0%

C38	1	0	0%	1	1	100%
C39	5	3	60%	2	1	50%
C40	1	0	0%	0		
C41	4	0	0%	4	1	25%
C42	2	0	0%	0		
C43	2	0	0%	0		
C44	2	0	0%	1	0	0%
C45	2	0	0%	7	1	14%
C46	13	3	23%	15	1	7%
C47	4	1	25%	4	1	25%
C48	0			1	0	0%
C49	0			1	0	0%
C50	3	0	0%	0		
C51	8	5	63%	10	2	20%
C52	0			7	2	29%
C53	0			3	0	0%
C54	1	1	100%	0		
C55	3	0	0%	1	0	0%
C56	4	0	0%	3	0	0%
C57	0			3	1	33%
C58	4	0	0%	0		
C59	0			2	0	0%
C60	2	0	0%	2	1	50%
C61	3	0	0%	8	0	0%
C62	0			3	1	33%
C63	0			2	1	50%
C64	3	1	33%	5	2	40%
C65	0			1	0	0%
C66	5	0	0%	4	1	25%
C67	0			2	1	50%
C68	1	1	100%	4	2	50%
C69	3	1	33%	0		
C70	0			2	1	50%
C71	0			1	0	0%
C72	0			1	0	0%
C73	5	1	20%	2	0	0%
C74	6	2	33%	7	1	14%
C75	4	0	0%	5	1	20%
C76	1	0	0%	4	0	0%
C77	1	0	0%	1	0	0%
C78	2	0	0%	3	0	0%
C79	0			1	1	100%
C80	1	0	0%	3	1	33%