

Evaluation of Stress Echocardiography Delivery in the UK

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Evaluation of Stress Echocardiography Delivery in the UK

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DECLARATION

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ABSTRACT

This thesis provides a detailed examination of stress echocardiography (SE) services within 34 different hospitals, focusing on the SE workforce and highlighting the evolving roles of doctor-led (DL) and cardiac physiologist/scientist and nursing led (CNL) services. Traditionally, SE testing has been predominantly supervised by cardiologists, with nursing and physiologist staff in supporting roles. However, increasing demand and evidenced efficiencies in service delivery have driven the growth of CNL-led services, particularly by cardiac physiologists and scientists. To evaluate the implications of this shift, the study systematically compared DL and CNL SE testing across multiple dimensions, including test modalities, patient risk profiles, workforce contributions, and outcomes.

This observational cohort study aimed to focus on four key objectives surrounding the current workforce in SE and how this is adapting to meet growing demand.

1. To describe the demographics, indications and stress echo details for the study cohort.
2. To identify the current workforce involved in delivering stress echocardiography and categorise these based on the staff's individual roles.
3. To investigate if significant differences exist in the patient group and test outcomes seen within a modelled doctor-led or cardiac physiologist/scientist and nurse-led stress echocardiography clinic
4. Also, to identify if there are any significant differences in the reporting volume and style of the different workforce groups.

Using an already established collaborative SE research network, data was collected from 34 different Trusts already involved with SE research. These Trusts, based predominately within NHS England, recruited any patient undergoing a SE test over an approximately 3-year period. The collected data examined for each Trust, the volume of SE activity, the size of the recruiting Trust, the modalities used, the risk stratification of patients, the immediate test outcomes and the training and reporting structures employed on a cohort of 8506 patients recruited over three years.

Interestingly, the results revealed that 82% of the hospitals within the study group already ran a combined DL and CNL service, resulting in 42.7% (n=3636) of all the SE activity being undertaken on a CNL list. This model was not only limited to larger Trusts.

Significant differences existed between the DL and CNL groups, but there were also many similarities. There were similarities in the test indications and in the use of dobutamine as the most common stress agent within the two groups. However, when compared, dobutamine use was significantly higher in the DL group, whilst exercise stress was higher in the CNL group

DL SE testing was focused primarily on higher-risk patients with prior cardiac investigations and evidence of cardiac damage. In contrast, CNL-led services demonstrated flexibility, performing SE testing on a broad spectrum of patients, with variable stress mediums. Notably, both groups maintained low complication rates, highlighting the safety of SE testing regardless of the supervising group.

The findings also suggest the expanding role of the CNL workforce in SE reporting. Whilst the DL group dominated reporting SE results, the study identified a growing dual and independent reporting trend among CNL practitioners, particularly cardiac physiologists and scientists in the later stages of the study.

Current training opportunities remain heavily focused on registrars and fellows within established medical pathways, leaving gaps in training for CNL professionals. This study highlights the importance of addressing these gaps, as this will be critical to ensuring the continued growth and sustainability of SE services across a multidisciplinary workforce.

This thesis concludes that the rise of CNL-led clinics reflects an essential adaptation to growing demand, enabling a more robust and flexible diagnostic pathway for patients. Future research should continue to utilise the large-scale, multi-center approach and further explore how the integration of CNL professionals can enhance the efficiency and effectiveness of SE services across diverse healthcare settings. The potential to include more of the devolved nations within future work, can only look to strengthen the national picture, and also seek to identify variations that may exist due to funding models in place.

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Statement of Intent.

The following paragraphs have been included to clarify how the contents of this doctoral thesis (DClinSci) will contribute towards a more expansive project focusing on the use of stress echocardiography, known as the British Society of Echocardiography National review of Stress Echocardiography Practice (BSE NSTEP) project. The data for this study has been acquired as part of the NSTEP network (of which I am a member). This thesis centres on clarifying and modelling the current NHS workforce delivering stress echocardiography services. The study design, research questions, data analysis, interpretation, and final written thesis have all been undertaken as part of the DClinSci programme. The structure of the DClinSci programme has facilitated a more significant in-depth look at the indications, the staffing models, the stressors used, and the test outcomes.

This thesis has focused on delivering new knowledge to the field of stress echocardiography beyond what was previously known around the workforce, focusing on the doctor and healthcare science and nursing teams working in the stress echo field. This level of investigation into the stress echo workforce has never, to our knowledge, been undertaken before and will contribute to supporting further development in this field. The contents of this thesis will, in time, be formatted into a manuscript for publication as part of the wider NSTEP group, where I will be the lead author.

In addition to this workforce summary, follow-up (post-stress echo long-term data) data was obtained from a large number of patients who were recruited into the study. This data was requisitioned via the appropriate channels from the NHS digital services (application no. DARS-NIC-620484-W0B2K) over a period of 18 months as part of the DClinSci programme. However, contractual issues arose around the different higher education institutions involved and the primary use of the data. Subsequent restrictions were imposed, meaning the data acquired via the NHS digital application could not be published within this DClinSci thesis.

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LIST OF ABBREVIATIONS

BSE – British Society of Echocardiography

CABG – coronary artery bypass graft

CAD - Coronary artery disease

CNL – Cardiac Physiologist/scientist & nurse led

CPLSE - Cardiac physiologist led stress echo

CRF - Case reporting form

CVD - Cardiovascular Disease

Cx - Circumflex

DL – Doctor Led

DSE – Dobutamine Stress Echocardiogram

ESC - European Society of Echocardiography

ETP - Echocardiogram Training Programme

EVAREST - Echocardiography – Value and Accuracy at Rest and Stress

HCS - Health Care Science

HSST – Higher Specialist Scientific Training program.

LAD - Left Anterior Descending

LTP – Long Term Plan

LV - Left Ventricle

METS - Metabolic equivalent

MI – Myocardial infraction.

MSC - Modernising Scientific Careers

NHS - National Health Service

NSHCS - National School of Healthcare Science

NSTEP - National Review of Stress Echocardiography Practice

PCI – Percutaneous coronary intervention.

PSD - Patients specific direction

RCA - Right coronary artery

RWMA - Regional wall motion abnormality

SE – stress echocardiography

STP – Scientist Training Program

TOE – Transoesophageal echocardiography

TTE – Transthoracic Echocardiography

UEA - Ultrasound Enhancing Agent

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1 INTRODUCTION

1.1 General Introduction

Cardiovascular disease is a significant drain on health resources and, across the world, is responsible for more deaths than any other disease (Kaptoge *et al.*, 2019). In the UK, coronary heart disease is the second highest cause of death behind Alzheimer's and dementia and is the most common cause of premature death. The British Heart Foundation has identified that 7.4 million people within the UK have cardiovascular disease at an estimated cost of £19 billion every year to the UK economy (British Heart Foundation, 2025). Despite falling rates nationally in death from cardiovascular disease, early death and circulatory disease are still more common in the north of England, central Scotland and south Wales compared to southern areas (Robinson, 2021), with this regional variation often associated with a socioeconomic gradient due to different levels of social deprivation (Conrad *et al.*, 2024).

Whilst recent results of a large population-based study have demonstrated that the rates of coronary heart disease and stroke are reducing over time, this reduction was seen mainly in the older than 60 population, with little or no improvement in the rates of disease in younger age groups. This has, in parallel, been associated with an increase in the diagnosis of cardiac arrhythmias, valve disease and thromboembolic diseases (Conrad *et al.*, 2024). To make many of these diagnoses, there is a need for suitable diagnostics testing that can either rule in or rule out the presence of pathology such as valvular heart disease and inducible ischaemia. This younger population, which presents with a more static rate of cardiovascular disease, will also live longer than prior generations and, as a result, will likely receive additional health investment in the form of increased diagnostic tests over their lifetime (Roth *et al.*, 2018).

For many patients being investigated for any form of cardiac disease, cardiac ultrasound in the form of a transthoracic echocardiogram (TTE) is often required. The relative ease with which this test can be performed and its versatility to address anatomical and structural heart abnormalities (such as valve lesions) at both rest and with exercise (Robinson *et al.*, 2021), the ability to monitor the impact of cancer treatments and track functional changes over time (Dobson *et al.*, 2021) and the role it plays in the assessment of coronary artery disease through functional testing (Steeds *et al.*, 2019) have made TTE an essential cardiac diagnostic test.

As a result, there is a recognised sustained increase in demand for TTE nationally. However, with demand outstripping the supply of both trained individuals to perform the scans and also a lack of physical space and equipment with which to increase, there is now a substantial national backlog. With over 90% of all TTE being undertaken by cardiac physiologists, who operate within the field of healthcare science (HCS), the capacity to deliver additional staff through recognised training routes is becoming more paramount, but so too is the need to redesign services to create additional capacity and provide more innovative ways of working in order to both meet demand and to reduce the backlog (Richards, 2020). This has created a need to evaluate the delivery of cardiac services to address the sustained epidemiological burden of cardiovascular disease and, expressly, the impact that this may have on TTE services.

1.2 Transthoracic Echocardiography

In order to understand the complexities surrounding the delivery of SE testing as a dynamic functional test, and therefore the skilled workforce required, it is important to consider the fundamental imaging modality within which SE is based upon. TTE is a specialist ultrasound diagnostic test, used to assess the size and function of the heart. It can assess in detail the anatomy, geometry and functional status of all the cardiac chambers, valves and vessels at rest and, if required, during exercise (Upton, 2019). TTE is a pivotal non-invasive imaging modality that has revolutionised the field of cardiology. It has application throughout a patient's lifetime, with imaging available in utero, infancy and childhood through to adult imaging across a range of congenital and pathological conditions (Gillam and Marcoff, 2024).

Echocardiography is essentially a non-invasive and painless test with minimal risk and no ionising radiation emitted (such as Computed Tomography (CT) scanning), it is often a first-line diagnostic employed within the National Health Service (NHS) in various clinical settings.

TTE uses ultrasound waves to generate real-time images of the heart, allowing users to assess cardiac parameters, including chamber sizes, wall motion, and valvular integrity. It is an integral part of clinical cardiology and has a considerable impact on the diagnosis, management and decision-making for patients across a wide range of pathological conditions (Otto, 2018).

1.2.1 TTE – training and delivery within the NHS.

As a diagnostic tool, TTE remains one of the largest imaging specialities. Within the NHS, a high volume of diagnostic tests are performed each year, and the demand for TTE is predicted to grow at 5.7% per annum. This demand and growth currently outstrip the supply of trained sonographers and will in time significantly impact patient care (Richards, 2020). Its application includes inpatient settings, ranging from routine ward-based scans to scans performed in theatre or emergency settings such as during a cardiac arrest. It is also commonly used within the outpatient setting. Patients will often attend for a detailed assessment using a standardised, structured dataset during routine clinic appointments ranging from 30 to 60 minutes in length (Robinson *et al.*, 2020).

Training to perform basic TTE independently takes many months. Structured training programs, such as the Echo Training Practitioner (ETP) programme, have been recently introduced by the National School of Healthcare Science (NSHCS) in response to the increased workforce demands for TTE. This program requires an intensive 18 months of training, focusing only on TTE during this time, to achieve the minimum standard to practice independently.

Within the UK, the assessment of basic competence is generally accepted to be personal accreditation by either the British Society of Echocardiography (BSE) or, the European Society of Cardiology (ESC). These skills are formally assessed through a written exam, a package of evidence that demonstrates a varied case mix with different pathologies presented in the form of a logbook involving upwards of 250 scans, and with examples of the candidate's best work put forward for scrutiny.

There is also a knowledge-based competency assessment that must be completed that covers the more theoretical elements of the test. Combined, this provides a robust assessment of skill from which further experience and skill must be gained through continued exposure to complex pathology and continued professional development (Fox *et al.*, 2004, Robinson *et al.*, 2020). Whilst this process exists for TTE, the accreditation process is also available for more specialist tests such as stress echocardiography (SE).

1.3 This is the minimum standard required for staff to independently perform resting TTE imaging. By comparison, obtaining the images at both rest and stress required for SE, is considered to be extended scope practice, and requires a high level of individual confidence and competence. This therefore creates a much smaller, more highly skilled workforce delivering these services which may have further implications for how Trusts chose to structure and deliver their SE services. Stress Echocardiography

Within the TTE domain, SE is well established as a non-invasive sub-speciality, used mainly to assess patients with known coronary artery disease (CAD), but also with application into non-ischaemic testing such as valvular heart disease and diastolic function (Steeds *et al.*, 2019, Lancellotti *et al.*, 2016). Clinical guidance into the management of chronic CAD identifies SE as the recommended pathway in individuals with suspected chronic coronary syndromes and a moderate to high (>15%-85%) pre-test likelihood of obstructive CAD, although this has been subject to change in recent years with a preference for anatomical imaging like CT scanning of the coronary arteries ahead of functional assessment (Vrints *et al.*, 2024).

SE is an advanced diagnostic and requires additional experience and training beyond standard TTE imaging training (Steeds *et al.*, 2019). The technique's non-invasive nature and ability to provide real-time imaging make it a preferred choice for many clinicians (Picano *et al.*, 2020). In terms of diagnostic accuracy, a recent multi-centre study consistently demonstrated that SE exhibits a sensitivity and specificity >90% in the detection of ischaemic heart disease (Woodward *et al.*, 2021). Stress echocardiography also plays a significant role in the prognostic evaluation of patients with known or suspected CAD. Yao *et al.* (2012) evaluated a group of patients who underwent both SE and coronary angiography for the assessment of CAD. After a three-year follow-up period, they demonstrated that the SE result added incremental prognostic value to the coronary angiography result, and that in those patients with a normal SE (no evidence of ischemia) this conferred a more benign prognosis for CAD events.

1.3.1 The clinical application of SE.

The prognostic value of SE as a modality remains a current and important subject matter within the research field. Detailed here, is some of the important and more current studies that identify the clinical application that SE as a tool can deliver. Importantly, it also introduces the established research network collaborative (known as EVAREST), which provided the patient recruitment for this study. The predictive value of SE has recently been evaluated in a larger multicentre study looking at the impact of SE results on patient follow-up. The EVAREST (Echocardiography – Value and Accuracy at Rest and Stress) trial recently published by Woodward *et al.* (2024) identified the predictive risk of SE results in a group of 5503 patients

recruited from multiple different centres across the UK and followed up for a period of up to five years via the use of NHS digital data. They identified the predictive ability of a negative SE to provide a five-year warranty period where patients then have no more than a background risk of cardiovascular events. In addition, those patients with a negative SE test who also had a history of CAD, were found to have a four-year warranty period. This provides valuable insight into the ability of SE to inform the longer term management of patients both with and without CAD. However, SE is not just limited to the assessment of CAD and has application in the assessment of non-ischemic heart disease also.

SE, in its most simple form, combines two-dimensional echocardiography with a physical, pharmacological, or electrical stress agent designed to induce a supply and demand mismatch in cases where myocardial ischaemia exists (Sicari *et al.*, 2008). However, ischaemic heart disease is one of only a number of indications for SE to be undertaken. Valvular function, diastolic heart failure, cardiomyopathy, pulmonary hypertension, athletes heart assessment or assessment of the transplanted heart are also indications where the use of stress imaging provides important prognostic and diagnostic information (Lancellotti *et al.*, 2016).

1.3.2 Image acquisition within SE – utilisation of a highly skilled workforce.

The success of SE as a technique lies in the ability to reproduce the same image or Doppler measurement at varying stages of stress throughout the test. The ability to reproduce the same image in the same plane quickly is key, and forms part of the competency skills required for personal SE accreditation (Shah *et al.*, 2018). This is why those staff involved with SE activity will likely come from a more experienced workforce and have had additional training beyond standard TTE training (Steeds *et al.*, 2019). Baseline images are obtained of the left ventricle (LV) at rest using a range of views that provide adequate visualisation of the myocardium throughout the cardiac cycle. These resting images are then used for comparison at the various stages of the test as there is an increase in both heart rate and contractility.

Figure 1 demonstrates the images obtained from the apical four-chamber view (a standard view from which parts of the LV can be well visualised) at rest (A), at low dose stress (B), and two sets of images obtained at peak stress (maximal age-related heart rate) (C & D). These are freeze frames obtained at end-diastole (when the heart is at maximum volume); however, in clinical use, these would be images synchronised to all move simultaneously throughout the cardiac cycle. This methodology would typically be applied in assessing for inducible ischaemia, where inotropic agents such as dobutamine are used to make a controlled assessment of regional thickening throughout the test. This makes identifying variations in wall motion easier to identify compared to the more dynamic exercise stress echo (Marwick, 2003). For comparison, Figure 2 provides the same images but taken at end-systole (the

smallest chamber volume). This again helps to identify where areas of the myocardium, which have subsequently become ischaemic and may fail to thicken as well when compared to earlier images.

This process of image acquisition for the assessment of inducible ischaemia is undertaken across a range of echocardiographic views that ensures all areas of the LV myocardium have been imaged, assessing the blood supply from the three major epicardial coronary vessels – the Left Anterior Descending (LAD), the Left Circumflex (Cx) and the Right coronary artery (RCA). These views typically include the apical four-chamber, two-chamber and three-chamber shown in Figure 3. Additional imaging from the parasternal long and short axis and three-dimensional (3D) imaging may be included if required and this may vary depending on individual Trust protocol. Figure 3 demonstrates the common echocardiographic views used, then subdivided further into segments (typically base, mid and apex) based on their anatomical supply from the epicardial coronary artery vessels. This mapping helps in the precise description of any possible wall motion abnormalities. Some centres score the individual segments with a higher value indicating a greater degree of ischaemic response at peak stress, building a cumulative score for the test, known as the wall motion score. This is then divided by the total number of segments seen to give the wall motion score index with a higher value indicating a greater degree of abnormality (Yao *et al.*, 2003).

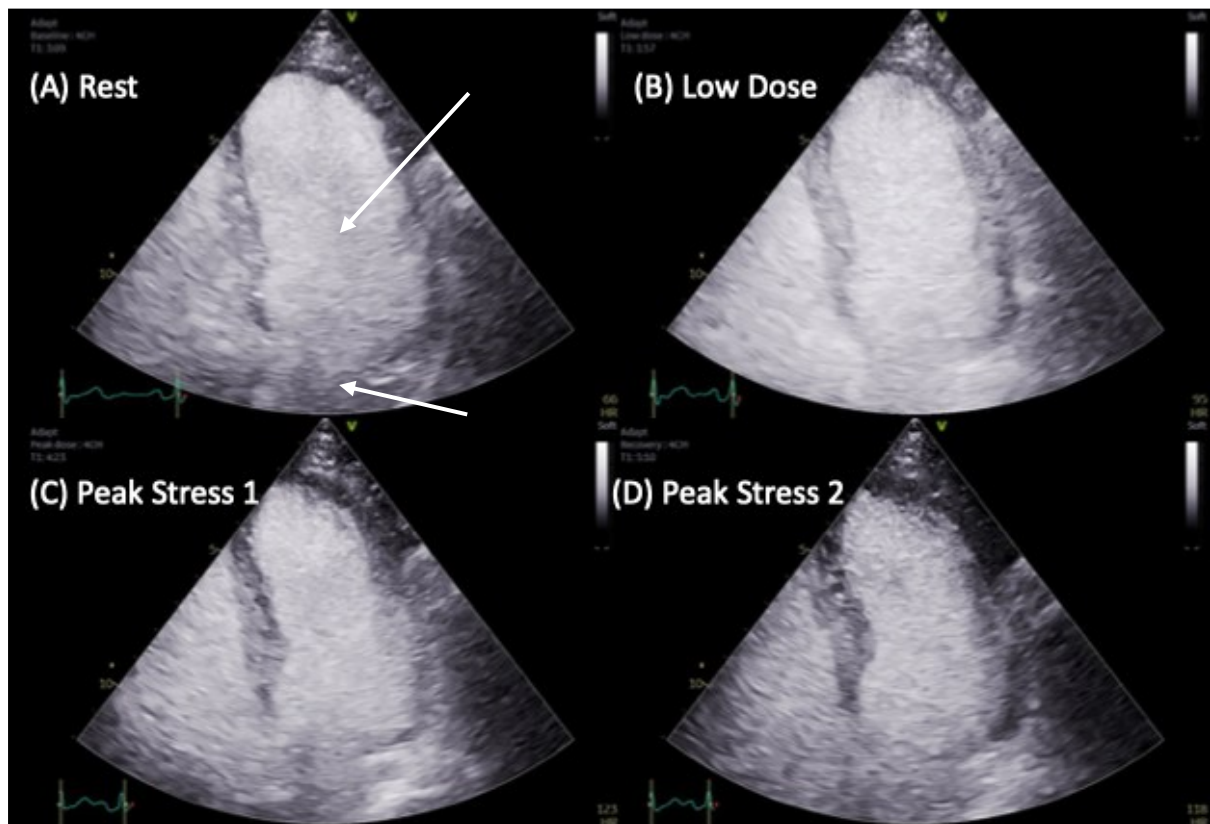


Figure 1 Standard SE image review setup for inducible ischaemia. This demonstrates the apical four-chamber view, focusing on the left ventricle, seen at the various stages of the stress test. (A) Baseline imaging: The heart is not under the effects of any stress or medication and provides the baseline from which all other images are compared. (B) Low Dose: where the early inotropic effects begin to take effect with a visual increase in contractility. (C-D) Peak Stress – maximal heart rate/stress is achieved and myocardial thickening is at its greatest, accompanied with a reduction in chamber volume resulting in an increased ejection fraction (Marwick, 2003). These stills have been taken at the end of diastole, a standardised time frame to enable comparison between views.

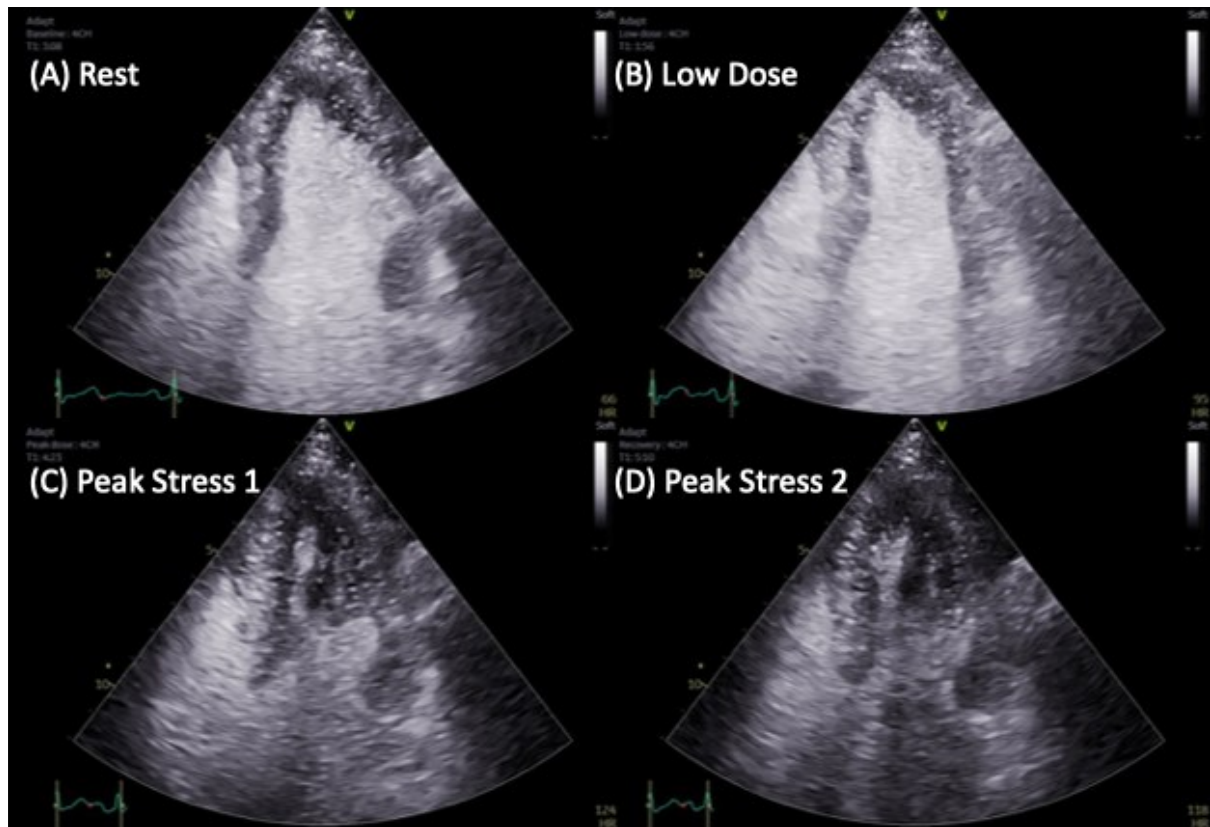


Figure 2 Standard SE image review setup for inducible ischaemia. Like Figure 1, these images demonstrate the left ventricle at all the aforementioned stages of the test but recorded at the end of systole, where myocardial thickening is at its greatest in an effort to eject blood at both the rate and volume required. This is where possible wall motion abnormalities can be demonstrated with a visibly reduced amount of myocardial thickening present (Marwick, 2003).

1.3.3 Stress Echo indications

This study has been designed to capture the array of different indications for SE within the study cohort. This has important implications for training and for competencies within the field by understanding better those which are common and those which remain underutilised. Furthermore it is anticipated that this may further impact the potential workforce models employed and subsequently the demographics of the patients.

SE is a versatile test that has developed a robust set of indications beyond just assessing for the effects of inducible ischemia and has, over time, matured into a robust and reliable diagnostic test for assessing and risk-stratifying patients with known and also suspected CAD (Senior *et al.*, 2005). The assessment of CAD is now the most common indication for a SE test to be performed. (Picano *et al.*, 2024). Images are acquired during a rest state (no stress)

which gives a baseline of cardiac function. Using an appropriate stressor such as Dobutamine (an inotropic cardiac stimulant) and Atropine (M2 receptor antagonist), exercise or via an implanted pacemaker (Picano, 2015), the heart rate is increased at a steady rate to a pre-determined level based on the patient's age. If there is a fixed stenosis in the epicardial vessels that supply the myocardium, this can create a supply and demand mismatch and result in a change in cardiac contractility known as a wall motion abnormality. This presents as a reduction in the thickening of the affected myocardial area, which is subjectively graded based on the extent of that reduction compared to the baseline images. Table 1 shows the range of descriptive responses available during inducible ischaemia testing when describing wall motion abnormalities at peak stress and the scoring allocated to calculate the wall motion score index (Yao *et al.*, 2003).

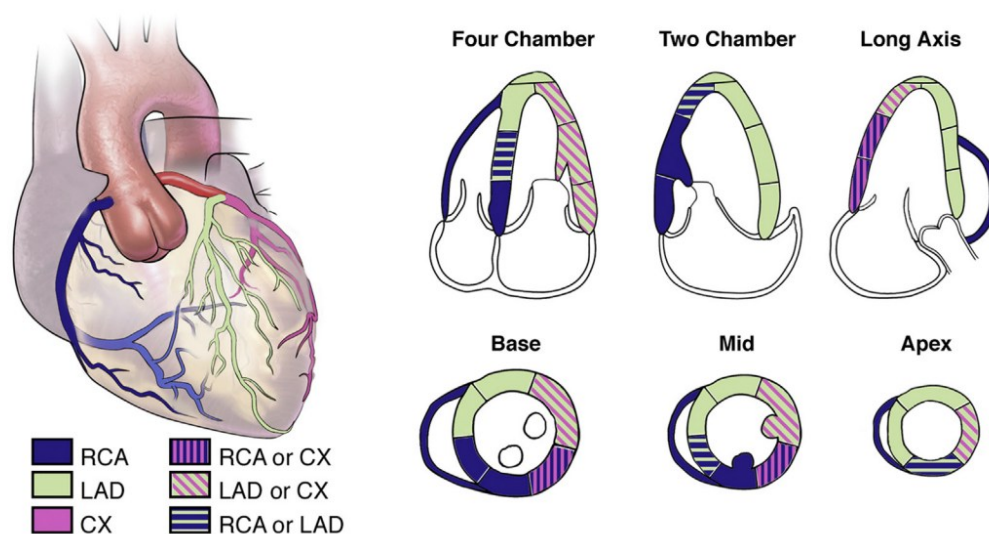


Figure 3 Visual representation of the standard echocardiographic windows used to assess the LV and the associated epicardial coronary anatomy supplying the myocardium. RCA -right coronary artery. LAD – left anterior descending. Cx circumflex. (Lang *et al.*, 2015).

The use of SE to assess native valvular heart disease is focused on identifying those patients in need of surgical intervention with a concentration on either the stenotic or regurgitant valve (Citro *et al.*, 2022). Unlike the assessment of inducible ischaemia, which relies on experience to visually assess myocardial thickening, valvular stress echo is more focused on quantifiable measures such as the flow dynamics across the valve in question or demonstratable changes in chamber pressure, measured at both rest (baseline) and then again at peak stress for comparison (Robinson *et al.*, 2021, Ring *et al.*, 2021).

Much like the assessment of valve disease conducted at rest, Broadly, there are three groups of patients that typically present for SE assessment. Firstly, there are those patients who have

known severe valvular heart disease, such as aortic stenosis but do not display any symptoms with it. In this circumstance, the purpose of the SE is to unmask any symptoms that only occur with exercise and then increase the need for surgical intervention. The second group of patients are often symptomatic but do not present with evidence of severe valve disease on their resting TTE. When placed under the additional haemodynamic burden of exercise, it is possible to demonstrate an increase from baseline moderate to exercise severe valve disease. The final group of patients are those that present with discordant measurements in the setting of low flow. Here, SE is used to assess if the valve disease is severe based on changes in flow parameters induced by exercise.(Lancellotti *et al.*, 2016).

Stress echocardiography is also indicated in the assessment of diastolic dysfunction. SE is used to assess LV filling pressures when patients demonstrate exertional symptoms such as shortness of breath and have identified impaired LV relaxation at rest. Stress agents such as dobutamine do not elicit the same response as exercise in terms of venous return and as such, exercise, normally performed on the bike is the preferred method of stress (Robinson *et al.*, 2024).

Table 1 The wall motion score and terminology used when describing myocardial thickening during each stage of an ischaemia SE test. The cumulative score is then calculated and divided by the number of segments seen, with a higher score indicating an increased risk (Yao *et al.*, 2003).

Wall motion score	Myocardial action during stress	Visual interpretation
1	Normal or hyperkinesis	Systolic increase in thickening >50%
2	Hypokinesis	Impaired systolic thickening
3	Akinesis	<10% systolic thickening
4	Dyskinesis	Paradoxical systolic motion
5	Aneurysmal	Diastolic deformation

1.3.4 Stressors used in SE. What are they and how might they influence service design?

Given the versatility of stress echocardiography to help diagnose different cardiac based conditions, it is also logical that there would be a range of stress agents to support the various tests. The stressors commonly used within SE include exercise (typically treadmill or bicycle), pharmacological (typically dobutamine), a vasodilator such as dipyridamole or adenosine or

pacing via a permanent pacemaker (Picano *et al.*, 2024). The range and versatility of stressors ensure that the test can be tailored to the patient and the desired outcome is safely achieved. Importantly, the various stress agents also carry varying degrees of risk.

It is anticipated that the different stressors utilised, broadly pharmacological and exercise, would provide one of the biggest variations between the workforce models described later in this thesis. As such, the stressor is an important consideration for the workforce delivering the testing with regard to the management of possible complications and the governance around the management and administration of medicines for non-medical professionals. This is discussed more in section 1.3.6. The following paragraphs provide some background detail on the most common stressors, and their application within SE services.

1.3.4.1 Exercise stress echo.

Exercise is considered the stressor of choice in cases where the patient is able to undertake some form of physical stress for the assessment of myocardial ischaemia (Pellikka *et al.*, 2020). It preserves the normal electromechanical function of the cardiovascular system whilst increasing myocardial oxygen demand, creating a potential deficit, and resulting in regional wall motion abnormalities, seen with echocardiography. This particular form of testing also provides valuable information on patient exercise capacity, assessment of symptoms and haemodynamic response to exercise, which are all strong prognostic markers (Picano *et al.*, 2024). Exercise as a stressor has frequently been reported by centres providing non-medical-led SE clinics, as the stressor of choice, often citing that it fits more naturally into the scope of practice of the non-medical practitioner (Kane *et al.*, 2008).

When exercising a patient on the treadmill, centres will typically use the Bruce treadmill protocol to achieve the desired heart rate. This protocol (shown in Figure 4) demonstrates the gradual increase in both speed and gradient at three-minute stages until there are exercise-limiting symptoms, the target heart rate has been achieved, heart rhythm changes, or changes in ST segments suggestive of coronary disease (Pellikka *et al.*, 2020). Critical to this form of testing is the ability to obtain post-exercise images as soon as possible after completing the test, as wall motion changes can quickly normalise (Roger *et al.*, 1995). This is further hampered by the physiological impact of exercise, with both rapid breathing and lung artefact (Pellikka *et al.*, 2020)

An alternative to treadmill testing is SE performed on a bicycle. This is often a supine bicycle, designed for SE due to the ability to recreate the left lateral position adopted by the patient in resting TTE through motorised controls on the bike. The patient is required to cycle against an increasing workload, measured in watts, until the same endpoints already described are achieved. As shown in Figure 5, the initial workload begins at 25 watts and then increases

every 2-3 minutes. The advantage of this type of testing over the treadmill, is that images can be acquired simultaneously as exercise is taking place. This means there is potentially very little drop in peak exercise heart rate, which can help improve test sensitivity (Pellikka *et al.*, 2020). Another advantage of performing SE on a bicycle is the ability to stress patients at a lower exercise intensity, resulting in less chronotropic rise and facilitating the assessment of diastolic function in cases of suspected impaired myocardial relaxation, known as diastolic dysfunction. (Nagueh *et al.*, 2016, Ha *et al.*, 2005, Robinson *et al.*, 2024).

There are some limitations in that patients unfamiliar with cycling can find this technique challenging, and walking on the treadmill is, for some, more comfortable. A recent Spanish study demonstrated that patients in the study group stressed on a treadmill could achieve a higher workload (METs) and a higher percentage of conclusive tests through better heart rate augmentation than those stressed on a supine bike. The study conclusion being that test selection is imperative and may in fact hinder performance for those not experienced in cycling (Monteagudo Ruiz *et al.*, 2023) There is also the additional cost burden with having equipment such as the stress bike that, outside of SE, may have limited use compared to the treadmill.

Bruce protocol:				
Stage	Grade (percent)	Speed (mph)	Total time (min)	METS*
1	10	1.7	3	5
2	12	2.5	6	7
3	14	3.4	9	10
4	16	4.2	12	13
5	18	5	15	15
6	20	5.5	18	18
7	22	6	21	20
* metabolic equivalents - 1 MET = 3.5 mL O ₂ /kg/min				

Figure 4 BRUCE Treadmill protocol used for exercise stress echo (Pellikka *et al.*, 2020)

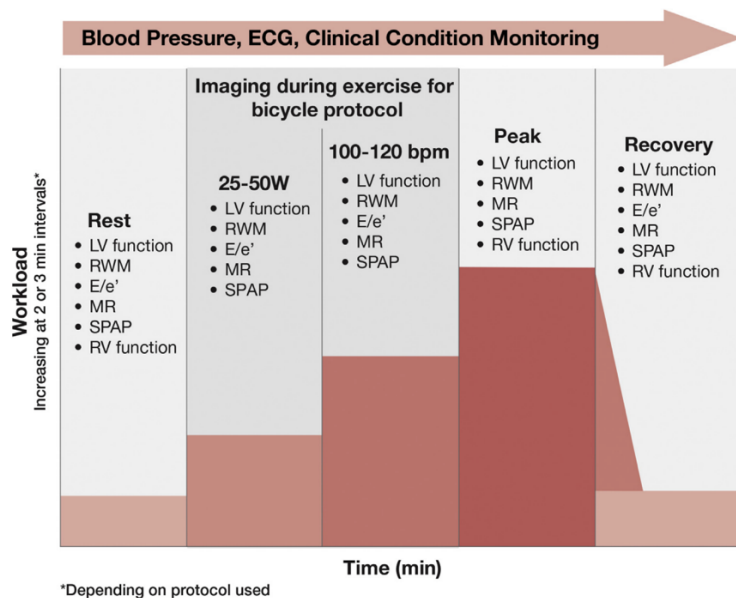


Figure 5 Exercise Stress Echo protocol utilising the bicycle protocol for both ischaemic and non-ischaemic stress testing. This shows the increasing workload applied through resistance (watts) over time. This protocol also offers the opportunity to test for diastolic function at low-level heart rates prior to testing for inducible ischemia (Lancellotti *et al.*, 2016).

1.3.4.2 Pharmacological stress echo

Pharmacological stress testing is most commonly performed using dobutamine and it is primarily recommended for use in patients who cannot exercise, or where the test indication requires a lower stress response such as valvular assessment (Lee *et al.*, 2023). It is delivered via infusion pump, in a graded dose of 5/10/20/30/40 mcg/kg/min over 3 minute intervals until the target heart rate is achieved. The lowest dose of dobutamine is often reserved for viability assessment, the intermediate dose for myocardial perfusion and then high dose for ischemia testing (Camarozano and Picano, 2023). Dobutamine stimulates the beta-1 adrenoreceptors, which causes heart rate to increase twofold, increased systolic blood pressure, and contractility to increase threefold, the results is a substantial increase in myocardial oxygen demand (Camarozano and Picano, 2023). Should dobutamine fail to reach the target heart rate, atropine is also then added in to supplement this and improve the sensitivity of the test. This is normally delivered at the 20/30 mcg/kg/min stage in order to minimise the potential side effects of dobutamine (Ling *et al.*, 1996). In terms of safety, there are some common side effects from dobutamine which can include nausea and Dobutamine has also been shown to have a favourable safety profile in studies involving both physicians and specialist nurses (Kane *et al.*, 2008) and cardiac physiologists (Ntoskas *et al.*, 2018).

Vasodilators such as dipyridamole are an alternative pharmacological agent, also used in the assessment of ischaemia, viability and myocardial perfusion and unlike dobutamine, they work by decreasing subendocardial flow supply secondary to arteriolar vasodilation and a coronary steal phenomenon (Sicari *et al.*, 2008). This creates a supply and demand mismatch and induces ischemia.

1.3.4.3 Pacemaker stress echo

If available, a patient's permanent pacemaker can be used as a mechanical stressor agent, through increased oxygen demand simply due to the increased heart ideally driven through atrial pacing with little increase in patients blood pressure and only a mild increase in contractility (Płońska-Gościński and Picano, 2023). The base rate can be increased up to 100 beats per minute and then from there further increased by 10 beats per minute, every 2 minutes until the target heart or a natural end point is reached. Whilst this minimises the need for pharmacological agents, there is some reservation around the technique should ventricular pacing occur as this itself can lead to wall motion abnormalities due to right ventricular pacing that can make functional assessment more challenging (Crouse and Kramer, 2001).

1.3.5 Stress Echo in Clinical Practice – understanding better the workforce.

The use of SE as a diagnostic tool within the UK has never been well understood. In 2014, partly in response to the need to help with workforce planning, the BSE who represents and supports clinical echocardiography professionals across the globe, commissioned a self-reported questionnaire to be sent to all UK hospitals undertaking SE testing. This study by Bhattacharyya *et al.* (2014) was designed to help reveal the extent of SE activity in the UK, looking at the number of centres performing SE, the volume and indications undertaken and also the workforce involved.

What the study found was that over 60% of all centres in the UK performing TTE, also provided SE as additional diagnostic imaging. Bhattacharyya *et al.* (2014) identified 120 centres currently performing SE activity across the NHS (private practice was not included), totalling 40876 SE studies performed from November 2011 to November 2012. Of the available 120 centres, 85 (71%) responded to the questionnaire. Questions were focused on identifying the number of SE performed per year, the number of operators and their respective staffing grade, indications for SE and stressors used and briefly, how SE results are reported. From the responses, this study then built a picture of what centres were doing across the country, giving valuable insight into how the field of SE was progressing and what the capacity and cumulative experience looked like throughout the country.

Results showed that all centres who responded to the questionnaire reported undertaking SE for the assessment of CAD. Looking at the use of SE for the assessment of non-ischaemic heart disease, 84 centres (95.3%) reported using SE for evaluating low-flow low gradient aortic stenosis valvular heart disease however, further valvular assessment reduced significantly, with only 34 (40%) assessing asymptomatic AS. This importantly highlighted the disparity in demand for valvular SE assessment compared to the assessment of CAD. The workforce undertaking the SE studies was also reported. Whilst this gave valuable insight into the teams available, the data derived on how the workforce was being used was limited, and commented only on the grade and profession of those staff performing the tests.

This important study presented one of the first national perspectives on SE activity within the UK. Whilst there are some limitations with regards to centres self-reporting retrospectively the cumulative work undertaken, it provided new insight into the varied practice across the country and also, for the first time, a look at the workforce involved in SE. This highlighted that SE services were almost exclusively being delivered using a model that relied on medical doctors supervising and reporting the test results. This included as the lead clinician supervising the test, consultant cardiologists and doctors in training (Bhattacharyya *et al.*, 2014).

A similar study was conducted by Weidenauer *et al.* (2015) looking at SE activity within Austria. Again, this study conducted a nationwide survey looking at the indications, numbers of cases performed annually, operator details and the techniques applied to stress the patient, because this level of detail remained unknown. This study was conducted initially in 2008 (looking at 2007 data) and then again in 2013, looking at the 2012 SE data.

The study group contacted all available cardiac and internal medicine departments with details of the electronic questionnaire and obtained a higher compliance rate (compared to Bhattacharyya *et al.*) with 100% of centres responding to the questionnaire, but with lower numbers overall with just 50% of centres conducting SE, and at much lower volumes compared to the UK study. Interestingly, assessing valvular heart disease was the most common indication for SE (74% of studies) with the assessment of CAD second (60% of studies).

Further national perspectives have been presented on the use of SE, in a recent large Italian study published in 2023, on behalf of the Italian Society of Echocardiography and Cardiovascular Imaging (Ciampi *et al.*, 2023). This study, much like the 2014 UK study, looked at the national output of their SE centres via an electronic questionnaire. Unlike the UK study however, this was focused on just one months' worth of SE activity. This was felt to obtain a more accurate representation of the work undertaken rather than an estimate of 12 months.

80.6% of the centres approached in this study undertook SE activity during the study period, performing a total of 4057 SE studies for a range of indications.

The percentage of work undertaken for each indication was very similar to that found in Bhattacharyya *et al* (2014) study, with all centres performing SE for the assessment of CAD, with dobutamine and exercise the two primary stressor agents used. Interestingly, the indications for SE were subdivided based on the volume of work each centre undertook, and this found that for many of the indications, the frequency of testing increased significantly with the volume of SE undertaken across indications such as aortic and mitral valve disease.

Despite the similarities and in some cases significant differences presented by these national studies into the use of SE, what many of them have failed to report or, provide only limited estimated data, is detailed information of the workforce that undertake the tests. Each of these studies provide a very focused look at the how and why of the SE but there is minimal information on the who.

1.3.6 Pharmacological use and stress. Implications for the non medical workforce leading SE services.

One crucial factor that must be considered in the expansion of services such as SE is the interaction required with giving and managing medications (Ntoskas *et al.*, 2018). The traditional SE model relies upon doctors as the supervising clinician, giving medications such as dobutamine and ultrasound enhancing agents (UEA) designed to improve endocardial definition, such as Sonovue, throughout the SE. If required, atropine can be used to augment the heart rate further. Finally, beta-blockers may be required to alleviate symptoms or suitable medications to treat an allergic reaction in symptomatic patients (Steeds *et al.*, 2019)

This has traditionally been a limiting factor in expanding services such as cardiac physiologist-led SE. However, the use of appropriate documentation processes and governance has seen many centres create and use Patient Specific Direction (PSD) forms to facilitate this (Campbell *et al.*, 2019, Hampson *et al.*, 2019). The PSD is a recognised process which permits the use of specific prescribed medications, up to a maximum dose in specific clinical situations, prescribed by a suitable medic but delivered by an authorised individual or group (NHS England, 2020b).

Greater utilisation of the PSD process in conjunction with a well-designed clinical pathway has the potential to create an opportunity to expand models further, moving away from primarily Dr led services if required. These expansions have been well documented within both nursing and HCS professions for many years, with success in areas such as valvular heart disease (Chambers *et al.*, 2020), device implantation (Lim *et al.*, 2019) (Eftekhar *et al.*, 2022), and chest pain assessment (Mathieson *et al.*, 2017).

1.4 The Healthcare Science workforce

To understand better, the design and implementation of SE pathways with regards to workforce models (medic vs. non-medic) and also the volume and indications of work undertaken it is helpful to consider prior research into the field as a comparative baseline. The work of Bhattacharyya *et al.* (2014) captured an overview of SE services within the NHS in 2014 which was helpful in determining the scope of services provided within Trusts that were willing to engage. However, it was a self-reported questionnaire with questions on five areas of service provision, namely service demographics, indications, methods, reporting and adverse events but not on outcomes or, a detailed assessment of workforce. As a result, there currently remains a gap in the understanding of how SE services are being delivered on a national level across the country with respect to achieving the aims of the NHS Long Term Plan (LTP) (Department for Health, 2019). Developing a sustainable and robust workforce is key to any organisation's success. As one of the largest employers within Europe the National Health Service (NHS) has a constant need to review, develop and streamline its services to ensure that it is delivering the best care for its patients, in the most efficient way possible (Health Foundation, 2018).

There are several streams that contribute to this process including improving services, correctly staffed resources and the use of world-leading technologies designed to improve care (Alderwick and Dixon, 2019). These have been carefully articulated in key documents that support growth within the NHS HCS workforce focus. These include, the LTP and with a particular focus on diagnostics, the Richards Report – *Diagnostics: Recovery and Renewal* (Richards, 2020).

The HCS workforce is comprised of approximately 56,000 people who make up a diverse group of scientists from 150 specialisms such as data science, physiological sciences, medical physics and clinical engineering (NHS England & Improvement, 2020). The HCS workforce within Cardiology represents one of the largest groups within the Physiological Sciences specialty with roles from practitioner through to consultant level. These advanced roles are now becoming more commonplace due to the introduction of the Modernising Scientific Careers (MSC) pathway, which has created an academic and clinical pathway for the HCS workforce (Campbell, 2009).

In order to establish the impact that the NHS LTP changes could have on patient care, it is imperative that a stable national baseline be established so that a cohesive plan can be established and the risk of regional care disparity is not extenuated (Timmis, 2015, Bhatnagar *et al.*, 2015). Richards (2020) recognised the need to invest in both the workforce delivering the care and new technologies, designed to support both the workforce and patient care, in

order to achieve the LTP plans. TTE is a crucial diagnostic investigation with high demand across many different speciality groups due in part to its ability to provide detailed clinical information on cardiac anatomy and function with minimal risk to the patient. Therefore, TTE was identified as a key area for expansion and investigation.

The rapid progression of the MSC pathway within the HCS profession, along with an increasing demand for diagnostics has created opportunities for services such as SE to develop in new directions which includes those being led by clinical scientists or cardiac physiologists (Campbell *et al.*, 2019) rather than physicians (Ntoskas *et al.*, 2018). The benefits of this diversification are twofold. Firstly, it increases the capacity for diagnostics to be undertaken, helping to meet demand and ensure that patients are seen quickly through increased numbers of practitioners. Secondly, it provides additional scope for career development within the HCS workforce and as a result, creates the opportunity to reallocate medical staff time to other clinical areas, such as initial patient consultations or more complex diagnostic procedures (Hampson *et al.*, 2019, Chambers *et al.*, 2020).

1.4.1 The NHS Long Term Plan, How does this feed into service delivery?

This study is investigating on a Trust level, the workforce and delivery of SE services. Much of the current models in place will have directly resulted from the challenge made within the NHS LTP document to expand the scope of practice for clinical scientists in order to support the need for more diagnostic testing. However, the logistics of how this service expansion should take place, was left to individual Trusts to design. This diversification of the workforce represents many of the objectives promoted by the NHS LTP. The LTP was written with an aim to clearly set out the key ambitions for the NHS in the next 10 years. This identified five key clinical priorities, namely, cancer, mental health, neonatal health and cardiovascular disease (CVD). Expressly, the plan set out to improve the detection and care of patients with CVD and prevent up to 150,000 cases of heart attack, stroke and dementia over the next ten years (Charles and Ewbank, 2019).

To achieve the stated aims, this report identified that the success of this 10-year plan will depend heavily on the workforce provided to deliver the care and requires innovative thinking with regard to service and workforce development. The authors recognised that diversification of staffing and upskilling suitable professional groups to assist with demand was essential to its success (Department for Health, 2019). In a follow-up to the publication of the LTP, a document from the Chief Scientific Officer detailing the involvement of the HCS workforce in meeting these aims, lists the delivery of transformation in scientific-led services for the benefits of patient care as a priority (Department for Health, 2010). However, whilst the LTP provides guidance and challenges to how patient care is delivered, there are critics that suggest it is

too ambitious and the use of too much technology could lead to a reduction in the clinical skills associated with many jobs within healthcare (Jones-Berry, 2019).

1.4.2 Stress Echo workforce.

Physicians have traditionally led SE services. However, there is a current gap in understanding the impact of programmes such as the MSC (Department for Health, 2010) pathway and the impact that this has had, and could have on the workforce of the future. This pathway, designed to increase the clinical scope and autonomy of the HCS workforce, has allowed services such as SE to develop in new directions. This includes services led by cardiac physiologists and clinical scientists as a viable alternative workforce to supplement physicians (Campbell *et al.*, 2019). These physician alternative pathways are already well established in healthcare and can provide additional clinical capacity and improved flexibility without compromising patient care (Moore *et al.*, 2007, Jones *et al.*, 2017).

Despite a 2014 scoping document identifying that 60% of cardiac departments were undertaking SE lists (Bhattacharyya *et al.*, 2014), there remains a lack of understanding surrounding who is performing these tests, how they are doing it and, importantly, their effectiveness. This creates both a need for better knowledge around this developing area and an opportunity to collect and share best practices, identifying if this is an area that can build on the challenges set out in the 2019 LTP document.

In a single-centre study undertaken in 2018, alternative to physician-led pathways, the use of a Cardiac Physiologist Led Stress Echocardiography (CPLSE) clinic was shown to be effective and safe (Ntoskas *et al.*, 2018). What made this study different to the earlier work of both Singh *et al.* (2017) and Khan *et al.* (2017a) who utilised exercise as the main stressor in a physiologist-led service, was that Ntoskas *et al.* (2018) looked at the safety and efficacy of using dobutamine as the main stressor (in 306 patients, dobutamine was used in 98% tests performed) along with UEA for endocardial delineation (n=267, 89%). During the six-month audit period, a total of 333 patients attended for a SE test seen by either a physician or a cardiac physiologist, the latter undertaking 306 (91.9%) SE tests compared to just 27 by physicians.

Whilst the focus of the study was on the outcome of the test as a potential measure of safety, the important distinction here is the use of dobutamine as the main stressor within this retrospective audit. The use of exercise as a stress modality sits more naturally within the cardiac physiologist skillset. Whilst there is a recognised decline of 8.4% in the number of exercise stress tests performed since 2017, due in part to a change in clinical guidance (Asher *et al.*, 2019), as a modality, it still forms part of the undergraduate and post-graduate training syllabus for those training to become a cardiac physiologist (undergraduate) or a clinical

scientist (postgraduate). Given the challenges already described around the use of cardiac physiologists and clinical scientists administering medications through the use of PSDs, and the changing landscape of exercise testing Ntoskas *et al* (2018) presented an interesting look at the scope of expansion possible within the HCS workforce.

Whilst this study saw a large number of patients (n=333) during the six-month duration, 98% were seen within the CPLSE clinic, providing a limited basis for comparison to the traditional physician-led model in this setting, having almost exclusively adopted cardiac physiologist led practice. Based on the study data, a predicted 54 consultant-led studies per annum would potentially only be required. Ntoskas *et al* (2018) and colleagues acknowledge as much, recognising this is only the experience of a single centre and thus the results may not represent the experience of the wider profession with such a unilateral move to a CPLSE pathway.

This also comes with its own set of challenges based on the need for staff to remain competent in both performing and reporting SE. Recommendations within both European and American guidelines (Lancellotti *et al.*, 2016, Pellikka *et al.*, 2020, Steeds *et al.*, 2019) suggest that those involved within the field of SE, ensure their competency and skills are up to date yearly with a need to obtain a minimum number of tests per year, from both a variable test indication and test stressor background in order to be exposed to multiple pathological examples and to retain a broad scope of practice with different stressors agents (Lancellotti *et al.*, 2016, Pellikka *et al.*, 2020, Steeds *et al.*, 2019, Sicari *et al.*, 2008). The actual number appears to vary between societies; the ASE suggests 150 scans per year (Pellikka *et al.*, 2020), whilst the BSE has a sliding scale, starting at 250-500 per year and reducing to 75-150 per year. This is offset by an increased need for continued professional development (CPD) points as the number of tests per year reduces (British Society of Echocardiography, 2024).

A recent review by Hampson *et al.* (2019) looked at a hybrid model with test management and image acquisition performed by the cardiac physiologist and interpretation undertaken by a single cardiologist acting as study 'reader'. Whilst this study looked at data acquired using the cardiac physiologist-led model, results were obtained retrospectively from 2014 to 2015 and like those of Khan *et al* (2017) were predominantly in favour of exercise stress echocardiography (n= 703, 92%) rather than dobutamine (n= 65, 8%). Hampson *et al.* (2019) reported their model produced a high level of diagnostic accuracy, however, a single reader was used to interpret all studies which limits the ability to assess interobserver variability.

Work by Khan *et al.* (2017a) on the feasibility of cardiac physiologist-led SE, provides further evidence of varied practice within UK centres. Whilst this study, unlike Ntoskas *et al* (2018), provides a comparison between CPLSE and cardiologist led SE (CLSE) there is an imbalance

in the distribution of work undertaken with CPLSE performing 96.7% of all exercise stress echo (272 out of 281) but only 19.6% of all dobutamine stress echo (121 out of 617) compared to the cardiologists (registrar level) who performed 3% and 80.3% respectively during a 24 month period.

The use of non-physician teams to lead services such as SE is not without controversy. In an editorial reply to the work conducted by Ntoskas *et al* (2018), Porter (2018) questions two key elements within the study. Firstly, the performance of the test and secondly, the subsequent interpretation of the results, with the latter raised as being a cause for concern. Porter goes on to suggest there is a danger in the process if interpretation is to be left within the hands of the physiologist rather than a cardiologist due to a lack of experience in image interpretation. A subsequent reply by Pearce and Chambers (2018) to Porter (2018) goes on to question why it would be inappropriate for the interpretation to be undertaken by a cardiac physiologist or clinical scientist given their extensive experience in the interpretation of resting images, and as the main workforce delivering all echocardiography within the UK. Pearce and Chambers (2018) make an interesting suggestion that perhaps the discrepancy is within the clinical scope of practice extended to echocardiographers in the UK versus those in the United States. These comments highlight the difference in service provision surrounding the scope of practice within the cardiac physiologist and clinical scientist workforce internationally.

In reference to the training element raised by Porter (2018) it is often based on an international suggestion for a minimum standard of assessed training cases prior to solo interpretation. Picano *et al.* (1991) produced an elegantly simple research study on the effects of training/teaching on the ability of echocardiographers to interpret stress echo images. They noted that with adequate training, suggested to be 100 studies, supervised by an experienced operator, it was possible to obtain comparable levels of accuracy between echocardiographers. They also noted that after 100 studies, there tended to be a plateau in the diagnostic accuracy that the test can yield. Interestingly, this 100 patient threshold despite being advocated as far back as 1991, remains today, featuring in the key SE training documents (Sicari *et al.*, 2008), consensus documents on functional assessment (Mor-Avi *et al.*, 2011) and 2020 Training, competence and quality improvement documentation released by the European Society of Cardiology (Popescu *et al.*, 2020).

Whilst this 100-study threshold appears to be advocated as a suitable competency standard, Picano's original 1991 work is unlikely to reflect the current imaging capabilities with improvements in harmonic imaging, UEA and digital image processing. Yet, there is a lack of follow-up research suggesting potential improvements or adjustments. There is also a lack of reference to the interpreting sonographer being a medical doctor in any of the above documents, despite the suggestions from Porter (2018).

Porter's (2018) comment on the research undertaken further highlights the need for a structured and deeper understanding of how SE is being performed on a wider scale, including importantly the interpretation of results which often seems to be overlooked. This could allow national societies such as the BSE to promote best practice with its members and provide continuity across the profession whilst also aspiring towards the aims laid out in both the NHS LTP (2019) and the Richardson report (2020) on diagnostic recovery by providing better access to services through a more digitally enabled, and diverse workforce.

There was a focus within this study that to achieve these aims the need to rapidly develop, adopt and establish a robust workforce capable of delivering these aims was paramount (Department for Health, 2019). This was further echoed in the 2024 study by (Dixon-Woods *et al.*, 2024) looking at the impact the staffing investment and training will have on the future delivery models for medicine.

In 2014, a SE service was present in over 60% of UK-based echocardiography departments (Bhattacharyya *et al.*, 2014). With a change in clinical guidance, using SE as a functional imaging modality showed sustained growth in demand between 2011 and 2017 (Asher *et al.*, 2019). Since this study was conducted, further details around the extent of stress echo activity being undertaken across the UK and information surrounding the workforce delivering SE services still need to be improved. Studies documenting experience to date are often limited to the experiences of a single-centre (Hampson *et al.*, 2019, Khan *et al.*, 2017, Ntoskas *et al.*, 2018)

Changes in workforce practice, including services led by physiologists/scientists as an alternative workforce to supplement physicians, are now more common and well documented via programmes such as the MSC programme '(Campbell, 2009, Pearce and Chambers, 2018). These physician alternative pathways have been shown in other areas of diagnostic testing to provide additional clinical capacity and improved flexibility without compromising patient care (Moore *et al.*, 2007, Jones *et al.*, 2017) and have the capacity to be more financially beneficial by reallocating clinician time into other highly skilled areas (Khan *et al.*, 2017a).

Recommendations from the European Association of Cardiovascular Imaging (EACVI) released in 2020, which includes details on training and competence in SE, also discuss details on potential delivery models, along with suggested numbers required for gaining competence and maintaining adequate skills (Popescu *et al.*, 2020). However, how these suggestions translate into actual clinical practice is unknown. To date, there is limited up-to-date knowledge about the current delivery of SE services across the country concerning the

workforce and in the scope of delivery concerning testing strategies, protocol implementation and training.

1.5 Research Aims

This study aims to comprehensively investigate the current delivery of stress echocardiography services within the UK.

The main objectives are:

1. To describe the demographics, indications and stress echo details for the study cohort.
2. To identify the current workforce involved in delivering stress echocardiography and categorise these based on the staff's individual roles.
3. To investigate if significant differences exist in the patient group and test outcomes seen within a modelled doctor-led or cardiac physiologist/scientist and nurse-led stress echocardiography clinic
4. Also, to identify if there are any significant differences in the reporting volume and style of the different workforce groups.

The secondary aims of the study include

5. To report the current levels of training within the stress echocardiography clinics that are being undertaken within the study group. Who is receiving the training and who is delivering the training.
6. To investigate the impact that the Trust size, categorised by the number of beds, has on the delivery of stress echocardiography services.

By understanding the national picture of SE service delivery, interpretation, and reporting, the study will provide evidence-based guidance to support workforce education and promote the dissemination of best practices across SE clinics in the UK.

2 METHODOLOGY

2.1 Ethical approval and data access.

NHS ethical approval for the study was granted as part of phase 3 of the EVAREST project (Ref: 14/SC/1437). Institutional ethical approval was granted by the Faculty of Science of Engineering Ethical Advisory Committee (Ref: 48615). Permission to access the Castor database (Castor, New York) was applied for via a temporary working visitor contract with the University of Oxford. This was permitted from 26/02/2021 until 1/10/2024 to work exclusively within the Clinical Cardiovascular Research Facility (CCRF) and allowed remote access to the Castor database containing the raw study data. An expression of interest in the data outlining the aims and objectives of this thesis was submitted to, and approved by, the wider NSTEP study management group.

2.2 Study recruitment and database management

The primary study, the EVAREST study, ended recruitment in September 2023. Between March 2015 and September 2023, that study recruited 17,656 patients across all three arms of the trial. The study data used within this thesis was sourced from phase three of the trial. The data obtained from each test was self-reported by trust research teams into the project database – Castor, using an electronic case reporting form. Each patient was recorded individually on the database with a unique patient identifier. This included patients recruited from the 1st September 2020 until the 30th June 2023. Given there was a delay in the data being uploaded onto Castor, this date was selected to ensure that enough time remained for follow-up data to be obtained should it have been required and also that all reports where available, had been uploaded. This ensured that, if required, further details on the study workforce could be identified from the individual study reports.

The castor database was a live database throughout the study recruitment period which allowed interim data to be downloaded and analysis to be undertaken, which shaped the final separate study database. It also meant that any queries about the staffing within the study data could be addressed shortly after recruitment. The data collected within the Castor database was very extensive and covered demographic details of the patient, the indications for stress, prior cardiac history if applicable and details around the actual SE test itself.

Thirty four different Trusts formed part of the recruitment group for this study. Trusts joined the study at varying stages across the 2020 – 2023 study period. There was an open expression of interest advertised through several research channels. This included the BSE who undertook a series of webinars in which details for interested sites were available. For those sites who expressed an interest and were subsequently recruited, a site visit was undertaken and induction performed by CCRF team.

This study was conducted with an open recruitment policy in order to capture the greatest representative sample. This was designed to reflect any size trust performing stress echo from a large teaching hospital to a smaller district general. The aim also was to reflect a range of different staffing models given the different constraints Trusts may face. The geographical location of each Trust has been plotted in Appendix 1. Any patient undergoing a SE test was eligible to be recruited. Study recruitment was interrupted by the Covid-19 pandemic, which saw SE services change how tests were undertaken (Dockerill *et al.*, 2021) and as a result, this will have impacted the rate of recruitment and the number of centres involved.

As part of the patients' pre-test documentation, they received an information leaflet and consent form prior to attending their appointment and were not required to do anything different than what was required by each individual Trusts process. The stress methodology, staffing, and stressors were all standard care for each of the 34 different trusts, and there was no requirement for randomisation or sub-selection.

Whilst the focus of this study was on the workforce, it was appropriate to obtain and examine the impact that variables such as prior cardiac history and individual patient data could have on study outcomes; therefore, the full dataset for each patient was exported into SPSS (SPSS Inc., Chicago, IL, USA) for further more detailed analysis. The final study downloads from the Castor database into SPSS was made during September 2023.

The Castor database contained 5 main sections to be completed. This included (1) consent and inclusion data (2) Patient demographics, (3) Stress Echo data, (4) Workforce data, and (5) withdrawal. A possible 157 separate data fields could have been completed for each study. Pending the choices made in the primary question of each section, this then triggered secondary and tertiary questions that required answering. It was possible to enter dummy data that highlighted a particular piece of information was missing at the time of upload. Where possible, these missing variables were re-checked post-download against the study reports and filled in for the study if the data was apparent..

Demographic, clinical, and echocardiographic data were collected at the time of recruitment and immediately post-SE for all patients. This was undertaken by either the team conducting the SE, or by research teams within the Trust. Because Castor was a live database with each

centre entering its own data, there were a large number of entry errors that required correcting. Examples included the date of consent being entered as the date of birth, which led to errors with the patient age column. Missing data such as sex, height and weight were also sought from the uploaded study reports with requests made to recruiting centres where available. This forensic assessment of the raw study data was undertaken for several months before any analysis or categorisation of the data took place. Data quality was checked using the tools within SPSS to identify erroneous data and variations in entry style.

2.2.1 Test exclusions and missing data.

From September 2020 to June 2023, 8870 SE exams were recruited into the NSTEP database from 34 different hospital sites. 264 (3%) SE tests were not undertaken and, therefore did not have any workforce or outcome data associated with them so were excluded from the final group analysis this is reported in figure 6. Eight thousand six hundred six then proceeded to have a SE performed however not all tests were completed. Thirteen patients requested to withdraw from the study with no further detail recorded. Their data was then removed and a note made on the database. Thirty nine studies had not had the workforce details entered. This was also unavailable from the test reports. Forty eight studies were missing the entire SE test data. Again, this was unavailable from the study reports. Centres were approached to recover this data but it for many this data remained unavailable with both Castor and the test report the only official documentation available.

This left a total of 8506 potential participants eligible for analysis. However, as previously noted, not all parameters were recorded for each test statistic. This was a combination of appropriate acknowledgement of missing data (using the available coding in Castor) and in many cases, simply a lack of data entry. Both were treated the same, with missing data acknowledged by quoting the available data for each of the individual measures when presented in the tables below, with results then compared as a percentage of the group size. This was in line with prior publications within the EVAREST group.

2.2.2 Data entry into Castor.

Following the data checking and cleaning, initial data analysis was undertaken. Details surrounding individual SE were recorded for each patient recruited into the study. This included the indication for the test, the stress modality and associated stressor, the immediate test outcome and the workforce delivering the stress test.

The stress agent (known as the stressor) used within the SE was identified from a pre-determined list with the option to describe alternatives. This allowed the data within this group to be compared across different stress methodologies, such as exercise stress echo and

dobutamine stress echocardiography. The stressors were then described in further detail, by identifying the specific method used; in the case of exercise stress for example, this was broken down into either treadmill or bicycle stress, with other options available if required. For dobutamine stress, the volume of dobutamine used as a dose based on the patient's registered weight in kilograms was also documented as micrograms per kilogram per minute.

Further details were also recorded on the use of additional medicines during the assessment such as the use of atropine to support the achievement of the desired heart rate. Atropine is often used as an adjunct to dobutamine to quickly raise the patient's heart rate to the desired test level within a safe time frame. It is also used to help treat and minimise the risk of a vasovagal event during the test (Steeds *et al.*, 2019). Details around its use, and the volume administered were documented in the SE details.

The use of any UEA was also documented. This included common agents such as Sonovue, Luminity and Optison with the option to add additional brands if required. Again, the volume and delivery method (via an infusion pump or hand injection) were also documented.

Details surrounding the patient's current risk factors (hypertension, hypercholesterolemia, smoking, and diabetes) were recorded. Further risk factors, such as a known family history of premature CAD and previous myocardial infarction (MI), coronary artery bypass graft (CABG), and percutaneous coronary intervention (PCI), were listed as a binary response and used to build a collective risk profile for each patient. Details on resting regional wall motion abnormalities (RWMA) were also recorded. Basic anthropometric data was collected on each patient, as these featured in the calculation of drug dosage and also in the indexing of results. However, certain demographic data such as the ethnicity of the patient were not recorded in the initial design of the study.

Several options existed concerning test outcomes. A test was recorded as either positive, negative or inconclusive/abandoned for each test modality (for example, positive for inducible ischemia or positive for worsening valve function). Studies documented as inconclusive or abandoned were still included in the final workforce analysis, given the study is based mainly on the workforce delivering these tests, however the test outcome was focused more on a comparison between positive and negative test results.

2.3 SE workforce details.

The workforce involved with each SE was documented within the Castor database in two distinct ways. This allowed for a more accurate assessment of the roles and responsibilities and the profession of staff, present during the test.

Firstly, the workforce group involved in the SE study were identified from a pick list. Options available included Consultant cardiologist, Cardiology registrar/fellow, Cardiac physiologist/Scientist, Nurse, Healthcare assistant, student or Other. This was answered as a binary yes/no entry in the database. If Other were selected, further details on the staffing group would be required as a manual text entry. Given the binary data entry, it was not always possible to discern if more than one physiologist, for example, was present during the test unless clearly indicated in the other section. When only one staff member was listed for the test, confirmation was sought with the respective Trust to clarify the staffing arrangements.

The database required each SE study to identify a staff member who performed each of the roles listed in Table 2. These roles were set out in the study case reporting form (CRF). A sample of the CRF is shown in Appendix 2. Each centre documented the respective roles that staff undertook during the live delivery of the SE encounter. These key roles were required for each individual test in order to categorise the type of clinics being run within each Trust.

Table 2 Roles and responsibilities of staff during SE testing and reporting.

Role	Description
Primary Operator	The individual performing the scan i.e. image acquisition.
Supervisor Role	The individual supervising the stress echocardiogram i.e. patient monitoring and administration of medicines.
Stress echo reported by	The individual reporting the stress echocardiogram.

Secondly, the workforce in the room during each SE test was split into professional groups. In some cases, this differed from those documented as having specific roles described in Table 2 and provided an alternative look at the staffing arrangements. For example, a consultant cardiologist may have reported the SE result, but they may not have been present in the room during the test. This is discussed in more detail in section 2.2.3.

2.3.1 Doctor-Led Vs. Cardiac Physiologist/Scientist & Nurse Led Supervision.

In order to address the study objectives, the data was categorised based on the designated roles during the stress test itself and also the reporting of test results. Secondary fields were added to the database that designated a SE test as either doctor led (DL) or cardiac physiologist/scientist and nurse led (CNL). DL included consultants and doctors in training, such as the cardiology registrar/fellow group. The CNL group included cardiac physiologist/scientist or nursing-led tests. This categorisation was focused on the test delivery,

where the staff supervising were considered to be leading the test and, therefore, the accountable clinician within the dynamic test scenario.

This grouping was subsequently used to split the data, and statistical testing was performed based on this. In some cases this was undertaken on the whole study database using the split file option in SPSS, allowing the frequency of different variables to be assessed between the DL and CNL groups. From here, the individual value and the percentage of each measure was used to provide a comparison between the two different test groups. Where further analysis was required (such as looking at the data for positive and negative test outcomes), the option to split the database into sub-files was used, creating smaller databases with the same study fields, but containing, for example, only the negative SE tests. From here the same method assessment method applied.

The collective group data is presented in Table 3. This looked at the patient demographic data, the type of stressor used, and the indication for stress across the whole cohort. Further analysis was undertaken using this baseline staffing data, looking at the supervision of SE activity around which staffing groups were supervising SE services. Results were first compared across each individual variable and then combined as a part of a binary regression model, highlighting the key variables contributing to patients being allocated into a DL or CNL SE service model.

2.3.2 Doctor-Led Vs. Cardiac Physiologist/Scientist & Nurse Reporting.

Given the way staffing was recorded, several different models became apparent. Using a similar method with regards to patient demographics, test indications, and outcomes, each test was then individually categorised into either DL or CNL for the clinician listed as reporting the test result.

It became apparent that the reporting model was more complex with a lot of different reporting combinations. Where the staff (e.g., consultant) listed as reporting the test differed from those present in the room (e.g., physiologist/scientist & nurse), the reporting individual was deemed to be acting as a “reader” where reporting of the test is undertaken and authorised by a senior clinician outside of the group directly supervising the test and without any influence on the dynamic test situation (Hampson et al., 2019).

To accommodate this more complex presentation, the data was further categorised based on this combined structure of staff present in the room and then those recorded as reporting the test. This was also recorded on the SPSS database. Where the consultant was listed as being present within the room, but the report was documented as performed by another (e.g., the registrar, also listed as being in the room), this was considered to be dual reporting, where the

study results were interpreted and reported in conjunction with (usually) the consultant lead and the noted staff member. This style of collaborative reporting is often performed to help improve reporting skills, considering, for example, the language used, the correct interpretation and the recommendations for further management (Popescu *et al.*, 2020). This model was also documented within certain centres in the 2014 SE review (Bhattachya *et al.* 2014).

2.3.3 Training within SE clinics.

The potential for staff training during each SE was also recorded. This involved an initial binary question of whether training occurred during the SE. This was followed up by a question on who was involved and a second question asking who was leading the training. This was designed to better understand the capacity and scope of training for the future workforce and the scope of staff present to engage with SE services. This yes/no grouping was then used to identify the training group, which was then sectioned into a separate database where further assessment was undertaken, looking at who was undergoing training and who the training was being led by.

2.3.4 Trust bed size.

For each recruiting centre, the number of beds available was documented as an approximate measure of hospital size. Trusts were then categorised based on their respective bed grouping (<600, 600-799, 800-1000 and >1000 beds). This was used to investigate the impact of Trust size on potential service delivery (models employed) and both training volume and trainees being trained. Hospital data was based on NHS bed data for each Trust (NHS England, 2020a) and this was also used to gauge a more representative sample of Trusts within the study group.

1.

2.4 Statistical Testing

When categorised into the different groups, patient demographics were reported using mean, standard deviation, and median values where appropriate, as well as percentages and interquartile ranges (IQR) for categorical variables (Moyé, 2016). Where appropriate, continuous variables such as height and weight were measured, and normality was assessed using the Shapiro-Wilk test. This allowed parametric testing such as the T-test to be used for comparison between DL and CNL groups when assessing the demographic data and, for example, the volume of contrast and atropine used.

The study data was firstly grouped with presentation of the study cohort in line with the study aims looking at indications, outcomes, and testing method. This was then repeated, but with

the total group allocated into either the DL or CNL pathway. This created the opportunity to identify differences between groups such as test outcomes and patient presentation. Initial comparisons between the groups discussed in sections 2.3.1 – 2.3.3, were made using Mann-Whitney or Chi-square testing, where appropriate. Binary logistic modelling was then used to identify key variables impacting the assessment of outcomes such as a positive or negative SE or which variables would contribute towards a SE test more likely to occur within a DL or CNL based clinic.

Where multiple categorical outcomes existed, multinomial logistic regression analysis examined the relationship between test supervision models (Consultant, Registrar/Fellow, Physiologist/Scientist, and Nurse) and predictor variables, including patient demographics and documented risk factors, including smoking status and regional wall motion abnormalities at rest.

Using these different exposure variables within the regression modelling, the odds ratios were calculated through SPSS. This helped to identify which variables were more prevalent within the different workforce models when compared to one another. This was key in recognising the varying levels of clinical risk undertaking the test, the typical clinical presentation of patients within either the DL or CNL group, and also where in the diagnostic journey the patient is more likely to be seen by a Consultant, Registrar/Fellow, Physiologist/Scientist, and Nurse. This data was then summarised to provide an overview of the typical presentation of either a CNL patient or a DL patient.

2.5 Study Framework

Within this study, the design closely follows the theoretical foundations provided within the Donabedian evaluation model, which focuses on three interrelated measures of quality - (1) structure, (2) process, and (3) outcomes, offering a framework from which the study results surrounding the use of SE and the SE services themselves can then be interpreted. Each of these three measures within the model, feed into the next and ultimately determine the outcome of the service evaluation (NHS Improvement, 2005).

For example, the workforce models (predominantly the CNL or DL pathways) employed by the different Trusts, and by Trusts of different sizes highlight the **structure** or setting in which the care is being delivered. The assessment of the test modalities, the differences between exercise and pharmacological stress, and who is subsequently supervising and reporting the test results all help describe the **process** by which care is given. Finally, by capturing the immediate test results, the complication rates, and the potential for training across all the workforce models, this addresses the **outcome** element of the Donabedian model.

This model helps provide a background structure from which the results have subsequently been organised, inline also with the main study objectives.

3 RESULTS

3.1 Study Demographics

The following results have been presented initially as a general overview of the entire study cohort. This addresses the initial study aim by providing a cohort wide look at the acquired data including the indications for stress, the stress mechanism used and patient presentation.

The cohort patient demographics are reported in Table 3. The median age was 66 years (IQR 57-74), and 4957 (58.3%) of the participants were male. Hypertension and hypercholesteremia were the most common risk factors, affecting 52.2% and 44.2% of participants, respectively. 19.4% of participants had undergone previous percutaneous coronary interventions (PCI), 16.7% had a previous MI and 6.6% had undergone a coronary artery bypass graft (CABG). In response to the smoking criteria, over half of the study group were identified as non-smokers (51.1%), with 32.7% as ex-smokers and 11.2% as current smokers.

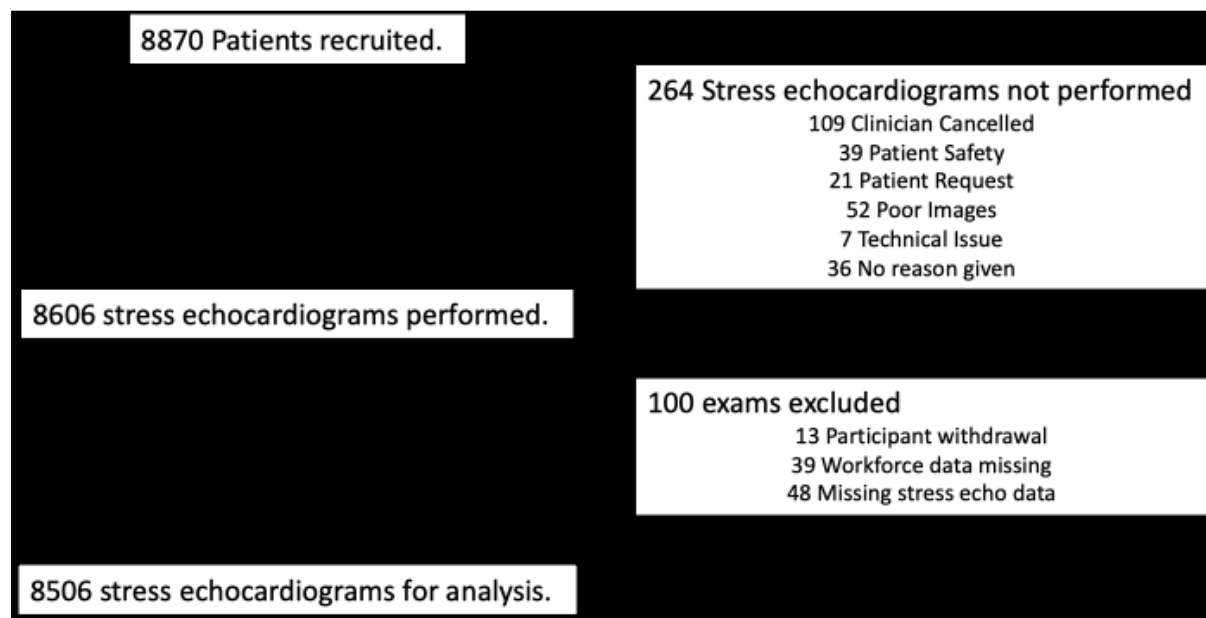


Figure 6 Recruitment flow chart from September 2020 to June 2023

Table 3 Patient demographics at time of stress echocardiogram.

Patient demographics	Total Group (%)
Male (%)	4957 (58.3)
Median Age (years) IQR	66 (57 - 74)
Median BMI (Kg/m2) (IQR)	28.56 (25-32)
Smoking	
Non-Smoker (%)	4350/8091 (51.1%)
Ex Smoker (%)	2785/8091 (32.7%)
Current Smoker (%)	956/8091 (11.2%)
Hypertension (%)	4440/8469 (52.2%)
Hypercholesterolaemia (%)	3756/8469 (44.2%)
Diabetes mellitus (%)	1829/8469 (21.5%)
Family History of Premature CAD	2613/8469 (30.7%)
Previous MI	1419/8468 (16.7%)
Previous PCI	1649/8468 (19.4%)
Previous CABG	558/8468 (6.6%)
Peripheral Vascular Disease	175/8468 (2.1%)
Resting RWMA	956/8468 (11.2%)

3.1.1 Indications for SE

The indications for SE are listed below in Table 4. It was important to appreciate the current cohorts perspective on why SE was being undertaken prior to looking at the impact of different workforce pathways. The most common indication for performing SE was excluding ischaemic heart disease, with 7602 studies performed (89.4%). This was present across all 34 Trusts. As a percentage of the total test indications performed across different Trusts, excluding

ischaemic heart disease, ranged from just 12.8% to 99.6%. Following this, “Other” testing was listed as the following highest volume indication and most prevalent, with all 34 Trusts recording something within this category.

Pre-transplant or pre-operation stress testing was the third most common indication for SE, with 250 tests (2.9%) of the total group volume. This was documented across 28 (82%) different Trusts and represented between 0.4% and 57.4% of their requested workload. The assessment of valvular heart disease was recorded in 147 SE tests and represented 1.7% of the total work undertaken. 22 (65%) different Trusts undertook this type of testing, ranging from 0.5% to 21.1% of their total workload with a minimum of just one test and up to 40 tests undertaken within a single Trust throughout recruitment.

Table 4 Indications for SE. Data is presented as n./total n. and percentage.

Indication for Stress.	Total Group	%
Exclude Ischaemic Heart Disease	7602/8480	(89.4%)
Myocardial Viability Assessment	80/8480	(0.9%)
Valve Assessment	147/8480	(1.7%)
Left Ventricular Outflow Tract Obstruction Assessment	28/8480	(0.3%)
Diastology Assessment	1/8480	(0.01%)
Pre-Transplant/ Pre-Operation Assessment	250/8480	(2.9%)
Other	355/8480	(4.2%)
Inconclusive prior cardiac testing	14/8480	(0.2%)

Eighty individual viability tests were recorded, representing 0.9% of the total indications for the group. This testing was found in 17 (50%) different Trusts and ranged in overall Trust testing prevalence from 0.2% to 4% with some Trusts undertaking a single study and others up to a maximum of 22. LV outflow tract obstruction assessment represented 0.3% of the total test indications and was recorded in 12 (34%) different Trusts. These Trusts undertook between one to a maximum of four studies during recruitment. This represented between 0.2% and 10% of the total SE performed within these Trusts. Only one Trust within the study cohort undertook a SE for the assessment of diastolic function. This represented 0.3% of their total SE activity.

3.1.2 Type of stress test used.

Having established why a SE was being undertaken, looking at what test protocol was applied provided insight into how later workforce models may be applied. Table 5 shows the stressors used within the total study cohort. Dobutamine was the most common stressor, accounting for 5116 (89.4%) of tests, whilst exercise was used in 3328 (39.2%). Of those undergoing exercise, treadmill testing was the most common, with 2414 (72.5%) of exercise studies performed this way and 908 (27.3%) undertaken using a bicycle ergometry. Thirty-three patients (0.4%) underwent a pacemaker-mediated study, and 16 patients (0.2%) underwent a perfusion (vasodilatory) study, with all studies using dipyridamole as the vasodilator. 6 studies (0.1%) did not have any stress modality listed

Table 5 –Type of stress echocardiogram performed.

Stressor	Total Group	%
Dobutamine	5116/8480	(89.4%)
Exercise	3328/8480	(39.2%)
Treadmill	2414/3328	(72.5%)
Bike	908/3328	(27.3%)
Pacemaker stress	33/8480	(0.4%)
Perfusion stress (vasodilator)	16/8480	(0.2%)

The next stage involved looking at the indication for SE and each stressor used. 4514 (88.5%) of the dobutamine studies were undertaken to exclude ischaemic heart disease. 76 (1.4%) dobutamine studies were used to assess valve disease. 67 (1.3%) dobutamine studies were used to assess myocardial viability. 213 (4.2%) dobutamine studies were used in patients undergoing assessment for pre-transplant / pre-operation studies. 7 (0.1%) dobutamine studies were undertaken for left ventricular outflow tract assessment and 229 (4.5%) were listed as other or were inconclusive prior testing. 30 dobutamine tests were missing an indication of stress.

Exercise stress had a slightly higher but similar preference as a stressor in the assessment of ischaemic heart disease, with 3033 (91%) of studies indicated. 76 exercise stress studies were used to assess valve disease (2.3%). 13 studies were performed to assess myocardial viability (0.4%). 21 exercise stress studies assessed left ventricular outflow tract obstruction and 36 (1.1%) for pre-transplant or pre-surgery. A single exercise stress study was undertaken to

assess diastolic function (<0.1%). 141 (4.3%) studies were listed as “other” or “inconclusive other testing”. Seven exercise stress studies had a missing indication for stress.

Thirty-two (97%) pacemaker studies were performed to assess ischemic heart disease with one pacemaker study (3%) undertaken to assess valvular function. Fourteen myocardial perfusion studies (87.5%) were performed to assess for ischaemic heart disease. One study (6.3%) for assessing a pre-transplant/pre-operation patient and 1 (6.3%) listed as other. All 16 perfusion studies used the vasodilator, dipyridamole as the stressor agent.

3.1.3 Test Outcomes

For a number of tests, double outcomes were recorded for various SE indications, with many patients undergoing viability or valve assessments as the primary test, combined then with an ischaemia assessment as a progression of the initial test, often conducted with dobutamine. This section provides an overview of the study results as a whole and then will investigate the results with respect to the different workforce models undertaking these tests.

For patients assessed for inducible ischemia during stress, there were 6631/8506 (78%) negative tests, 1476/8506 (17.4%) tests were positive, and 399/8506 (4.7%) were inconclusive/abandoned or not applicable. For the valve studies, 31/83 (37.3%) showed worsening valvular function with stress compared to 46/83 (55.4%). Six out of the 83 reported tests (7.2%) were inconclusive or abandoned. Despite documenting 147 valve assessment tests, the outcome data was unavailable for 64 individual tests.

Thirty five out of a possible fifty five (63.6%) studies were reported as demonstrating viable myocardium under stress, whilst twelve (21.8%) did not, and eight (14.5%) were inconclusive or abandoned. The single diastolic stress test was inconclusive. Nine (45%) studies out of 20 demonstrated an LV outflow tract obstruction at stress. 10/20 (50%) did not demonstrate an obstruction during stress, and one study (5%) was inconclusive or abandoned.

Table 6 shows the overall patient demographics of those patients undergoing an assessment for inducible ischemia (both initial and progressive assessments of ischemia included), comparing positive or negative test results. The positive SE group were marginally but statistically older than the negative SE group 67 years (IQR 60-74) and 65 years (56-73) ($p<0.001$), respectively. A higher percentage of males was also seen in the positive group (66.1 vs 56.7%, $p<0.001$).

Table 6 Test outcomes for ischemia assessment

	Positive n=1476	Stress Echo	Negative n=6631	Stress Echo	P-value	Total N = 8506	Group
	n	%	n	%		n	%
Demographics							
Male (%)	975/1476	66.1%	3758/6631	56.7%	<0.001	4733/8107	58.4%
Median Age (years) IQR	67	(60-74)	65	(56-73)	<0.001	66	(57 - 74)
Median BMI (Kg/m2) (IQR)	27.7	(24.1 - 31.5)	27.5	(24.0 - 31.2)	0.254	27.6	(24.0 - 31.3)
Smoker							
Non-Smoker (%)	663/1333	44.9%	3503/6380	52.8%	0.001	4166/7713	54.0%
Ex Smoker (%)	488/1333	33.1%	2152/6380	32.5%	0.001	2640/7713	32.4%
Current Smoker (%)	182/1333	12.3%	725/6380	10.9%	0.001	907/7713	11.8%
Hypertension (%)	829/1468	56.2%	3399/6610	51.3%	<0.001	4228/8078	52.3%
Hypercholesterolaemia (%)	726/1468	49.2%	2864/6631	43.3%	<0.001	3590/8099	44.3%
Diabetes mellitus (%)	410/1468	27.9%	1317/6610	19.9%	<0.001	1727/8078	21.3%
Family History of Premature CAD	479/1468	32.5%	2021/6610	30.5%	0.12	2500/8078	30.9%
Peripheral Vascular Disease	37/1470	2.5%	126/6607	1.9%	0.133	163/8077	2.0%

Previous MI	324/1470	22	1036/6607	15.7	<0.001	1360/8077	16.8
Previous PCI	375/1470	25.4	1209/6607	18.3	<0.001	1584/8077	19.6
Previous CABG	160/1476	10.9	367/6607	5.6	<0.001	527/8083	6.5
Resting RWMA	331/1054	31.4	564/5656	10	<0.001	895/6710	13.3

3.2 Dobutamine Vs. Exercise

Patients who underwent a SE using dobutamine were compared to those who underwent exercise testing as the two main stressors undertaken. This helped provide valuable information on the individual patient cohorts and how their cardiac risk factors may then influence their pathway for stress testing. This follows the process element of the Donabedian model, addressing how care is being delivered. Given the significant difference in the test methodologies employed within the DL and CNL groups, the cohort was split into either exercise or dobutamine testing where applicable. The same methodology was applied to examine the demographics and any differences between the two groups.

Table 7 Patient demographics separated by use of exercise stress echocardiography and dobutamine stress echocardiography. Presented as n. / total n. Percentages are quoted in brackets.

	Dobutamine Stress		Exercise Stress		p
	N =5116	%	N=3328	%	
Male (%)	2886/5116	56.4	2027/3328	60.9	<0.001
Median Age (years) IQR	68	60-75	61	52-70	<0.001
Median BMI (Kg/m2) (IQR)	27.8	23.9-31.8	27.3	24.2-30.8	0.017
Smoker					
Non-Smoker (%)	2301/4762	45%	2018/3269	60.6%	<0.001
Ex Smoker (%)	1836/4762	35.90%	932/3269	28.0%	<0.001
Current Smoker (%)	625/4762	12.20%	319/3269	9.60%	<0.001
Hypertension (%)	2781/5082	54.40%	1624/3328	48.80%	<0.001
Hypercholesterolaemia (%)	2323/5082	45.40%	1395/3326	41.90%	<0.001
Diabetes mellitus (%)	1196/5082	23.40%	616/3328	18.50%	<0.001
Family History of Premature CAD	1585/5082	31%	1017/5082	30.60%	0.553
Peripheral Vascular Disease	145/5116	2.80%	30/3328	0.90%	<0.001

Previous MI	987/5116	19.30%	414/3328	12.40%	<0.001
Previous PCI	1038/5116	20.30%	593/3328	17.80%	<0.003
Previous CABG	386/5116	7.50%	157/3328	4.70%	<0.001
Resting RWMA	731/5116	14.30%	220/2777	6.60%	<0.001

Table 7 demonstrates the differences between the two groups. The dobutamine group had an increased number of significant risk factors compared to the exercise group, which was younger and had a higher percentage of males. The use of both contrast and atropine was also recorded for each study. Overall contrast was used in 6550 (78.5%) of studies with Sonovue contrast the most common with 5421 studies (64.9%), compared to 1125 for Luminity (13.5%) and 4 Optison studies (<0.1%). 1798 (21.5%) studies were conducted without the use of contrast. Contrast was used mainly within those patients undergoing dobutamine stress, compared to exercise stress ($p<0.001$).

3.3 Workforce.

Addressing the second aim of the study, this section presents the results from each of the different staffing groups involved within the SE test and looks at their impact on the testing methodology. This, in later sections will build to then look at the outcomes of each test and identify the impact these various models could have on service delivery. By undertaking a detailed assessment of the patient demographics, combined with a balanced comparison in terms of risk factors and prior medical history, this aims to identify if the CNL service is inferior, non-inferior or superior compared to the DL group.

The workforce data was assessed to examine the number and profession of staff present during the SE test. On average, testing was performed by two clinical staff, with some centres reporting up to five being present during a test. No SE testing was conducted in isolation with a single member of staff. A physiologist/scientist was present in 6965 (81.9%) tests and was the most frequent professional group present across the study cohort, working across multiple different roles, including leading the test, imaging, supervision and training of other staff. A consultant cardiologist was listed as present in 4085 (48%), a registrar/fellow in 2451 (28.8%) and a nurse in 2972 (34.9%).

These staffing groups combined in various ways to provide the clinical cover and expertise needed to undertake the test, with roles being interchangeable based on training needs if

appropriate. The data also emphasised subtle differences in the workforce looking after each SE test by highlighting where supervisory roles, performed in most cases by the consultant, were undertaken remotely. This gave rise to a specific situation where the cardiologist was documented as being involved with the patient's care during the SE episode (either in the supervisor or reporting role) but was not present in the room during the test.

Looking at staff's specific roles during the SE test, a physiologist/scientist was listed as the primary operator in 5004/8480 (58.8%) of cases. This occurred in 28 out of 34 different Trusts (82%). In three Trusts, a physiologist/scientist was the primary operator for 100% of the respective studies and in 12, they were the primary operator for over 70% of all the SE undertaken, equating to 4276 studies in total and 50.4% of the total SE undertaken. In six Trusts, the physiologist/scientist did not act as a primary operator.

A cardiologist was documented as the primary operator in 2147 SE exams across the study cohort. In 11 Trusts, in over 70% of the SE studies a cardiologist acted as the primary operator. Within four Trusts, a consultant undertook the role of primary operator in 100% of the studies conducted. The registrar/fellow group acted as the primary operator for 1313 studies in total, and in one Trust was responsible for 96.4% of the work as primary operator. This was the largest contribution of the registrar/fellow group in this role. The next most significant contribution was 88.1% as primary operator in a single Trust. This reduced significantly to 26.1% for the next Trust, where the registrar/fellow acted as the primary operator. Only 2 Trusts recorded a nurse as the primary operator for a total of 4 studies within the study group. This represented just 1.4% and 0.3% of the total cases for each of the two Trusts involved.

Studies were initially categorised based on the professional group performing the test, in a leading role. From this group, patient demographics, the indications for SE, and the stressors used to undertake the test were tabulated. Table 8 shows the breakdown of patient demographics and cardiac risk factors. Cardiologists supervised 3864 (46.5%) studies compared to 2864 (34.5%) within the cardiac physiologist group. The registrar/fellow group supervised 978 studies (11.8%) and nurses supervised 776 studies (9.3%). Data was not available on 24 studies in total. These were then combined and displayed as both DL and CNL for subsequent analysis in section 3.6.

Table 8 SE supervision is categorised based on profession.

	Cardiologist n=3864		Reg/fellow n=978		Physiologist n=2864		Nurse n=776	
	n	%	n	%	n	%	n	%
Male (%)	2189/3864	56.7%	575/978	58.8%	1714/2864	59.8	467/776	60.2
Median Age (years) IQR	66	(57 - 74)	65	(56 - 73)	65	(55 - 73)	67	(58 - 74)
Median BMI (Kg/m2) (IQR)	27.6	(23.6 - 31.6)	27.2	(23.9 - 31.2)	27.7	(24.4 - 31.2)	27.8	(24.6 - 31.3)
Smoker								
Non-Smoker (%)	1921/3638	52.9%	479/856	56%	1630/2828	57.6%	310/747	41.5
Ex Smoker (%)	1327/3638	36.5%	252/856	29.4%	842/2828	29.8%	354/747	47.4
Current Smoker (%)	388/3638	10.7%	125/856	14.6%	358/2828	12.7%	83/747	11.1
Hypertension (%)	1905/3856	49.4%	522/972	53.7%	1590/2860	55.5%	408/757	53.9
Hypercholesterolaemia (%)	1477/3856	38.3%	441/972	45.4%	1453/2860	50.8%	376/757	49.7
Diabetes mellitus (%)	720/3856	18.7%	192/972	19.8%	756/2860	26.4%	151/757	19.9
Family History of Premature CAD	1171/3856	30.4%	284/972	29.2%	859/2860	30.0%	294/757	38.8
Peripheral Vascular Disease	85/3854	2.2%	14/975	1.4%	32/2862	1.1%	43/753	5.7

Previous MI	565/3854	14.7%	159/975	16.3%	573/2862	20%	120/753	15.9
Previous PCI	630/3854	16.3%	206/975	21.1%	672/2862	23.5%	138/753	18.3
Previous CABG	212/3854	5.5%	71/975	7.3%	238/2862	8.3%	36/753	4.8
Resting RWMA	529/3683	14.4%	109/537	20.3%	244/2022	12.1%	75/752	10

3.4 Doctor-Led vs. Cardiac Physiologist/Nurse Led Stress Echo Supervision.

The study cohort was categorised based on either DL supervisory pathway or a CNL supervisory pathway. A total of 8475 studies were categorised based on the workforce data available, with several studies having incomplete workforce data. 4839 (56.9%) studies were identified as DL, and 3636 (42.7%) were identified as CNL. This was based on the self-reported “supervisor” data taken from the Castor database. Table 9 provides the patient demographics for both the DL and CNL groups.

Of the 34 centres recruiting, 28 (82%) ran a DL and CNL-supervised SE service, with the remaining six running a solely DL service. No centre ran a CNL service in isolation without cardiologist involvement. In 12 of the 28 Trusts, the volume of SE activity supervised by non-medical teams was more significant than that undertaken in the medic-led clinics. The CNL model was responsible for over 70% of all SE activity undertaken in eight Trusts.

This section focuses the analysis into the two main cohorts of the study, providing the opportunity to compare testing methodologies and also comparatively examine their outcomes, patient groups and reporting models. This was addressed in the third main objective of this study.

3.4.1 DL vs. CNL patient demographics

Initial Chi-Square analysis of the results identified significant differences between the two groups across a range of demographics shown in Table 9. The CNL group saw a higher percentage of males (59.9% vs 57.1%, $p < 0.008$); however, there was no significant difference in age or BMI across the two groups. There was no significant difference in smoking status. Risk factors hypertension (54.9% vs 50.1%), hypercholesteremia (50.3% vs 39.6%), and diabetes (24.9% vs 18.8%) were all significantly higher ($p < 0.001$) in the CNL group. The known prior cardiac disease conditions such as previous MI (19.1% vs 15%, $p < 0.001$), previous PCI (22.2% vs 17.3%, $p < 0.001$) and previous CABG (7.5% vs 5.8%, $p = 0.002$) were also significantly higher within the CNL group. Interestingly, resting RWMA was significantly higher within the DL group compared to the CNL group (13.2% vs 8.8%, $p < 0.001$).

3.4.2 DL vs. CNL SE test indications.

Table 10 displays the different test indications between the two groups. The proportion of patients seen for ischaemic heart disease tests was similar between DL and CNL clinics (89.1%

vs 89.7%, p=ns), but CNL services performed more viability (0.8% vs 1.2%, p= 0.04) and pre-op studies (2.6% vs 3.4%, p= 0.03). Compared to the CNL group, DL performed a higher percentage overall of dobutamine stress studies (63.0% vs 56.3%, p=<0.001), whilst the CNL group performed more exercise SE (42.8% vs 36.4%, p=<0.001) and specifically more treadmill exercise (25.1% vs 32.8%, p=<0.001) whilst rates of bicycle exercise were similar (11.2% vs 10% p=ns) (Figure 7).

Table 9 Patient demographics, risk factors and previous cardiac history organised by either DL or CNL test supervision.

	Doctor Led (DL) supervision.		Cardiac Scientist or Physiologist / Nurse Led (CNL) supervision.		
	n	%	n	%	p
	4839	56.9	3636	42.7	
Male (%)	2762	57.1	2179	59.9	0.008
Median Age (years) IQR	66	57 - 74	65	56 - 73	0.059
Median BMI (Kg/m2) (IQR)	28.3	25.1 - 32.4	28	25.3 - 32.5	0.28
Smoker					
Non-Smoker (%)	2400/4839	49.6%	1936/3636	53.2%	0.489
Ex Smoker (%)	1578/4839	32.6%	1194/3636	32.8%	0.11
Current Smoker (%)	513/4839	10.6%	441/3636	12.1%	0.201
Hypertension (%)	2425/4839	50.1%	1995/3636	54.9%	<0.001
Hypercholesterolaemia (%)	1916/4838	39.6%	1828/3636	50.3%	<0.001
Diabetes mellitus (%)	911/4839	18.8%	905/3636	24.9%	<0.001
Family History of Premature CAD	1454/4839	30.0%	1153/3636	31.7%	0.08
Peripheral Vascular Disease	99/4939	2.0%	75/3571	2.1%	ns

Previous MI	724/4827	15.0%	693/3628	19.1%	<0.001
Previous PCI	835/4827	17.3%	809/3636	22.2%	<0.001
Previous CABG	283/4839	5.8%	274/3636	7.5%	0.002
Resting RWMA	637/4839	13.2%	319/3636	8.8%	<0.001

Table 10 Indications for SE organised by either DL or CNL test supervision.

	Doctor supervision.	Led (DL)	Cardiac Physiologist / Scientist or Nurse Led (CNL) supervision.		
	n	%	n	%	p
Exclude Ischaemic Heart Disease	4312/4839	89.1%	3262/3636	89.7%	0.108
Myocardial Viability Assessment	37/4625	0.8%	43/3636	1.2%	0.046
Valve Assessment	89/4839	1.8%	58/3636	1.6%	0.412
LV Outflow Tract Obstruction Assessment	22/4400	0.5%	6/3100	0.2%	0.022
Diastology Assessment	1/4839	0.02%	0/3636	-	-
Pre-Transplant/ Pre-Operation Assessment	127/4839	2.6%	123/3636	3.4%	0.037
Inconclusive prior cardiac testing	10/4839	0.2%	4/3636	1.0%	0.34



Figure 7 Stressor agents used during SE testing, organised by either DL or CNL test supervision.

Logistic regression was then conducted to investigate the combined effects of age, sex, cardiac risk factors, and trust bed size on the likelihood of test supervision being either DL or CNL, with the CNL group as the reference category. This was key in helping to categorise the different patient presentations that existed between the two groups which in turn may help provide more of a rationale for why patients were selected to be seen within a particular SE model.

The model demonstrated that when compared to the DL group, the CNL group was younger (OR 0.990 95% CI 0.986-0.995, $p < 0.001$) and with reduced odds of seeing ex-smokers (OR 0.855 95% CI 0.763-0.958, $p = 0.007$) and current smokers (OR 0.711 95% CI 0.593-0.852, $p < 0.001$) compared to non-smokers.

The CNL group were more likely to see patients with hypercholesteremia (OR 1.300 95% CI 1.16 – 1.44, $p < 0.001$) and diabetes (OR 1.286 95% CI 1.130 – 1.464, $p < 0.001$) but less likely to see patients with a previous family history of premature coronary disease (OR 0.708 95% CI 0.629-0.796, $p < 0.001$) or those with resting regional wall motion abnormalities (OR 0.644 95% CI 0.545-0.760, $p < 0.001$) compared to the DL group. A history of previous MI, PCI, CABG, and peripheral vascular disease was not found to be a significant predictor in the model.

3.5 SE test outcomes

Overall, the rate of positive ischaemia SE tests for both the DL and CNL groups were very similar (17.1% vs 17.7%, $p = \text{ns}$), as were inconclusive/abandoned tests (3.8% vs 3.6%, $p = \text{ns}$). Show in Table 11, the results when compared, the CNL group saw a higher percentage of

patients with cardiac risk factors such as hypertension (61.3% vs 52.7%, $p=0.001$), hypercholesteremia (59.9% vs 41.5%, $p<0.001$), diabetes (32.8% vs 24.1%, $p<0.001$), and positive family history (36.7% vs 29.6%, $p=0.004$). However, the DL group, as previously identified, retained a significantly higher percentage of positive tests with a resting RWMA (35.5% vs 25.6%, $p=0.001$).

Within the negative test group (Table 12), the CNL showed a higher percentage of males (58.3% vs 5.5%, $p=0.02$) than the DL group. Similar to the positive test group, cardiac risk factor results were significantly higher in the CNL compared to the DL groups within the negative test group. Hypertension (54.0% vs 49.4%, $p<0.001$), hypercholesteremia (48.8% vs 39.3%, $p<0.001$), diabetes (23.1% vs 17.4%, $p<0.001$) were all higher. However, a positive family history was not significant. Prior cardiac conditions such as MI (18.2% vs 13.8%, $p<0.001$), PCI (21.6% vs 15.9%, $p<0.001$) and previous CABG (6.4% vs 4.9%, $p=0.01$) were all higher in the CNL group, but like the positive test group, resting RWMA were significantly higher in the DL compared to the CNL (9.9% vs 8.5%, $p=0.002$).

When applied within a regression model, DL or CNL SE testing did not significantly impact positivity rates across the groups ($p=ns$). The DL group on average, used a significantly higher dose of dobutamine compared to the CNL (30mcg/kg/min 42.5% vs 38%, $p<0.001$), although the CNL did have a higher dose percentage of dobutamine dose overall (40mcg/kg/min 20.4% vs 17.6%, $p<0.001$).

Further regression analysis was conducted to examine the effects of supplementary aids such as contrast or atropine use on the likelihood of a SE test being performed within a CNL SE list and the rate of complications reported between the two groups. The model was significant ($p<0.001$) with contrast use a significant predictor (OR 1.3 95% CI 1.18-1.48, $p<0.001$), whilst atropine was not significant, however. When compared between the two groups, there was a lower rate of reported complications in CNL studies compared to DL studies (2.2% vs 5.3%, $p<0.001$).

Table 11 DL vs. CNL Positive ischaemia test outcome

	Doctor Led (DL) supervision		Cardiac Physiologist / Scientist / Nurse Led (CNL) supervision		n=1476 p
	n	%	n	%	
Male (%)	535/829	64.5%	437/642	68.1	0.156
Median Age (years) IQR	68	60-75	67	59-74	0.27
Median BMI (Kg/m2) (IQR)	27.5	23.9-31.6	27.8	24.6-31.4	0.6
Smoker					
Non-Smoker (%)	352/696	50.6%	308/632	48.7%	0.74
Ex Smoker (%)	253/696	36.4%	234/632	37.0%	0.53
Current Smoker (%)	91/696	13.1%	90/632	14.2%	0.71
Hypertension (%)	435/825	52.7%	391/638	61.3%	0.001
Hypercholesterolaemia (%)	342/825	41.5%	382/638	59.9%	<0.001
Diabetes mellitus (%)	199/825	24.1%	209/638	32.8%	<0.001
Family History of Premature CAD	244/825	29.6%	234/638	36.7%	0.004
Peripheral Vascular Disease	17/825	2.1%	20/640	3.1%	0.198
Previous MI	168/825	20.4%	156/640	24.4%	0.067
Previous PCI	198/825	24.0%	175/640	27.3%	1.45
Previous CABG	83/825	10.1%	77/640	12.0%	0.23
Resting RWMA	217/611	35.5%	112/438	25.6%	<0.001

Table 12 DL vs. CNL Negative ischaemia test outcome.

	Doctor Led (DL) supervision		Cardiac Physiologist / Scientist / Nurse Led (CNL) supervision		n=6609 p
	n	%	n	%	
Male (%)	2094/3772	55.5%	1653/2837	58.3%	0.025
Median Age (years) IQR	65	56-73	65	55-73	
Median BMI (Kg/m2) (IQR)	27.5	26.3-31.3	27.7	24.4-31.2	
Smoker					
Non-Smoker (%)	1938/3569	54.3%	1554/2791	55.7%	0.17
Ex Smoker (%)	1239/3569	34.7%	904/2791	32.4%	0.23
Current Smoker (%)	392/3569	11.0%	333/2791	11.9%	0.45
Hypertension (%)	1858/3762	49.4%	1526/2826	54.0%	<0.001
Hypercholesterolaemia (%)	1478/3762	39.3%	1378/2826	48.8%	<0.001
Diabetes mellitus (%)	656/3762	17.4%	653/2826	23.1%	<0.001
Family History of Premature CAD	1140/3762	30.3%	877/2826	31.0%	0.524
Peripheral Vascular Disease	74/3763	2.0%	51/2822	1.8%	0.639
Previous MI	519/3763	13.8%	515/2822	18.2%	<0.001
Previous PCI	598/3763	15.9%	609/2822	21.6%	<0.001
Previous CABG	186/3763	4.9%	181/2822	6.4%	0.01
Resting RWMA	375/3416	9.9%	189/2224	8.5%	0.002

3.6 Reporting SE results – Doctor Led vs. Cardiac Physiologist/Nurse Led.

3.6.1 DL vs. CNL SE reporting demographics

Reporting style and volume of the SE tests was identified as a the fourth objective of this study and was examined as a key component of the SE, separate to test supervision using the self-reported data. 94.6% (8038) of all SE reporting was undertaken within the DL group, with 453 (5.4%) studies reported within the CNL group. Table 13 compares the DL and CNL reporting groups. Regarding the age and gender split, the two reporting groups remained very similar. Whilst the group sizes were very different, the percentage trend of the data presented demonstrated a higher percentage for each risk factor within the DL reporting group. The exception to this is resting RWMA, which, whilst not significant, was marginally higher in the CNL group (12.1% vs 11.2%, $p=ns$). The number of non-smokers reported within the CNL was significantly higher than the DL group (57.2% vs 50.8%, $p=0.01$).

Table 14 compares the indications for SE from both reporting groups. The DL group reported a small but significantly higher percentage of reports for the assessment of ischaemic heart disease (89.6% vs 85.9%, $p=0.01$) compared to the CNL. All other indications were non-significant. Reporting of dobutamine SE reports was significantly higher within the DL group (61.2% vs 41.1%, $p<0.001$); however, this was reversed with regards to exercise SE where the CNL group reported a higher percentage compared to the DL group (58.9% vs 38%, $p<0.001$).

Table 13 Reporting of SE results organised by either DL or CNL reporting.

	Doctor reporting	Led (DL)	Cardiac Scientist (CNL) reporting	Physiologist / Nurse Led	n=8491
	n	%	n	%	p
	8063	94.6%	428	5.4%	
Male (%)	4701	58.3	248	57.9	0.924
Median Age (years) IQR	65	57 - 74	64	56 - 73	0.025
Median BMI (Kg/m2) (IQR)	28.1	25.0 - 31.8	27.6	24.7 - 32.4	0.688
Non-Smoker (%)	4098/8063	50.8%	245/428	57.2%	0.01
Ex Smoker (%)	2669/8063	33.1%	109/427	25.5%	0.001
Current Smoker (%)	932/8034	11.6%	23/426	5.4%	<0.001
Hypertension (%)	4214/8057	52.3%	217/428	50.7%	0.817
Hypercholesterolaemia (%)	3609/8056	44.8%	139/428	32.5%	<0.001
Diabetes mellitus (%)	1729/8063	21.4%	94/427	22.0%	0.837
Family History of Premature CAD	2496/8052	31.0%	112/427	26.2%	0.01
Peripheral Vascular Disease	171/8063	2.1%	4/428	0.9%	0.07
Previous MI	1365/8063	16.9%	52/428	12.1%	0.008
Previous PCI	1574/8063	19.5%	74/428	17.3%	0.234
Previous CABG	536/8063	6.6%	22/428	5.1%	0.191
Resting RWMA	906/8063	11.2%	52/428	12.1%	0.441

Table 14 Indications for SE organised by either DL or CNL reporting.

			Cardiac Physiologist / Scientist or Nurse Led (CNL) reporting		
			Doctor reporting	Led (DL)	
			n	%	p
Exclude Ischaemic Heart Disease			7201/8063	89.6%	0.016
Myocardial Viability Assessment			78/7100	1.0%	0.294
Valve Assessment			139/8063	1.7%	0.566
LV Outflow Tract Obstruction Assessment			26/8063	0.3%	0.614
Diastology Assessment			1/8063	0.01%	-
Pre-Transplant/ Pre-Operation Assessment			240/8000	3.0%	0.106
Inconclusive prior cardiac testing			13/6500	0.2%	0.721

Logistic regression was conducted to investigate the effects of age, sex, cardiac risk factors, and trust bed size on the likelihood of test reporting being either DL or CNL with the CNL group as the reference category. The model demonstrated the CNL group had reduced odds of seeing ex-smokers (OR 0.732 95% CI 0.574-0.933, $p=0.012$) and current smokers (OR 0.433 95% CI 0.279-0.705, $p<0.001$) compared to non-smokers. There were minimal differences in risk factors, with hypercholesteremia being the only significant difference (OR 0.646 95% CI 0.512 – 0.814, $p<0.001$). After adjusting for cardiac risk factors and anthropometric data, the odds of results being reported in a CNL clinic compared to a DL clinic were reduced across all the different trust sizes ($p<0.001$).

Table 15 Stressors used during SE, organised by either DL or CNL reporting which displays a preference for ESE reporting, and specifically treadmill testing within the CNL group compared to the DL, which maintained a preference for DSE testing.

	Doctor Led (DL) Reporting		Cardiac Physiologist / Scientist or Nurse Led (CNL) Reporting		
	n	%	n	%	p
Dobutamine Stress Echo	4921	61.2%	186	41.1%	<0.001
Exercise Stress Echo	3059	38.0%	264	58.9%	<0.001
Treadmill Exercise	2220	27.5%	191	42.1%	<0.001
Bicycle Exercise	837	10.3%	69	15.2%	<0.001
Pacemaker Stress Echo	33	0.4%	-	-	-
Myocardial Contrast Echo (Perfusion)	16	0.2%	-	-	-

3.6.2 SE reporting styles.

The individual data for each professional group revealed several different reporting combinations. This included scenarios where the reporting consultant was not present during the test (as previously described) and also where a consultant cardiologist was present during the test, but the report was undertaken by other staff, for example, the registrar or a cardiac physiologist. This was best demonstrated in the flow chart shown in Figure 8, including studies reported by registrars/fellows, physiologists/scientists, nurses, and cardiologists.

Cardiologists reported the highest proportion of SEs authorising 82% of all studies (n= 7039). Consultant reporting was present across all 34 Trusts and was the most common model identified. A cardiologist was present and reported the SE in 3597 (42.4%) SE studies, with the remaining 3442 (40.5%) reported by a cardiologist not directly responsible for test supervision who was assumed to be acting as a “reader,” authorising the reports away from the clinic setting. This reader model was documented in 22 different Trusts.

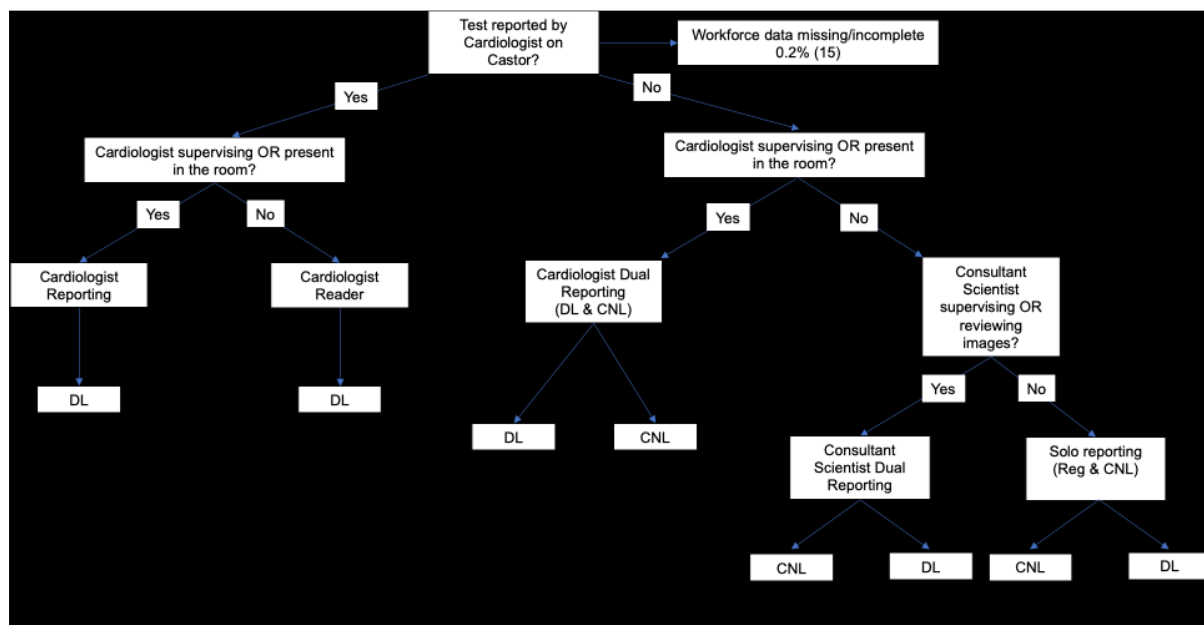


Figure 8 The decision tree diagram demonstrating the grouping process based on the reporting of SE results.

Dual reporting was identified across 445 studies, with either a registrar/fellow, physiologist/scientist, or nurse recorded as reporting the study within the study database, but also assumed to be reporting the study with consultant cardiologist oversight. Within the CNL group, 110 studies were dual reported with a consultant clinical scientist. The CNL group independently reported 343 studies, with 98.8% of this group reported by physiologists/scientists.

The physiologist/scientist reporting model was identified within 16 (47.0%) different Trusts and demonstrated a year-on-year increase in percentage distribution for both solo and dual reporting of studies, culminating in a combined total of 13.8% for reported studies in 2023. Registrars/fellows were responsible for independently reporting 540 studies across 12 (35.3%) different Trusts but did not demonstrate the same sustained growth as the physiologists/scientist group across the study duration. Figure 8 shows the trend over time in the displayed bar chart.

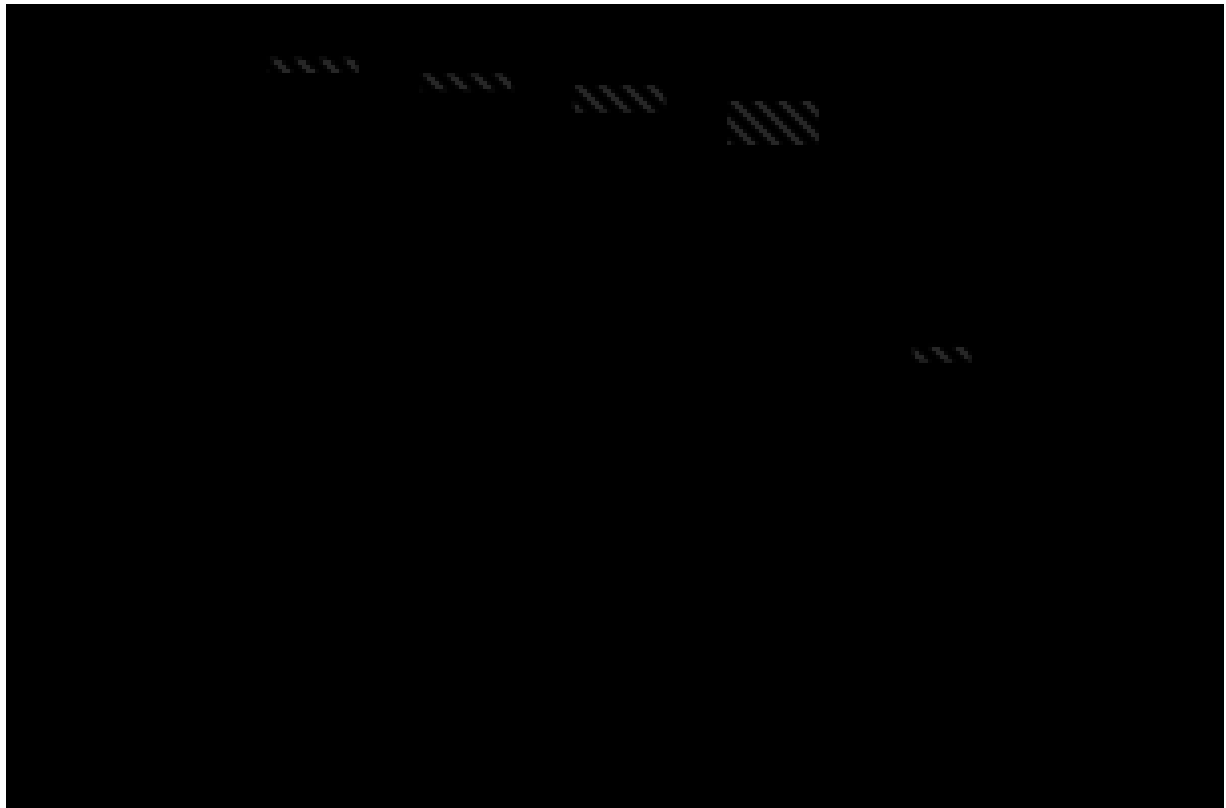


Figure 9 DL and CNL SE reporting as a percentage change, year on year. This shows how the CNL reporting pathway has increased over the duration of the project.

Using the test supervision data reported in section 3.6, the studies undertaken within the CNL group were then examined to see what percentage of this group went on to have a consultant cardiologist report the results generated from each SE test performed. Of the 3636 studies, 3065 (84.4%) had the results reported by a consultant cardiologist. 463 (12.7%) were independently reported by either a cardiac physiologist (n=458) or a nurse (n=5).

3.7 Training during SE lists

In total 20 of the 34 (58.8%) recruiting centres reported cases where training occurred within their SE clinics. This totalled 1729 SE exams (20.3% of the total study cohort), of which 1040 (60.2%) involved a cardiology registrar/fellow as the trainee. 560 cases involved a cardiac physiologist/scientist in training, 71 cases involved training nurses and 18 cases a consultant cardiologist. A further 40 (2.3%) training cases involved a range of staff from different professional groups or those on physiologist/scientist university training schemes who were unlikely to be training to assist or lead SE studies but were present to gain exposure as required for their respective educational programmes.

The training volume undertaken as a percentage of each Trust's total activity varied considerably. This ranged from a single case in two Trusts, which totalled 2.1% and 3.1% of their respective activity, to one Trust that logged 755 cases, representing 60.5% of the Trust's total activity and 43.6% of the total training activity of the entire cohort. The highest percentage split of training to non-training cases was 169 training cases, which represented 84.1% of a Trusts total SE activity. This was exclusively focused on the registrar/fellow group.

In those studies where training took place, the main indication for SE was the assessment of ischemic heart disease (92.2%) within the training cohort. There was a higher incidence of training in valve assessment compared to the general cohort at 2.9%, followed by pre-transplant / pre-operation (1.6%), other (1.6%), myocardial viability (1.4%) and LVOT obstruction (0.3%). The stressors used followed the main cohort trend, with 58% of studies using dobutamine and 41.2% of studies using exercise, broken down into treadmill exercise (86.8%) and bicycle exercise (13.2%). Twelve pacemaker SE studies (0.7%) and one myocardial perfusion study (0.1%) were also performed.

Supervision of training was mainly undertaken by the cardiac physiologist/scientist group (45.6%) and the consultant cardiologist group (38.2%) however, there was a significant volume of missing data, with 641 SE studies not having an identified supervisor reported. Whilst the roles that staff played during training were not officially documented within the study database, reviewing the stored SE reports made it possible to gain some understanding of the roles the trainee played during the SE. This included test management (supervision), image acquisition, and direct observation of the test. Some cases involved training a cardiology registrar/fellow and a physiologist/scientist during the same test.

3.8 Impact of Trust Size.

The Trusts were ranked based on the number of hospital beds available using NHS bed data (NHS England, 2020a). This, in part, reflected the overall size of the individual hospitals. Seven hospitals were identified as having less than 600 beds available. Cumulatively, they undertook 1691 studies, representing 19.9% of the overall study cohort. Within this bed size group, the median number of SEs undertaken was 86; however, two hospitals undertook 75% of the group studies, providing 523 and 807 studies, respectively.

Ten hospitals were grouped into the 600-799 bed group and contributed a total of 1576 studies (18.5% of the total study cohort). The median number of studies recruited was 78, with four centres contributing over 70% of the total group volume. Seven hospitals fell into the 800 – 1000 bed category, with a total of 2495 patients recruited. This represented 29.3% of the total study cohort, with a median number of studies of 275. One hospital contributed 50% of the total group contribution. The final group (>1000 beds) consisted of nine different hospitals. The median number of patients recruited was 174 with one trust recruiting 1157 patients, which equalled 42.2% of the group. Overall, this group contributed 2744 studies, representing 32.2% of the study cohort.

3.8.1 DL and Trust bed size and DL and CNL SE clinics.

Trust bed size significantly contributed to the DL and CNL model, using a Trust bed size of >1000 as the reference category. This showed reduced odds of the CNL model occurring in Trusts with 600 to 799 beds (OR 0.769 95% CI 0.666-0.887, $p<0.001$) and 800 - 1000 beds, respectively (OR 0.547 95% CI 0.468 – 0.640, $p<0.001$) compared to the DL clinics. Interestingly, the odds of a CNL service in Trusts with <600 beds, however, was almost double (OR 2.915 95% CI 2.541 – 3.345, $p<0.001$).

Within the Trust grouping of <600 beds, the percentage of CNL SE encounters compared to the DL SE encounters was higher (62.2% vs. 37.8%, respectively). This was the only group based on bed size in which this occurred, with the remaining groups 600-799, 800-1000 and >1000 beds, all demonstrating a higher percentage of DL lists 68.9% vs 31.1%, 54.8% vs. 45.2% and 64.3% vs. 35.7% respectively. In this group, there were seven Trusts, and the volume of CNL SE ranged from 98.1% in one Trust to 0%, with two of the seven Trusts running a solely DL service.

The CNL supervision was greater than DL in four of the seven Trusts. 1688 SE studies were performed by Trusts with less than 600 hospital beds. 41.8% of the SE performed in this group was supervised by nurses across three different Trusts, totalling more than any other profession in this group with 706 individual cases. One Trust accounted for 512 of the 706

individual cases, which equated to 97.9% of all SE activity for this individual Trust and 72.5% of the overall SE supervised by nurses.

To assess the impact of this one Trust, given the significant contribution of nurse-led SE in this one Trust, their results were excluded, and the regression analysis was repeated. 1165 SE studies were available for analysis within the < 600-bed group. The overall CNL group was responsible for 46.1% of SE activity, decreased from 62.2%. The percentage of nurse-supervised SE decreased from 41.8% to 16.7%. However, the overall regression model did not change, retaining all the same significant variables. Bed size remained a significant contributor, with the model still showing an increased odds of attending a CNL SE list at Trusts with <600 beds (OR 1.48 95% CI 1.27 – 1.73, $p < 0.001$) compared to the other group sizes.

Figure 10 shows the percentage distribution of supervised SE activity based on Trust bed size. This displays the grouped DL and CNL data and also the individual profession per bed size group for further comparison.

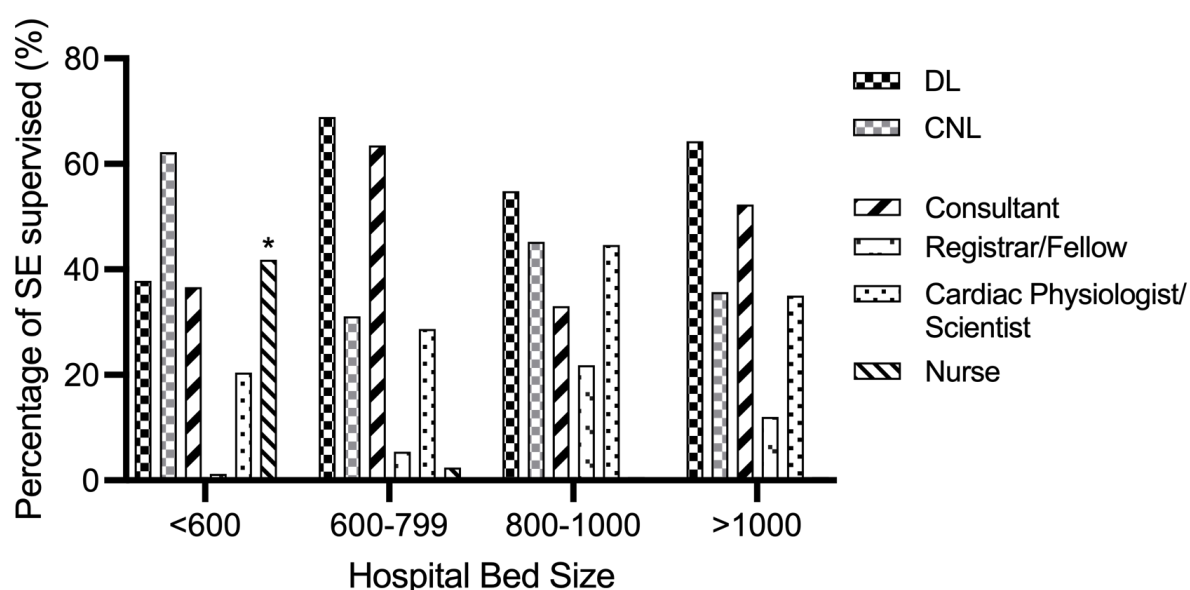


Figure 10 percentage of supervised tests for each professional group, organised by Trust bed size. *Indicates an outlier nursing group which featured significant contributions to this group.

When compared using regression analysis, training rates based on hospital bed size indicated staff training was most likely to occur in a Trust of 800-1000 beds (OR 2.98, 95% CI 2.61 – 3.40, $p < 0.001$), and this was primarily focused on the registrar/fellow group ($p < 0.001$).

4 DISCUSSION

This study has been designed to provide real-world data on the current SE activity within the NHS. It has focused on the variations in staff workforce models employed to deliver SE services. Specifically, it provides data on the immediate test management and subsequent reporting processes used in UK hospitals undertaking SE. It also highlights the impact of the non-medical workforce, such as cardiac physiologists, scientists, and nurses, on the delivery and reporting of SE testing and confirms the continued support that consultant cardiologists play in reading and reporting the test results.

Cardiologists have traditionally run SE activity within the UK. Cardiac physiologists/scientists and nursing teams have often played a supporting role, providing imaging and pharmacological support with both test management and reporting undertaken by cardiologists. This was often cited as being due to the experience in interpretation required to provide accurate results, requiring both extensive training and continued exposure to both positive and negative results and various different testing and stress modalities (Khan *et al.*, 2021, Ryan *et al.*, 2019)

The results of this study indicate that the workforce involved with delivering SE services encompassed a diverse range of staff who supported and led the service beyond the traditional cardiologist-led model. This included nurses, cardiac physiologists and scientists, consultant scientists, and doctors in training. The SE services that have been documented from this varying group have encompassed a range of different test modalities, different stressor agents, indications and also to some extent, reporting of test results also. These results present a similar outlook for the non-medical workforce as prior research but with the added benefit of both study design and study size, providing real world, multi-centre data over a three year period.

The increasing scope of practice for the non-medical workforce in supporting the delivery of services such as SE has been well documented across many specialities and diagnostic tests with examples of service development seen in clinical assessment (Chambers *et al.*, 2020, Jones *et al.*, 2017), device implantation (Campbell-Cole *et al.*, 2023) and SE itself (Khan *et al.*, 2021, Pearce and Chambers, 2018, Khan *et al.*, 2017b, Kane *et al.*, 2008, Ntoskas *et al.*, 2018). Within the field of SE, this has resulted in an organised evolution to now include clinical competencies and professional accreditations, providing a structured platform for cardiac

services to expand, formal accreditations to be developed and ultimately, improved access and reduced delay to patient diagnostics (Forshaw et al., 2021, Steeds et al., 2019).

The current evidence base supporting these new service models is mainly derived from single-centre studies with a focus on the safety and efficacy of the service. Unlike these studies, this study focuses on the volume and real-world use of SE services across an array of hospitals of varying sizes that are offering a range of services. What both this study and the prior research agree on, however, is how the diversification of the workforce to include non-medical experts in a more influential role, with appropriate support and training, can deliver SE testing via different models of workforce implementation (Kane *et al.*, 2008, Hampson *et al.*, 2019, Khan *et al.*, 2017, Ntoskas *et al.*, 2018a).

Using the notion of either a DL or CNL model for the supervision of SE services, the results of this study can be loosely applied to the wider NHS model using the prior research undertaken by Bhattacharyya and colleagues in 2014. This is a study that remains key in the understanding of SE services despite it being over 10 years old now. With 82% of the Trusts involved, running a combined DL and CNL SE service, and using data from Bhattacharyya et al. (2014), suggesting a possible 120 centres in the NHS providing SE services, this would (based on 2014 data), equate to 98 Trusts that could be providing this hybrid service model, requiring many staff such as cardiac physiologists and clinical scientists, to provide potentially thousands of SE tests per years, underlining their importance to maintaining a consistent diagnostic pathway for patients and therefore complying with the continued aims of the NHS LTP to expand scientific services.

4.1 Study demographics

The following section looks to address the first objective of this study, based on the Donabedian structure of the service delivery, which was to describe the indications, demographics and stress echo details of the study cohort and how this relates to current clinical practice.

4.1.1 Indications for Stress.

In a study of approximately 8,500 SE exams, cardiac physiologists/scientists remained the most present staff members across all the professional groups involved in delivering SE activity. Naturally, this creates a profession with a dual skill set for both imaging and experience in SE delivery. It is not surprising then that almost half of all the SEs undertaken

within this study were supervised by staff with a non-medical training background such as cardiac physiologists/scientists.

The distribution of test indications within the cohort was heavily weighted in favour of ischaemic testing. These results reflect the earlier work in the UK by Bhattacharyya *et al.* (2014) and in more recent multi-centre studies (Ciampi *et al.*, 2023), who also found a significant weighting in favour of ischaemic heart disease testing compared to other indications for SE when assessed on a national level.

These results are similar to those of Ntoskas *et al.* (2018), who (on a Trust level) also reported a similar distribution with 93.7% of overall testing in their physiologist-led clinic, performed to assess ischaemia. Results from Hampson *et al.* (2019), Wennike *et al.* (2010) and Khan *et al.* (2017a) all also reported the assessment of CAD or ischemia testing as the most common indication for their respective SE services. This is not unsurprising, given the sustained growth in national trends around CAD imaging seen after the introduction of the NICE Clinical Guideline Number 95 – chest pain of recent onset (CG95) in 2016 (Weir-McCall *et al.*, 2023). The volume of stress echocardiography performed in clinical practice has seen a notable increase over the past decade and this trend can be attributed to several factors, including advancements in echocardiographic technology, an increased understanding of its clinical utility, and a growing emphasis on non-invasive diagnostic methods in cardiology (Pellikka *et al.*, 2020, Picano *et al.*, 2024).

One interesting consideration is that, unlike the work of both Bhattacharyya *et al.* (2014) and Ciampi *et al.*, (2023), the nature of the data collected in this study allows for a much greater understanding of how these tests are being conducted, and if there is a pattern to the work undertaken by each respective group. Whilst both Bhattacharyya and Ciampi present results from a larger number of individual hospitals as a surrogate for a national perspective, it is important to acknowledge that there will be some limitations to how their data is acquired in a self-reported questionnaire with respect to presenting data for an entire service. Also, the aim of both these studies was to look at the provision for SE overall, with minimal focus on the workforce delivering the tests.

For example, the assessment of valvular heart disease with SE across the total study group and, subsequently, the DL and CNL groups remained low throughout recruitment, representing just 1.7% of the total cohort. Despite these low numbers, the 2014 national survey study reported that 81 individual centres (equating to 98.8% of the study cohort), reported the ability to perform valvular stress studies. Whilst this may be the case on a practical level with centres having the ability to perform the test if required, a decade later, this does

not appear to have translated into consistent output that would suggest that this particular type of testing is being performed regularly across the country.

This does, however, demonstrate the unique insight that this study provides as a registry of SE activity compared to a service evaluation questionnaire. This lack of valve studies may also be the result of a situational bias for centres recruiting within this network, with the 34 hospitals potentially not performing or at least not recruiting significant numbers of valvular SE. It is possible that, for example, valvular stress is undertaken more frequently within larger surgical centres that have a higher propensity for valve replacement and, therefore, possibly more inclined to perform this type of testing. If this is the case, then a greater focus should be placed on individual operators to ensure their skills and competencies are maintained. As such, this may present a limitation to the development of the CNL workforce with this particular style of SE testing should demand for testing remain low, and therefore, limited opportunities to maintain skills present themselves. Whilst formal accreditations in SE provided by the BSE, ESC and American Society of Echocardiography (ASE) provide the framework from which staff can gain a broad range of skills and formally demonstrate their knowledge, it is the maintained exposure and practice that is key to becoming a confident, independent practitioner.

This further demonstrates the importance of a competency framework for performing SE. Operators should be exposed to a varied case mix that includes the assessment of CAD, the abnormal haemodynamic responses in valvular heart disease, and the role of diastolic stress and viability assessment (Wiegers *et al.*, 2019). The 2019 ACC competency document for echocardiography highlights the need for centres to perform at least 200 SE annually to remain competent (Ryan *et al.*, 2019). Individually, the ASE and EACVI guidelines recommend that each operator perform at least 100 studies to remain competent (Pellikka *et al.*, 2020, Sicari *et al.*, 2008). Of these 200, only 1 – 2 per month, equating to just 25 per year, are required to be from non-coronary indications (Citro *et al.*, 2022). This is further emphasised within the BSE SE accreditation process, where 20 cases (out of 200 submitted) should demonstrate structural heart disease, including valve disease and cardiomyopathies (Shah *et al.*, 2018).

The implied responsibility has always been with the operator to maintain their skills within both TTE and SE with regard to different testing methodologies. This is why the accreditation process advocated by the BSE for both TTE and SE includes a logbook with a varying case mix. However, the surprisingly low number of valve SE undertaken within this study suggests two potential areas for development. Firstly, there may be a need for further investigation on a broader scale into valve SE activity to see if this is located within certain Trusts. Also, the volume of valve SE that is being undertaken. It is possible that the centres enrolled in this

study simply did not undertake significant volumes of valvular SE, or that these patients were not recruited either consciously or unconsciously, recognising the large observational cohort studies are susceptible to selection bias (Song and Chung, 2010)

Secondly, there may be potential for further education and training from the national societies, such as the BSE, in recognition that this study highlights exposure to valvular heart disease SE is not as prevalent as anticipated. This could support staff in lower volume centres, and also then highlight the possibilities of different workforce models further, with the cardiac physiologist/scientist workforce expanding the scope of practice already well established within the valve clinic setting to include valvular SE on a larger scale.

4.1.2 Stressors used.

Looking at the stressors used within the clinical setting, Khan *et al.* (2017), found the proportion of dobutamine SE was higher within the DL group than those undertaken by the CNL group. Unlike Khan *et al.* (2017), however, this study found that dobutamine was the most common stressor overall in the CNL group. This may indicate that some of the earlier restrictions and concerns placed on the CNL group using drugs, such as dobutamine, have been reduced as more studies demonstrate the safety of the CNL model.

The CNL group continued to perform a higher percentage of exercise stress compared to the DL group, indicating an ongoing trend for exercise methodology within the CNL group. Whilst there is an increased use of dobutamine usage within the cardiac physiologist/scientist group compared to earlier studies, exercise remains the preferred stressor in many situations and, as such, is unlikely to diminish significantly. Despite the differences in pharmacological studies versus exercise between the two groups, dobutamine was still the most common stressor within the CNL group.

This variation in preference for stressor (exercise versus pharmacological) may represent an individual, institutional variation, with dobutamine and exercise usage ranging from 0% to 100% across the CNL group. This may be influenced by Trust institutional processes that dictate a degree of patient selection, such as an internal triage process into a DL or CNL pathway with a preference for exercise stress over dobutamine stress given the need for fewer drug interactions and reduced risk profile overall for those patients stressed using exercise (Pellikka *et al.*, 2020).

Given the higher overall proportion of dobutamine testing within the DL group and the associated risk compared to exercise SE (Lee *et al.*, 2023), this may also have contributed to the differences in complication rates within this study. This is further supported within the literature with UK centres performing cardiac physiologist/scientist-led SE, reporting a

preference for either exercise (69.2%) (Khan *et al.*, 2017), (91.5%) (Hampson *et al.*, 2019) and those in which there was a preference for dobutamine (98%) (Ntoskas *et al.*, 2018). The use of dobutamine as the primary stressor was also found in Italian and Austrian national surveys, where it was the most commonly used agent in 85.4% and 91% of studies.

4.2 DL and CNL SE supervision

By categorising and studying the workforce present within the study cohort, this study has been able to provide valuable insight into the continued professional development of non-medical led services as set out in the second objective of this study and then describe how these operate compared to the traditional medical led model as identified in the third objective. The study successfully captured the changing extent of stress echo services employed by Trusts regarding test supervision and reporting results. This is evident, with 82% of recruiting centres running combined DL and CNL services, which is a unique finding within the field of SE research.. This may represent a steadier recognition of the benefits provided by these hybrid services in overcoming some of the challenges to help the workforce meet current and future demand whilst also providing enhanced career and training pathways for those staff engaged with these clinics (Dixon-Woods *et al.*, 2024). This also complies with the aims of the current NHS LTP, which requires an expansion of staffing skill sets to encompass greater flexibility and quicker access to diagnostics (Department for Health, 2019).

Compared to results derived from the 2014 contemporary review of SE practice, there is a diversification in the staffing able to deliver SE tests. It is important to note however that this level of workforce information may have been more challenging to capture through the use of a questionnaire rather than a study database such as this study which was able to derive greater detail on the services delivered. This is in part to how the database was designed, recognising the importance of the changing medical workforce and the need to document this. One such example is the SE reader model described by Hampson *et al.* (2019) who reported on the ability of a physiologist to safely supervise SE studies within a RACPC setting and provide diagnostic images from which an expert cardiologist reader reported the formal results. The notion was that it was possible to achieve the safety and volume of SE studies required to meet demand whilst also benefitting from the expertise of the cardiologist reader. The volume of CNL SE activity employed by some Trusts indicates how productive these sessions can be, with over 70% of all SE activity in some Trusts within the study undertaken using the CNL model.

This model can present potential cost savings concerning salary cost and staff skill mix without compromising clinical care, alongside the flexibility of a larger, more responsive workforce to provide the volume required to meet demand (Khan *et al.*, 2021, Ntoskas *et al.*, 2018). Studies advocating for more non-medical led clinics have described various staffing cost models whereby staff members employed under the Agenda For Change (AFC) salary scale (NHS Staff NHS Staff Council, 2024) (typically operating anywhere between Band 7 and Band 8) are likely to cost less per hour than a substantive consultant cardiologist, regardless of the number of years served in the post. In addition, this also then releases the cardiologist to

undertake complex tasks unique to their skill sets, such as new initial patient consultations, invasive procedures or assessment of ward-based patients (Kane *et al.*, 2008, Khan *et al.*, 2021, Khan *et al.*, 2017b, Ntoskas *et al.*, 2018).

Whilst this study demonstrates that CNL services are non-inferior to the traditional DL model, there are in fact advantages to it as well. Teams such as cardiac physiologists and clinical scientists can also provide a greater degree of clinical flexibility, with testing such as SE falling more so within their normal scope of practice, meaning potentially fewer adjustments to job plans and clinical pathways. This also has the added benefit of meaning that services like SE can be tailored to meet surges in demand. However, this must be met with the ability to maintain sufficient numbers to retain clinical competence and, therefore, must balance the demand for SE and the number of operators required. The use of accreditation processes as a training pathway in CNL centres, brings with it the standardisation of process and the requirement to adhere to national standards which supports more the current CNL model of working which remains very protocol driven.

With a clinical shift from providing advanced diagnostic testing performed in small numbers by a DL group in a less established service, to providing consistently increased levels of clinical output requires reduced variation in practice and a mature service. This is something that the CNL has demonstrated with the safe adoption and auditable delivery of other services such as valve clinics over the last decade (Chambers, 2019), lending itself well to the SE delivery models represented in this study.

Again, where emphasis is placed more on test supervision within the CNL pathway, consideration should also be made regarding the ability to report the generated results, given the discordance between the number of supervised tests and the volume subsequently reported by the CNL group. This is discussed in more detail in section 4.3 however there is an anticipation that for many of the CNL supervised lists, a semi structured report was potentially generated at the time of the test and then checked and ratified by the reporting consultant. This level of detail was challenging to capture for each individual study but would be supportive of a progressive strategy to increase CNL reporting in the future.

While much emphasis is placed on the ability of the expert reader to review and interpret SE images concerning subtle changes in the myocardial contractility (Pellikka *et al.*, 2020, Picano *et al.*, 2024, Picano *et al.*, 2020), the test's interpreted results can only be as good as the study imaging and diagnostic confidence provided during the test. This reinforces the need for high clinical competence and confidence in test management and in image acquisition to generate the diagnostic images suitable for reporting. This requirement for high-quality imaging to assist

in clinical decision-making is common across many areas of echocardiographic assessment, such as strain or LV ejection fraction analysis (Lang *et al.*, 2015, Robinson *et al.*, 2020).

Interestingly there are also subtle differences seen in the risk profile of the patients categorised into either the DL or CNL pathways. The results of the regression analysis suggest that the demographics of the CNL patients tended to represent that of a patient presenting for initial testing with limited prior knowledge on their cardiac functional status, but (compared to the DL group) identified cardiac risk factors. The DL group however, contained patients with a significantly higher percentage of resting regional wall motion abnormalities and with a prior family history of CAD.

This suggests that patients within the DL group may have been risk-stratified because of a known cardiac risk profile, which may have been higher than those seen within the CNL pathway for their first presentation for SE. This triage process, whether intentional or not, appears to mimic the previously used pre-test probability scoring and then may also help explain the increased rate of complication seen within the DL pathway, should that group knowingly stress more high-risk patients. This was also suggested by Forshaw *et al.* (2021) who noted that the lack of randomisation of patients into CNL pathways may inadvertently result in further risk stratification and create this two-tier system of high and low risk patient groups. Whilst potentially unintended, maybe the acknowledgement of this formally could encourage other hospitals to engage with CNL services further.

4.3 DL and CNL SE Test Reporting

There is limited research on the training and on-going development of reporting practices within SE. The final primary objective of this study sought to address this by looking at any significant differences between the identified workforce models with regards to reporting style and volume. The available literature is often focused on describing the practicalities of SE, detailing for example the minimum numbers required to remain competent and the distribution of testing methodologies. It is considered an advanced skill (Level III) (Popescu *et al.*, 2009, Ryan *et al.*, 2019) , and this study's results very much suggest that the involvement of a cardiologist, either through test supervision, reading the SE studies and providing results or in training, somewhere in the SE pathway is very much still adopted.

Identifying those responsible for reporting SE results revealed a varied reporting model matrix despite 94.6% being reported within the DL group. Interestingly, 40.5% of the cardiologist-reported studies were conducted in a reader capacity, with the reporting medic reported as not present in the room, away from the clinical setting itself. This may represent an attempt by Trusts to balance the efficiencies of a CNL SE list with the experience, skill, and oversight

reported in the literature required to interpret results obtained during stress (Picano *et al.*, 2020; Ryan *et al.*, 2019; Hampson *et al.*, 2019). The reader reporting process could over time be transferred back to the supervising CNL team if a suitable training plan and competencies are in place and therefore realising even more cost savings per clinic.

The results suggest that this initial step in the diversification of SE workforce may in fact continue into the more definitive reporting element of SE. Figure 8 demonstrated a year-on-year trend that suggested an increase in the amount of independent reporting and dual reporting undertaken by the CNL groups, potentially demonstrating an experiential shift in service development to encompass test supervision and reporting as a standalone process. This would be instrumental in creating a more independent workforce.

The act of reporting SE however is not without its challenges, and whilst the workforce available to supervise SE testing on a day to day basis has been demonstrated to be more diverse than ever, some have reservations about the scope of practice allowed to groups such as cardiac physiologists with regards to reporting SE results. Porter (2018) highlighted their concerns in response to the research published by Ntoskas *et al.* (2018) referencing the educational and experiential requirements to report SE results and suggesting that there was a “danger” with a physiologist-led programme if interpretation is left in their hands.

Similar to Potters concerns, Forshaw *et al.* (2021) comments on the training and experience required to supervise and report SE results in their review of Khan *et al.* 2021 study into the safety and efficacy of physiologist-led SE. Forshaw raises concerns over conclusions drawn surrounding safety implications that can be derived from a single operator. However, interestingly, then goes on to highlight the author’s attempts to describe the physiologists’ experience and training, presumably suggesting they are competent to report studies, whilst highlighting the lack of comment on the training of the registrar used as a comparator within their (equivalent) DL model.

This study did not identify any immediate significant safety implications within the CNL group compared to the DL grouping with regard to complications however the longer-term follow-up of the patients seen within either pathway is yet to be published, using the data derived from NHS digital data sources.

There does not appear to be an extensive evidence base surrounding the different styles and methodologies of reporting echocardiograms and in particular, SE studies. The study by Hampson *et al* (2019), which details their experience using what they nicely describe as the reader model, is one of the only examples outside of national guidelines and recommendations investigating SE reporting as a primary research aim. Yet, the evidence presented within this study suggests that almost half of all consultant-reported SE studies were performed this way.

It is important to note that the recruitment volume varied between the different centres and that the reader model was favoured by a larger recruiting centre. However, it was not limited to a single Trust with 22 Trusts (65%) using this style of reporting within their SE clinics to varying degrees.

Alongside the reader model, the concept of dual reporting of studies between a cardiologist, registrar/fellow and cardiologist and physiologist/scientist, or nurse is certainly not trailblazing and likely to be something that is far more commonplace than the current evidence bases suggests. Indeed, the requirements for BSE accreditation in SE, list the need for 200 cases reported in a logbook, therefore there must be a stage in a trainees' development that supports reporting as a process, and dual reporting seems to be a suitable methodology. A recent study by Blissett *et al.* (2021) looked at the concept of learning TTE in a group of doctors in training, based in America. Using structured interviews they identified both barriers to learning and also supporting measures that helped develop their ability to interpret TTE. The supporting measures included the ability to read TTE images alongside their attending doctors (US equivalent to a UK consultant) in a dual reporting process. This was found to improve their cognitive load and therefore support a more rapid development.

Forshaw *et al.* (2021) comments specifically on the issues surrounding the interpretation of SE results in their review of Khan *et al* (2021) . The author highlights that the interpretation of the SE results has not been tested within the study. They then comment that the model likely to be adopted within the Australian healthcare system would be a dual reporting model, as this is standard practice due to regulation controls for sonographers. Unlike the UK model, where reports (most commonly for TTE) are issued by the scanning cardiac physiologist/scientist, in Australia, it is a requirement of the Medicare reimbursement process that a cardiologist reviews results. Interestingly, whilst there is no link to reimbursement for TTE undertaken in New Zealand, there remains a mixed model of reporting that maintains some review by a cardiologist (Forshaw *et al.*, 2021, Brown *et al.*, 2019).

The results of this study appear to suggest that the potential flexibility of the UK SE service, compared to that of both New Zealand and Australia for example has evolved to provide a range of reporting/training options for those staff involved in SE that has facilitated the expansion of the workforce outside of consultant lead services. This use of dual reporting was noted within the 2014 Bhattacharya study, occurring in 29 Trusts (34.5%) and 11 Trusts (13.1%) for cardiologist/registrar and cardiologist/physiologist dual reporting, respectively. Whilst there was no further elaboration on these results within the study it does acknowledge that there is a training need surrounding the reporting of studies that perhaps is not well represented in research.

This collaborative approach to reporting potentially enhances the quality of the echocardiographic assessment and allows for a more streamlined workflow within the clinical setting. This method has the potential to support independent reporting skills similar to both TTE and TOE and improve the accuracy of the study results, given the dynamic nature of the test (Khan *et al.*, 2017;(Kaye *et al.*, 2023). Interestingly, as of January 2025 there are currently 55 BSE SE accredited members. However this equates to only 1.5% of the total BSE accredited cohort (n=3454), and there will be a percentage that will be doctors which further confirms the limited national picture for structured accredited training.

Compared to the reported results within the 2014 study, there appears to be an increase in Trusts where registrars/fellows and non-medical clinicians independently report SE studies but the overall number within this cohort remains very low and limited to individual Trusts, rather than a collective approach across the cohort.

However, the disparity in numbers between the DL and CNL reporting groups does mean the statistical significance of the results should be carefully considered. Interestingly whilst the data suggests that there is an established pathway for non-medical staff to supervise SE testing, the reporting aspect of SE does not seem to have increased proportionally and further research into supportive measures or follow-up assessment via the EVAREST network could be beneficial in understanding more, the future direction of this key component to independent practice.

4.4 Training in Stress Echo

Whilst the medical training programme designed to support doctors in training is well established, the legacy of skills development within the cardiac physiologist/scientist and nursing professions may be less well developed for advanced practice such as the running of SE services. The training data captured in this study further supported this idea.

Training being undertaken during SE testing was predominately focused on registrar/fellow training compared to other staff groups. Unsurprisingly, this was evident more within the larger hospital groups, where the availability of middle grade doctors is more apparent and the expectation is more specialist training is undertaken (Khan, 2012). By comparison, Forshaw *et al.* (2021) when discussing the possibilities of CNL SE lists within the Australasia region, also recognised the impact of trust size and teaching capacity as a barrier to furthering the implementation of CNL lists, however did advocate for the benefits of these services which include a potential to be more cost effective and increase access to SE.

It may be that over time, as access to suitable master-level training in areas such as clinical assessment and history-taking via university modular courses and more formal courses such

as the Scientist Training Programme (STP) and the Higher Specialist Scientist Training (HSST) programme becomes more commonplace for the cardiac physiologist/scientist workforce, the cardiac physiologist/scientist led SE model will become more apparent across all Trust sizes. These educational opportunities and educational programmes may also see a continued increase in the use of the cardiac physiologist/scientist workforce across more imaging specialties such as TOE which presents many of the same challenges as SE, with regards to the administration and management of medications for patient (Kaye *et al.*, 2023). Cardiac physiologist/scientist led heart valve clinics are also well established and have been around for over ten years and are present in a wide range of Trusts with varying degrees of autonomous practice, but a very positive impact on the patient pathway and re-utilisation of clinicians' time (Chambers, 2019, Bhattacharyya *et al.*, 2019). These therefore may present a useful blueprint from which these CNL services in SE can be expanded (Zhou *et al.*, 2024)

4.5 Trust Size

It is clear from the study results that the use of the CNL pathway is not restricted to the larger Trusts, with an increased OR of patients being seen for SE on a CNL pathway in Trusts with <600 beds, than in some Trusts with a higher bed capacity. Interestingly, the findings remained significant even when potential recruitment bias was considered within this group, given the high percentage contribution of one particular Trust. This is a unique finding that to date, appears unreported elsewhere in the literature. 1688 SE studies were performed by Trusts with less than 600 hospital beds. 41.8% of the SE performed in this group was supervised by nurses across just three Trusts, and this totalled more individual SE studies than any other profession. Even when the outlier Trust was removed, the results still indicated increased odds of patients attending a CNL list compared to a DL list.

Services like this may have developed in smaller trusts using a more established and reported nurse-led rapid access chest pain clinic model. These services may have provided a model by which nursing staff already well-trained in assessing patients for chest pain, taking a clinical history and also having the ability to prescribe or administer medications progress more naturally into a route where they support functional testing such as SE (Pottle, 2005) with a suitably trained and experienced cardiac physiologist available to provide the imaging expertise required (Kane *et al.*, 2008).

Historically, lower numbers of middle-grade doctors undergoing training in smaller and more remote hospital settings (compared to larger teaching hospitals), combined with an expectation they cover more ward or clinical management (Khan, 2012) may have created the opportunity for nurse-led clinics to support demand over time across a range of cardiac services within smaller hospitals (Kane *et al.*, 2008, Pottle, 2005).

What this model presents in fact though, is a combined nurse/cardiac physiologist model assuming that the nursing teams are unable to provide the image acquisition required. Therefore, there is an argument to promote further the cardiac physiologist/scientist-led model, given that two imaging specialists could be present during each test should challenging images be encountered, therefore presenting a more robust staffing model. This study has demonstrated that outside of the consultant-led model, the cardiac physiologist/scientist model is the second most common model of SE delivery with regards the volume of SE performed.

4.6 Limitations

In a study of this magnitude with multiple sources of data entry, controlling every aspect of the data collection is difficult. It is difficult to determine the number of operators available at each site. Some assumptions are made that studies were reported on the day of the test rather than during a separate reporting session, which was not captured in the study data and could impact the efficiencies claimed within the study. Whilst the larger EVAREST study has permission to follow-up patients up to 10 years post SE, this study reports only the immediate test implications. Despite this, the long-term follow-up of patients in both DL and CNL clinics has been previously documented (Kane *et al.*, 2008, Ntoskas *et al.*, 2018).

The volume of data by each recruiting centre, may not represent the total activity undertaken, and not all studies started recruiting at the same time. This means that some sites have contributed more significantly than others. There is also the recognition that selection bias may have occurred within the prospective study design (Song and Chung, 2010).

Whilst the angiographic follow-up has been reported in earlier iterations of this study (Woodward *et al.*, 2021), there was no follow-up on the test outcomes available for analysis. Restrictions around permission access to the NHS digital data meant that this was not possible. Additional patient data such as ethnicity may have provided a deeper insight into possible regional variation in disease presentation and also the test outcomes. However, the focus of this study was to highlight the current workforce models available which has been successfully achieved.

There may be some limitations here to using bed size alone as a gauge for the anticipated demand and complexity of disease (Jones, 2023), but the idea that newer models of working start within larger (bedded) Trusts and filter down, often via teaching routes to become recognised best practice may be present within the study cohort.

As a subsidiary of the main EVAREST study group, this study did not feature a patient and public involvement (PPI) group in the start-up phase conducted in early 2014. However, as the study has grown, the main study group have introduced a participant feedback group that

receives the results of study outcomes. Whilst this study does lack the initial input from a PPI group within the design, participants have been able to feedback into subsequent studies helping to form appropriate outcomes, voiced in a lay language for a wide and varied audience.

5 CONCLUSION

This thesis provides a detailed insight into the SE activity undertaken within a group of 34 UK hospitals. Supervision of SE testing has traditionally been led by cardiologists with nursing and physiologist staff acting in supporting roles. This study demonstrates that the UK SE workforce is evolving, with non-medical-led services contributing significantly to the volume of SE activity undertaken across a range of different stress modalities and test indications.

There are clear differences in the test modality and in the patient risk profile between both DL and CNL supervised SE testing, with DL testing focused more on performing SE in patients with prior cardiac investigation and increased cardiac damage, suggesting a possible triage process implemented by Trusts that presents with a potential low and high-risk pathway more in line with the previous use of pre-test probability. Despite this, complications in both groups were low.

This expansion of the CNL workforce is likely linked to the increasing knowledge base and increased use of PSD proforma and adaptations of traditional DL pathways. This has presented a CNL group that uses pharmacological stress more than exercise stress on an almost equivalent basis with that of the DL groups. This demonstrates the continued expansion within the SE workforce to accommodate the more complex pharmacological stress testing into the predominately cardiac physiologist/scientist workstream, providing a more flexible and robust diagnostic pathway for patients.

Whilst the expansion of the workforce performing SE tests has been clearly demonstrated in this study, the downstream reporting of results has been shown to remain predominately DL with a range of models presented. However, the current trend in reporting within this study group demonstrates an increase in the volume of both dual and independent reporting of SE results within the CNL group, and specifically within the cardiac physiologist/scientist profession. This may represent yet further progression for fully independent performance and interpretation of SE results across the whole diverse workforce. Further investigation should be undertaken to continue to examine this trend.

Training within the field of SE is primarily focused on the registrar/fellow group and is likely embedded within well-established medical training pathways in isolated Trusts. Further

expansion of the CNL workforce with more established training should be considered to ensure the continued expansion seen within this study. As a result, further large-scale studies, using the established research networks used within this study, should be employed to continue to observe the SE work across a range of different Trust sizes and workforce groups.

6 APPENDIX

APPENDIX 1 RECRUITING SITES WITHIN THE STUDY GROUP. 80

APPENDIX 2 – WORKFORCE DETAILS WITHIN THE CRF FORM. 81

APPENDIX 1 RECRUITING SITES WITHIN THE STUDY GROUP.



APPENDIX 2 – WORKFORCE DETAILS WITHIN THE CRF FORM.

Workforce Data
4. Workforce Data

4.1 Primary Operator Role

Consultant Cardiologist
Cardiology Registrar/ Fellow
Cardiac Physiologist/ Echocardiographer
Nurse
Other (Please specify)

4.2 Supervisor Role

Consultant Cardiologist
Cardiology Registrar/ Fellow
Cardiac Physiologist/ Echocardiographer
Nurse
Other (Please specify)

4.3 Stress Echo Reported By

Consultant Cardiologist
Cardiology Registrar/ Fellow
Cardiac Physiologist/ Echocardiographer
Nurse
Other (Please specify)

4.4 Was anyone being trained during the stress echo?

Yes ☒ No ☐

Consultant Cardiologist
Cardiology Registrar/ Fellow
Cardiac Physiologist/ Echocardiographer
Nurse
Other (Please specify)

Please specify the role of the primary operator (ie. the person performing the scan).

Please specify the role of the person supervising the stress echocardiogram.

Please specify the role of the person reporting the stress echocardiogram. (If the stress echocardiograms are not reported immediately, this information should be available on the procedure report when it has been finalised).

Please record whether anyone was being trained in stress echocardiography and, if so, their role.

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