

Imaging and Biomedical Engineering

Clinical Academic Group

About King's Health Partners

King's Health Partners brings together a world-leading university for health research and education, King's College London and three NHS Foundation Trusts Guy's and St Thomas', King's College Hospital and South London and Maudsley.

We are an Academic Health Sciences Centre (AHSC) where world-class research, education and clinical practice are brought together for the benefit of the patients.

To support our mission, we are delivering programmes of work to:

- Join up mental and physical healthcare so that we treat the whole person, through our Mind and Body Programme;
- Increase the value of the care we provide, and the outcomes we achieve for our patients and service users through a Value Based Healthcare approach;

- Bring together our partnership's collective strength in a range of specialist services to deliver world-class patient care and research through our institutes programme;
- Developing education, research and capacity building programmes in global health including partnerships with healthcare teams and organisations in Sierra Leone, Somaliland and Zambia.

We are uniquely structured to deliver our mission for excellence. Our 22 Clinical Academic Groups (CAGs) bring together all the clinical services and staff from the three trusts with the relevant academic departments of King's College London.

Foreword



At King's Health Partners we are committed to improving outcomes for our patients and service users and achieving maximum value for money in everything we do. We believe that being open and transparent about the care and outcomes we deliver results in a culture of improvement across our partnership.

This is why we are publishing a series of outcomes books that will help patients, service users, carers, referring clinicians and commissioners to make better informed decisions. They will also help our staff to drive up the quality of the care we provide. The books report key outcomes for treatments provided by our 22 clinical academic groups. CAGs form the building blocks of our Academic Health Sciences Centre. By bringing together our clinical and academic staff across teaching, training and research, we can use their combined expertise to achieve better outcomes for our patients and service users.

Our books are designed for a clinical and lay audience and contain a summary of clinical outcomes, educational activities, research innovations and publications. They also focus on other important measures, such as staff satisfaction and wellbeing.

The primary purpose of King's Health Partners is to improve health and wellbeing locally and globally. We must deliver this goal in a challenging economic environment with rising demand for, and costs of, healthcare. We will only achieve sustainable health improvement if we strive to increase value. We define value in terms of outcomes that matter to patients, over the full cycle of care, divided by the cost of producing those outcomes. By publishing outcomes books, we have more information to support us measuring the value of the healthcare we provide.

Our goal is to use these books to allow us to reflect on and demonstrate where we are driving improvement and innovation.

Please send comments and suggestions to us at kingshealthpartners@kcl.ac.uk










For more information please visit our website kingshealthpartners.org

A handwritten signature in black ink that reads "John Moxham".

Professor John Moxham

Director of Clinical Strategy, February 2018

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Welcome to the Imaging and Biomedical Engineering CAG Outcome Book

Imaging is the bedrock of almost all clinical pathways. Advances in imaging technology are allowing us to view the body and see its different organs and how they function in increasingly sophisticated ways. It enables us to make diagnoses, look at a patient's response to treatment and guide treatments in real time. Developments in imaging services are supported through the field of biomedical engineering – the physics, maths, engineering and chemistry that underpin the technology used in imaging.

Our primary aim as a CAG is to integrate excellence in clinical services, research and education by bringing everyone together to work as an integrated team. Comprehensive imaging facilities and expertise are provided

across the clinical radiology, nuclear medicine, PET and medical physics and engineering units of Guy's and St Thomas' and King's College Hospital, whilst at King's College London, we have a strong programme of research covering everything from new devices and radiotracers to software which simulates how the body works. By working together, we are able to be more effective in delivering clinical services and research innovations, and maximising the impact of our work for the benefit of patients.

The success of this approach is reflected through the results of the 2014 Research Excellence Framework (REF) assessment (a system for assessing the quality of research in UK higher education institutions, carried out by the

four UK higher education funding bodies). 99% of our submission was rated world-leading or internationally excellent. Of the impact case studies submitted, 80% of our activity was rated as having Outstanding Impact (4*) and 20% as having Very Considerable Impact (3*) in terms of reach and significance.

Through our teaching programmes, we aim to ensure our radiographers, technologists, nurses, doctors and scientists are stars of the future. Our training portfolio includes three – and four-year PhD training programmes, a suite of five Masters programmes which act as both a postgraduate qualification and part of the training programme provided for scientists working in the NHS, a popular intercalated BSc in Imaging Sciences and a growing BEng in Biomedical Engineering.

We also undertake specialist training for allied health professionals in radiography and are one of five national training centres for the NHS Breast Screening Programme. We have two of the biggest centres for postgraduate training in radiology as well as a programme in nuclear medicine and specialist training recognised internationally in areas such as interventional radiology, PET/CT, liver and cardiovascular imaging. We are the only centre in England providing the academic component of postgraduate training in clinical engineering, and one of only three such centres in medical physics.

For us, the bottom line is to improve patient care, by providing the most highly skilled imaging specialists using the best equipment and the latest cutting edge medicine, whilst empowering our workforce with the knowledge that they are pushing the frontiers of medicine through our group's developments in research, education and clinical practice.

**Andy Adam, Bernadette Cronin,
and Paul Sidhu**

Imaging Clinical Academic Group Joint Leads

The value of partnership at King's Health Partners

King's Health Partners aims to create a centre where world-class research, education and clinical practice (the 'tripartite mission') are brought together for the benefit of patients.

We want to make sure that the lessons from research are used swiftly, effectively and systematically to achieve better patient outcomes, improve public health and join up health and care services for people with physical and mental health problems.

By working together in this way, integrating care across different organisations and sectors, we can not only improve the health of the people we care for, but we can also achieve better value for money.

Integrating mental and physical health

The mind and body are inseparable, and mental and physical health conditions are often connected. The average life expectancy for someone with a long-term mental health illness or learning disability is 15–20 years shorter than for someone without, often due in part to smoking, obesity, diabetes or alcohol misuse. Likewise, many people with long-term physical health conditions suffer from depression or other mental health conditions. Despite this, health services separate care into physical and mental and often fail to share patient information.

At King's Health Partners we are working to overcome these barriers by treating the whole person, through our Mind and Body Programme.

We are committed to caring for vulnerable patients with both physical and mental ill health in an integrated manner with better, faster diagnosis and treatment because we know that addressing mental ill health improves physical health outcomes and vice versa. We will treat the whole person by:

- Screening all patients with chronic physical diseases for mental health conditions, and using the learning from this to improve the care we provide;
- Improving our understanding of the physical health needs of people with severe mental ill health;
- Addressing the traditional distinctions between the mind and body in research and education allowing us to train students and staff to deliver more integrated care;
- Better organising and expanding current training provision for physical and psychiatric comorbidity;
- Working with our local commissioners to find new ways of commissioning integrated services;
- Linking IT systems across our partner trusts so that clinicians have access to a person's physical and mental healthcare records;
- Investing in innovative programmes such as IMPARTS (Integrated Mental and Physical Healthcare: Research, Training and Services),

3DfD (3 Dimensions of care for Diabetes) and 3DLC (3 Dimensions of care for long-term conditions);

- Recognising the importance of employee mental and physical health and wellbeing.

Public health

Public health is one of our biggest challenges. At the root of much of the ill health in south London is a high incidence of smoking, alcohol abuse and obesity. With our health and social care partners, we are developing strategies to tackle these public health priorities. We are also developing plans for an Institute for Urban Population Health and care, a collaboration with local partners to bring about transformational change to health in local communities. We want to achieve a measurable improvement and impact on health gain and local management of physical and mental health problems through new evidence based interventions.

Alcohol strategy – key aims

- Developing appropriate resources for clinical staff and patients;
- Developing and implementing training for all staff on harmful drinking, supporting early identification and intervention;

- Establishing ourselves as a centre of excellence for integrated research, training and practice in the management and prevention of alcohol misuse;
- Monitoring the impact of the strategy on indicators of alcohol related harm.

Tobacco strategy – key aims

- Supporting all clinical sites to remain smoke-free after our successful multi-site implementation in 2015, followed by the university in 2016;
- Developing an informatics structure for routinely and systematically recording smoking status;
- Support, referrals and treatment uptake for smoking cessation across the partnership;
- Co-producing clinical care pathway for nicotine dependence treatment;
- Developing and implementing training packages for smoking cessation interventions for all our healthcare professionals;
- Monitoring the impact of our smoking cessation strategy in relation to knowledge and uptake of skills by staff, uptake of smoking interventions, outcomes of interventions, user satisfaction, prevalence of smoking, cost-effectiveness of interventions.

Informatics

Informatics is at the heart of our plans to join up care, research and education. Data is one of our most important assets at King's Health Partners and we have unique strengths in using informatics to improve care, public health, and the efficiency of our health system. Our aim is to use our strength to improve coordination of patient care, across physical and mental health, increase ownership by patients of their own health records, and to enhance clinical decision making through research and planning. We work with our partners across south east London to develop and test new opportunities to use informatics to advance how we care for our local population.

Systems have been developed to enable electronic healthcare records to be shared across our partner organisations and with other healthcare organisations. Our work includes the award-winning 'HealthLocker' programmes, Cogstack, the Clinical Record Interactive Search (CRIS) and the Local Care Record. We are working with patients to make electronic patient information available in an anonymised format between partner trusts, primary care and social care. Together we have a powerful information resource for both practitioners and researchers.

Value-based healthcare

King's Health Partners Value Based Healthcare programme is focused on supporting our partner organisations to deliver excellent and consistent health outcomes whilst protecting our NHS resources.

We believe that in order to deliver transformational health improvements that are patient-centred, population-based and sustainable, we must make the best use of every pound available by continually focusing on value for patients and carers across the full cycle at King's Health Partners, our goal is to:

- develop meaningful and consistent patient-centred metrics, based on outcomes defined by patients, service users and carers
- quantify the potential impact that investment decisions have on our patients, carers, the local health economy and wider society
- ensure that the mental, physical and psychosocial needs of people are treated as one
- evaluate and learn from the outcomes that we achieve through research and transparent use of data to reduce variation.

We are working with clinical teams across the partnership to redesign pathways of care based on the above principles.

Introduction

Imaging is the medical discipline of taking pictures of the body to see its different organs and processes and how they function. It enables us to diagnose illness, to make decisions about surgery and treatment, to guide treatment and monitor its effects and, in some cases, to deliver treatment. Biomedical engineering is the physics, maths, engineering, chemistry and biology that underpin the technology used in imaging.

In Guy's and St Thomas' Hospital and King's College Hospital, comprehensive imaging facilities and expertise are provided across the Clinical Radiology, Nuclear Medicine, PET and Medical Physics and Engineering units. At King's College London, as well as supporting clinical service delivery, we have a strong programme of research covering everything from new devices and radiotracers to software which simulates how the body works.

Our primary aim as a Clinical Academic Group (CAG) is to combine excellence in clinical services, research and education to improve patient care, by bringing everyone together to work as an integrated team.

Because imaging services are vital to inform and deliver high quality care across the whole

spectrum of healthcare, the Imaging CAG works closely with and supports many other CAGs.

In particular, the Imaging CAG has close links with both the Cancer and Cardiovascular CAGs and, within the Imaging CAG itself, there are Cardiovascular and Cancer Imaging academic departments which focus on those areas of medicine. Collaboration allows us to share best practice about how to manage patients and ensure that we are working in a coordinated way to strive for excellence.

The translational research delivered and supported by the Imaging CAG ranges from work to improve and enhance existing practice for common health problems through to developing and introducing new techniques for managing more complex challenges. Some examples, showing the breadth of current areas of research:

TOHETI

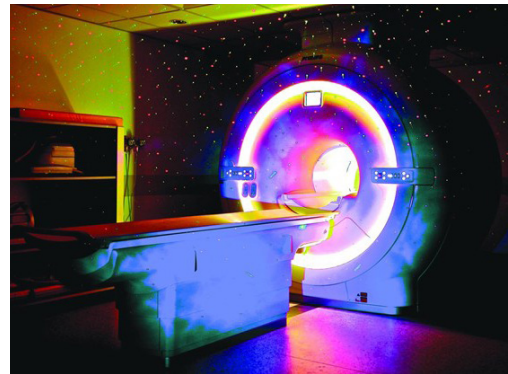
Through innovative programmes of work such as Transforming Outcomes and Health Economics through Imaging (TOHETI), we are working with partners across primary and secondary

care in Southwark and Lambeth to bring about system-wide change. By changing the use of imaging in the patient pathway, and through the introduction of cutting edge new technology, the TOHETI programme aims to show how imaging can be used more effectively as a diagnostic and therapeutic tool across a range of common patient pathways, with the aim of delivering improved outcomes and enhanced patient experience whilst removing waste and, therefore, delivering care more cost-effectively across KHP and beyond. Pathways under investigation include breast, colon, prostate and lung cancers, persistent headache, acute chest pain, uterine fibroids and scaphoid fractures.

Developing Human Connectome Project (dHCP)

The aims of the dHCP, to map the growth of the baby's brain during pregnancy and how it continues to develop after birth, are ambitious and require substantial scientific and technical advance in several fields. To achieve them the project is led by a team of four principal investigators – two from KCL's Centre for the Developing Brain (CDB), one from Imperial College London and one from Oxford University – who contribute complementary skills and techniques.

Few advances in neuroscience could have as much impact as a precise global description of human brain connectivity (connectome) and its variability. The dHCP aims to make



major scientific progress by creating the first 4-dimensional connectome of early life. Our goal is to create a dynamic map of human brain connectivity from 20 to 44 weeks post-conceptual age which will link together imaging, clinical, behavioural and genetic information. This unique setting, with imaging and collateral data in an expandable open-source informatics structure, will permit wide use by the scientific community enabling pioneering studies into normal and abnormal development.

Response adaptation for patients undergoing radiotherapy

Some of the most exciting work in the field of oncological PET/CT scanning is its application in supporting treatment planning and response adaptation for patients undergoing radiotherapy. Building on the experience of our team in response adaptation for lymphoma treatment, we aim to extend this to other tumour sites.



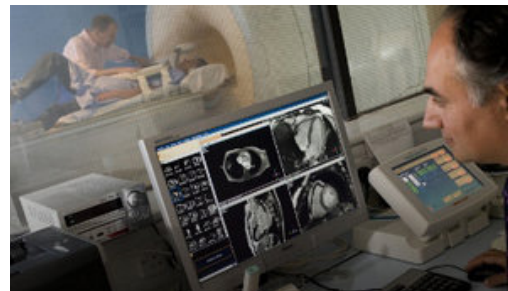
as it enables us to more accurately plan the radiotherapy treatment field, taking into account the variation in degree of malignancy throughout a single tumour site. Therefore, we can tailor the radiotherapy plan for each patient and 'prescribe' a boosted radiation dose to those areas that are most malignant whilst ensuring that we don't over-treat areas that do not require it, thus keeping radiation toxicity to a minimum.

In the same way, we can monitor the effects of radiotherapy throughout the patient's treatment, identify if parts of the tumour are becoming radio-resistant and modify the treatment plan to respond to this change. The ability to perform 4-D scanning, which captures the normal internal movement of organs within the chest and abdomen, further enhances the information provided for treatment planning as it shows how tumours move during normal physiological motion and will enable us to ensure that the maximum radiation dose is delivered to the tumour at all times.

Interventional radiology

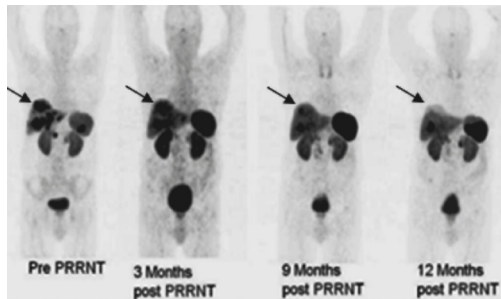
We are also expanding our work in Interventional Radiology (IR). IR uses minimally-invasive image-guided procedures to diagnose and treat diseases throughout the body. This image guidance can be provided by x-ray, fluoroscopy, ultrasound, CT and MRI. IR allows us to diagnose and treat patients using the least invasive techniques currently available in order to minimise the risk to the patient and improve health outcomes. Well recognised advantages of these minimally invasive techniques include reduced risks, shorter hospital stays, lower costs, greater comfort, quicker convalescence and return to work.

Interventional Radiology offers treatment options for many conditions including blood vessel disease, treatment of renal and gall stones and treatment of benign and malignant conditions (Interventional Oncology). Interventional Radiology techniques include use of radio-frequency, microwave and cryotherapeutic ablation as well as opportunities to develop the use of MR guided high intensity focussed ultrasound.



Molecular radiotherapy

Molecular Radiotherapy (MRT), also known as Radionuclide Therapy, uses radiopharmaceuticals (radioactivity attached to specific molecules, e.g. antibodies, peptides etc.) that can target diseased cells, including cancer, to deliver therapeutic levels of radiation dose to these disease sites. The choice of radiopharmaceutical is dependent on the disease being treated and this, in turn, determines whether the patient can be treated as an outpatient or requires admission. Expansion in our portfolio of MRT, alongside development of our IR service, will provide patients with increased options and enhanced choice for management of their disease.



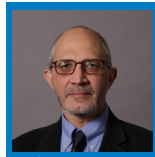
For example above is the use of Peptide Receptor Radionuclide Therapy (PRRNT) in molecular radiotherapy (arrow indicates reduction in tumour during the 12 months following Lutathera®, Lutetium (¹⁷⁷Lu) Dotatate therapy.

Nuclear medicine

Research in nuclear medicine at KCH is principally in support of haematological clinical trials, movement disorders studies in collaboration with the Maurice Wohl Clinical Neurosciences Institute, and King's HIV Research Centre.

Patients are referred to King's Health Partners to see the most highly-skilled imaging specialists using the best equipment and the latest cutting-edge medicine. Our staff come here to be part of an organisation where they know they are helping to push forward the frontiers of medicine as partners in our research and teaching.

CAG leadership structure



Professor Paul Sidhu
Clinical Director, KCH



Professor Andy Adam
Joint Clinical Director



Mrs Bernadette Cronin
Joint Clinical Director

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|--|---|---|---|
| Prof. Phil Blower Chair in Imaging Chemistry | Prof. Vicky Goh Research Lead | Prof. Gary Cook Molecular Imaging Lead | Prof. Alexander Hammers Joint Head of School of Biomedical Engineering and Imaging Sciences |
| Prof. Julia Schnabel Biomedical Engineering Lead | Mr Andre Nunes Mind and Body Lead | Dr Sarah Peel Education and Training Lead | |

Guy's and St. Thomas Clinical Imaging and Medical Physics

King's College Hospital Department of Radiology

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|---|--|---|--|
| Prof. Andy Adami Joint Clinical Director | Ms Alison Pollard Head of Nursing | Prof. Paul Sidhu Clinical Director | Ms. Laura Badley Deputy Director of Operations |
| Mrs Bernadette Cronin Joint Clinical Director | Narayan Karunanithy Intervention Radiology Clinical Lead | Dr. Nicola Mulholland Nuclear Medicine Clinical Lead | Dr. Colin Deane Head of Medical Physics |
| Dr. Sanjay Vijayanithy Intervention Radiology Clinical Lead | Ms. Holly Carey General Manager | Dr. Jason Wilkins Intervention Radiology Clinical Lead | Dr. Neil Deasy Head of Neuroimaging |
| Dr. Claire Lloyd Paediatric Clinical Lead | Ms. Kim Robertson Head of Radiology | Dr. Maria Sellars Paediatric Clinical Lead | Mr Colman Buckley General Manager |
| Dr. Sarah Wilson Breast Radiology Clinical Lead | Ms. Sarah Allen Head of Nuclear Medicine | Dr. Keshthra Satchthananda Breast Radiology Clinical Lead | Ms Helen Peskett Divisional Manager |
| Dr. Dhruba Dasgupta Nuclear Medicine Clinical Lead | Prof. Steve Keevil Head of Medical Physics | Ms Michele Mtandabari Matron | |

Biomedical Engineering and Imaging Sciences, King's College London

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| Prof. Alexander Hammers Joint Head of Division | Prof. Vicky Goh Cancer imaging | Prof. Sven Plein Cardiovascular Imaging | Prof. David Edwards Perinatal Imaging & Health |
| Prof. Rene Botnar Joint Head of Division | Prof. Julia Schnabel Biomedical Engineering | Prof. Phil Blower Imaging Chemistry & Biology | Prof. Alexander Hammers Head of PET Imaging Centre |

Our aims and ambitions

Top 10 globally

We have international leading programmes in cardiovascular imaging particularly cardiovascular MRI, aspects of cancer imaging, molecular radiotherapy, paediatric and fetal neuroimaging and interventional radiology – in particular, complex vascular interventions, radiofrequency ablation of tumours and a comprehensive liver interventional programme.

A few years ago, a generous contribution by the family of Mrs Mabel Norris enabled us to develop an excellent Visiting Professor Programme at GSTT. This has funded short visits to the Department of Radiology, by eminent academics from around the world, who have made an excellent contribution to the education of those working in Imaging within the whole of KHP.

We are delighted that our Visiting Professor Programme has recently received strong support from Siemens Healthineers, Philips Healthcare, Boston Scientific and Medtronic which enables

us to continue to invite eminent academics from around the world, who can teach our members of staff new techniques and broaden their horizons.

Academic expertise for clinical services

Our world-leading programmes have a strong research base and innovative postgraduate teaching. There are over 350 researchers in imaging within the CAG who focus on clinical translation in these areas with 25 clinical academics and 15 clinical professors that lead the CAG on clinical research and service delivery. These include three cancer imaging professors recruited from the Royal Marsden and Mount Vernon Hospitals, and four fetal and paediatric neuroimaging clinical professors. Within Radiology, we now have four professors – two based at Guy's and St Thomas and two based at King's College Hospital. The Radiology Department at KCH has been at the forefront of the development and clinical application

of ultrasound contrast agents in medical practice, with an internationally acclaimed unit in both adult and paediatric ultrasound imaging.

The King's College London and Guy's and St Thomas' PET Centre, at Guy's and St Thomas' Hospital, which provides scanning with PET/CT and PET/MR, opened in 1992. As well as state of the art scanning facilities and patient environment, it has full cyclotron and radiochemistry production facilities, enabling on-site production of radiotracers including those with short half-lives. As the first clinical PET Centre in the UK, work done here has been pivotal in informing development of clinical practice and national guidance on the use of PET, contributing to the body of research for the use of PET in oncology, neurology, infection imaging, paediatrics and cardiology and the level of experience and expertise across all disciplines is unparalleled. It is seen as a national and international centre of excellence with specialist expertise and, as such, manages referrals from across the UK. Members of the Department lead the UK National Cancer Research Institute (NCRI) PET core lab, that has successfully co-ordinated a number of national and international multicentre PET trials.

Specific objectives from the CAG leads

- Establishment of a new CAG executive team;
- Development of an agreed 3–5 year strategy to leverage benefits of being a KHP CAG;
- Review models of care across the acute Trusts to align and standardise where possible;
- Develop and implement new models of care where this provides patient and health economic benefit;
- Increase our engagement with acute services across King's Health Partners and continue to expand our specialist role and provision of services;
- Development of clinical, academic and educational scorecards so that progress can be demonstrated;
- Develop our workforce and the role of the wider multi-disciplinary team including opportunities for role expansion and apprenticeship working;
- Develop a standard referral dataset for imaging;
- Develop Interventional Radiology services;
- Support development of the KHP institutes model.

Imaging services

Background

Diagnostic imaging is at the heart of modern medicine and provides vital support for the majority of clinical specialties. It allows us to study both the structure and the function of the body. It also enables us to perform minimally-invasive procedures, to treat patients under imaging guidance and also includes other therapeutic applications such as Molecular Radiotherapy. Most patients who attend our hospitals will visit at least one of our departments, often many times throughout their treatment, and in many cases the diagnosis and decision as to how to treat the patient is made using findings from imaging investigations.

Diagnostic Imaging provision across KHP encompasses the full breadth and depth of state-of-the-art diagnostic, interventional and therapeutic investigations and procedures. This is provided through a combination of NHS Trust and University services delivered at Guy's Hospital, St Thomas' Hospital, Guy's Cancer, the Evelina London Children's Hospital, King's College Hospital and Princess Royal University Hospital, bringing together high-quality clinical and research expertise for specialist acute, elective inpatient and outpatient services. These serve the diverse boroughs of Southwark, Lambeth, Lewisham, Greenwich, Bexley and Bromley as well as providing specialist tertiary services, where required, for national and international patients.

Best practice and NICE guidance are used to inform how diagnostic imaging is used to support clinical care. The Imaging CAG has made significant contribution to this pool of knowledge and, in several modalities, is seen as a leader in emerging best practices.

At Guy's and St Thomas' NHS Trust, the Clinical Imaging and Medical Physics directorate (CLIMP) provides a full range of diagnostic, interventional and therapeutic radiology investigations and procedures, performing over 425,000 imaging examinations per year covering four sites: Guy's Hospital, Guy's Cancer, St Thomas' Hospital and the Evelina London Children's Hospital.

At King's College Hospital NHS Trust, the Department of Radiology similarly provides a wide range of diagnostic and interventional radiology investigations, including nuclear medicine for specialist acute, elective inpatient and outpatient services throughout multiple sites serving the economically-diverse boroughs of Southwark, Lambeth, Bromley and Bexley. Whilst the imaging services provided by Guy's and St Thomas' Hospital and King's College Hospital are comprehensive, the KCL imaging services focus on perinatal and cardiovascular MRI and PET.

The range of imaging modalities available has increased significantly in recent years. Referring clinicians, in conjunction with their Radiological colleagues, are able to select the most appropriate imaging modality to best answer the clinical question. Given the inherent radiation risk associated with ionising radiation, care is always taken to ensure that patients

are not unnecessarily exposed to this risk and we minimise the risk by keeping radiation doses as low as possible. This is particularly important when examining children and young adults. The services provided include the following:

Plain x-rays, such as those of the chest or the bones, are easy to perform and can provide important information in a very short time, for example about broken bones or chest infections.

Mammography uses low dose x-rays to visualise the soft tissue of the breast and enables us to identify and diagnose breast cancer at an early stage. To complement standard digital mammographic techniques, more recent advances include breast tomosynthesis, where multiple images of the breast from different angles are captured and reconstructed into a three-dimensional set of images.

Ultrasound uses sound waves of extremely high frequency to assess soft tissues without the use of x-rays. It is rapid and inexpensive and, using portable machines, can be performed outside the Radiology department. We also use an ultrasound scan to follow the progress of a pregnancy. King's College Hospital has pioneered the introduction of ultrasound contrast agents into clinical medicine, establishing the role in reducing radiation dose to children.

Figure 1 | Ultrasound is readily used within the partnership for a variety of diagnostic, therapeutic, interventional and research driven purposes



DEXA (dual energy x-ray absorptiometry) is a quick and painless test that uses low dose x-rays to assess the risk of and confirm the diagnosis of osteoporosis.

CT (computed tomography) uses x-rays and computers to produce detailed images of various organs such as the lungs, liver, heart and kidneys. The images are put together by a computer and can be viewed on a screen as 'slices' through the body from top-to-bottom, side-to-side and back-to-front or used to create 3-dimensional images. These images provide information about the structure and anatomy of the organs within the body. CT is extremely good at providing rapid assessment in very sick patients, for example, after serious trauma.

MRI (magnetic resonance imaging) – the combination of a powerful magnetic field and radiowaves produces detailed pictures of the inside of the body. These images provide much more detail than a standard x-ray and superior image contrast detail when compared to CT. Unlike x-rays and CT scans, MRI scans do not use harmful radiation. MRI scans are particularly good at identifying problems in the spine, brain and joints and are also very helpful in the examination of children. As well as standard 1.5T and 3T MRI, specialist cardio-vascular and perinatal MRI services are also provided.

Angiography uses contrast media (liquids visible on x-ray) injected into blood vessels to visualise them. This can be done for diagnostic purposes or can be a prelude to minimally-invasive treatment.

Fluoroscopy uses x-rays to obtain real-time moving images of the inside of the patient. In its primary application of medical imaging, a fluoroscope allows a physician to see the internal structure and function of a patient so that, for example, the pumping action of the heart or the motion of swallowing can be watched. This is useful for both diagnosis and therapy and takes place in general Radiology, Interventional Radiology and image-guided surgery.

Nuclear Medicine is a safe and painless way of taking pictures of the inside of the body. Because this technique tells us about function rather than anatomy, these images can be used to find problems in the very early stages of a disease, sometimes before they show

up on other tests. Nuclear Medicine uses small amounts of radioactivity attached to compounds to create radiopharmaceuticals (or tracers) that can target specific organs, disease types or abnormalities within the body. These radiopharmaceuticals can be swallowed, inhaled as a gas or (most commonly) injected. The radiation emitted by the radiopharmaceutical can be detected using a gamma camera, a special device which measures the distribution of the radiopharmaceutical within the patient's body and converts this information into an image that can show the presence, size and shape of abnormalities in various organs in the body.

In the majority of cases the radiopharmaceuticals for Guy's and St Thomas' and King's College Hospital are produced in our own on-site, GMP (Good Manufacturing Practice) licensed facility. This facility operates under a 'specials' license and also holds a Manufacturer's Authorisation – Investigational Medicinal Products (MIA-IMP) licence, which allows us to manufacture Investigational Medicinal Products to support research.

To complement routine gamma camera imaging, the CAG also provides hybrid SPECT/CT technology that allows us to collect Nuclear Medicine and CT data during a single scan and present these in one combined image, therefore providing both functional and anatomical information simultaneously. With consultant expertise in all aspects of diagnostic and therapeutic radionuclide medicine, the complex and highly specialised workload includes a full

range of nuclear medicine procedures and a variety of less common procedures which are not available in smaller departments.

In particular the nuclear medicine service supports the clinical specialisms at KCH in liver sciences, neurosciences, haematological malignancies and neuroendocrine oncology. In addition it provides hepatobiliary and pancreatic cancer molecular imaging to south London and the Kent Cancer networks, and complex post-colorectal surgery molecular imaging in patients with hepatic co-morbidities.

Positron Emission Tomography (PET) also uses radiopharmaceuticals to enable us to visualise function and displays this as 3-dimensional images. Typically, PET is combined with CT into a single hybrid PET/CT scanner which provides both the functional and anatomical information required. More recently, the CAG has acquired hybrid PET/MR technology which brings together the sensitive, functional information from PET and the exquisite soft tissue detail and contrast produced by MRI. Application of PET/MRI is still in its infancy and this system is currently being fully evaluated to establish where it adds value to the patient pathway across a range of specialities, including oncology and neurology. The radiopharmaceutical used for both PET/CT and PET/MRI will vary depending on the type of scan being performed and, once administered, will target the tissue(s) of interest. For most current scanning indications, the radioactive tracer of choice is fluorine-18 labelled fluorodeoxyglucose (FDG), which behaves in the same way as normal sugar and enables us to

identify cells whose metabolic rate is abnormally high or abnormally low. However, there are many alternative PET radiopharmaceuticals that enable us to image other physiological processes and we benefit from our in-house cyclotron and radiochemistry facility. This facility is based at St Thomas' Hospital and enables us to produce both standard and non-standard PET radiopharmaceuticals for clinical scanning, as well as developing novel radiopharmaceuticals for research.

Molecular Radiotherapy – by using therapeutic doses of radioactivity attached to key compounds, Nuclear Medicine enables us to target and treat certain conditions, including liver, pancreatic and gall bladder (hepatobiliary) problems, bone metastases from prostate cancer, thyroid and adrenal disorders, conditions that affect the endocrine and nervous system (neuroendocrine) and some rare cancers. The complexity of this form of treatment restricts availability to specialist units. Specifically, Molecular Radiotherapy for rare neuroendocrine cancers is only routinely available in a handful of UK institutions. Depending on the disease being treated and the radiopharmaceutical used, patients can either be treated as out-patients or as in-patients where they have to stay in specially-designed rooms.

Interventional Radiology – this uses imaging (e.g. x-ray, fluoroscopy, ultrasound, CT or MRI) to diagnose and guide delivery of treatment. Interventional Radiologists perform both diagnostic procedures (e.g. angiography to visualise the blood vessels and biopsy

to remove tissue samples for pathological examination) and therapeutic procedures, including (but not limited to) vascular stenting, endovascular aneurysm repair and embolisation as well as ablative therapies to destroy tumours (chemo-embolisation, radio-embolisation, radiofrequency ablation, cryoablation, microwave ablation and high intensity focussed ultrasound ablation). These minimally-invasive treatments reduce the need for open surgery.

Our Interventional Radiology (IR) services are known internationally for pioneering several minimally-invasive techniques under imaging guidance and our comprehensive portfolio of IR treatments is more diverse than most units in the world. Examples of the treatments we offer include: the destruction of tumours in the lung, liver and kidney using radiofrequency waves, the stabilisation of bones with the injection of cement, the treatment of weaknesses of the aorta with self-expanding metallic tubes covered with plastic and the unblocking of blood vessels with balloons.

In addition to established interventions, we also work collaboratively with our academic colleagues, nationally and internationally, to test new technologies and explore where these can be introduced into standard clinical practice to improve patient care. Across our two acute sites we perform over 30,000 Interventional Radiology diagnostic and therapeutic procedures each year.

Below are images showing the pre and post treatment appearances of a patient with a renal tumour treated with radiofrequency ablation.

Figure 2 | Top left CT image: right kidney removed for cancer. Small tumour in posterior part of left kidney. Middle CT image: radiofrequency electrode in place across the tumour. Bottom right CT image: Immediate post-ablation result: the normal renal parenchyma takes up contrast medium, whereas the ablated area (which includes the tumour) does not enhance

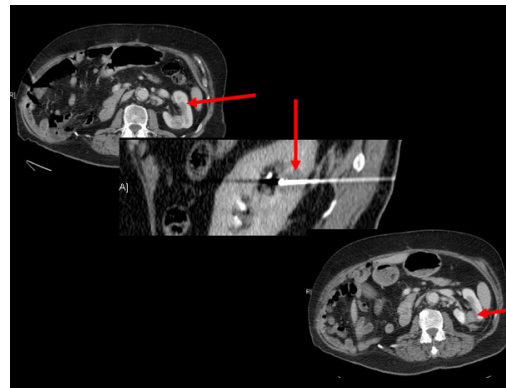
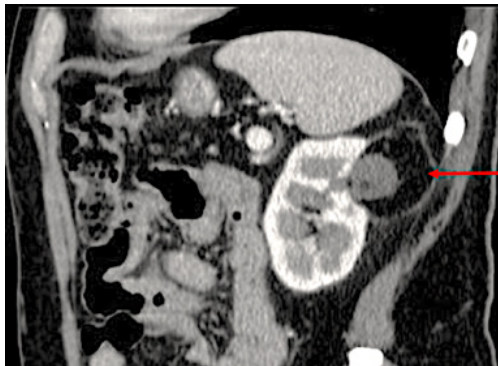


Figure 3 | After six months, the coagulated area does not enhance, in keeping with complete ablation. It has almost separated from the normal renal parenchyma. The thin white line around the ablated mass is the result of an inflammatory reaction in the perinephric fat



Examples of specific services

Nuclear medicine

The Nuclear Medicine department at Guy's and St Thomas' Hospital is very active in teaching and training across all disciplines and supports several MSc programs run by KCL, as well as clinical training for Nuclear Medicine Physicians and Radiologists, Clinical Scientists, Clinical Practitioners and Radiopharmaceutical Scientists. The service at GSTT Service has revenue streams of ~£6.5M and an establishment of ~50 WTE. It is one of the largest Nuclear Medicine services in the country and in 2013/2014 completed ~11,000 diagnostic examinations.

The service operates out of both Guy's and St Thomas' Hospitals, providing diagnostic Nuclear Medicine imaging, osteoporosis screening and a comprehensive range of Molecular Radiotherapy. St Thomas' Nuclear Medicine department supports inpatients, paediatric Nuclear Medicine and some outpatients and Guy's Hospital Nuclear Medicine department undertakes the majority of the outpatient diagnostic procedures plus outpatient and inpatient Molecular Radiotherapy. The service operates its own Radiopharmacy which is critical for running the department and facilitating research. Radiopharmaceuticals are supplied for Guy's and St Thomas' Hospital patients and also to several surrounding NHS organisations, including our KHP partner

King's College Hospital Nuclear Medicine department, and private hospitals in London and the South East. Sales of radiopharmaceuticals enables us to generate income.

At KCH the hub of nuclear medicine hub is at Denmark Hill with a smaller satellite unit at Princess Royal Hospital in Bromley. At Denmark Hill there is a dedicated Nuclear Medicine and PET-CT Department that provides specialist diagnostic and therapeutic services for the hospital. Performing approximately 10,000 examinations per annum the Denmark Hill service is housed in new premises, on the lower ground floor of the Golden Jubilee Wing. At the Princess Royal hospital the service performs approximately 3,000 examinations per annum to support this DGH site, plus a large GP requirement and a regional elective orthopaedic service.

Molecular radiotherapy

The Nuclear Medicine departments offer a range of treatments which use radioactivity, including treatments for both benign and malignant thyroid conditions, neuroendocrine tumours, radium therapy for prostate cancer and other Molecular Radiotherapies. The Molecular Radiotherapy Suite at GSTT is a two-bedded unit located on Sarah Ward, which currently does not meet same-sex compliance requirements, although we are operationally compliant. With an increased demand for inpatient treatment for benign and malignant thyroid disease, there is a requirement for investment in the unit, which will increase

capacity to four beds. At KCH the Molecular Radiotherapy service provided in Nuclear Medicine includes benign and malignant thyroid disease, selective internal radioembolisation (SIRT), mIBG and peptide receptor radionuclide therapy (PRRT) with Lutetium-177 Dotatate. The department also has the capability for offering inpatient therapies in a single dedicated radionuclide therapy suite and for offering day case therapies for PRRT.

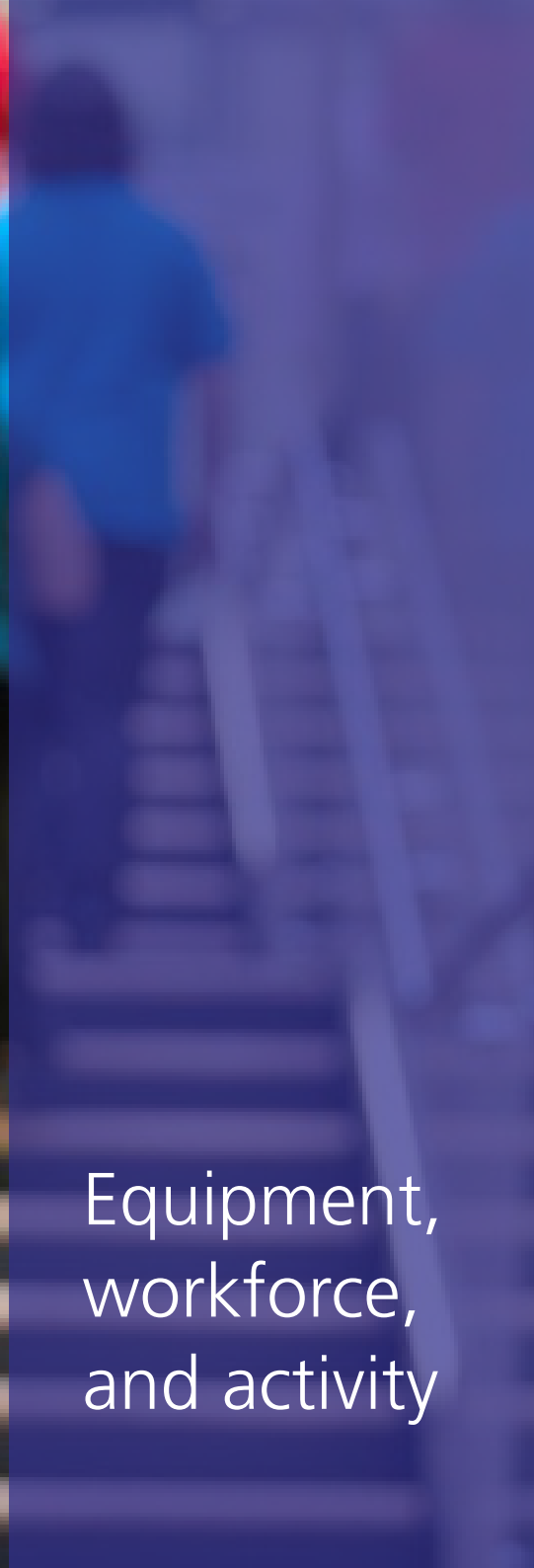
Medical physics and engineering

The Medical Physics and Engineering teams provide essential support which underpins all aspects of imaging, as well as supporting the wider trusts. Some of the work is patient-facing, whilst other aspects are 'unseen' but pivotal to the success of all services. Across KHP, the service is supported by 62 scientists, 130 technicians, 13 radiographers and 18 administrative staff. In addition, trainee scientists also contribute to service delivery as part of their placement.

Guy's Hospital was one of the earliest centres for the development of Medical Physics and engineering, with teaching of physics to medical students provided from the early nineteenth century. Before the establishment of hospital physics departments, academic physicists employed by the medical schools of both Guy's and St Thomas' hospitals provided support for clinical use of radiation and radioactivity. Innovations in KHP over the years included the first hospital bleep system, development of novel ultrasound technology and internationally

recognised contributions to professional education and training.

KHP Medical Physics and Engineering covers a broad range of activity, including the delivery of patient services and support for the safe and effective use of medical equipment, training of the next generation of Medical Physics and clinical engineering staff and cutting-edge research. Talented scientists, technicians and radiographers working within Medical Physics and Engineering apply science and engineering principles, using their analytical and specialist training, and a wealth of knowledge to meet the challenges and opportunities posed by modern healthcare. This includes everything from helping to introduce new techniques into clinical practice to solving subtle and challenging problems when equipment does not operate as expected.



Equipment,
workforce,
and activity

Equipment, workforce, and activity

Imaging services across the CAG

radiology investigations to all our sites,
24 hours per day, 365 days per year.

Details of the equipment and location is provided
in the table on the opposite page.

Imaging services within our Hospital Trusts

The multidisciplinary and complex nature of imaging requires a highly-skilled and diverse workforce. KHP is directly supported by a mix of Radiologists, Nuclear Medicine Physicians, Cardiologists, Clinical Fellows, Radiographers, Nuclear Medicine Clinical Practitioners, Nurses, Scientists, Chemists, Engineers, Technicians, Academics and support staff. These staff deliver clinical care alongside innovative research and educational programmes at Bachelor, Masters and Doctoral level.

An example of some of our most innovative facilities within the hospital trusts at KHP is the PET centre.

The PET Centre at St Thomas' has more than 25 years' experience of PET and PET-CT scanning and, more recently, PET-MR. The Centre provides PET services for referred patients at a local and national level and performs clinically-related research. We scan over 5,500 patients per year, and the enhancements of our newly refurbished Centre let us provide a patient experience that is as streamlined and comfortable as possible.

The Clinical Imaging facilities at Guy's and St Thomas Hospitals and King's College Hospital are provided across several geographical sites and our departments provide a full range of diagnostic, interventional and therapeutic

| | St Thomas Hospital | Guy's Hospital | Evelina London Children's Hospital | King's college Hospital | Princess Royal University Hospital | KCL Imaging Services (STH) |
|---|--------------------|-----------------|------------------------------------|-------------------------|------------------------------------|----------------------------|
| Computer Tomography (CT) scanners | 4 | 4 | | 4 | 2 | |
| SPECT CT | 1 | 1(2 from 03/18) | | 1 | 1 | |
| PET CT | | 1 | | 1 | | 2 |
| Magnetic Resonance (MR) Scanners – 1.5 T | 1 | 3 | 1 | 5 | 1 | 1 |
| Magnetic Resonance (MR) Scanners – 3T | | 2 | | 1 | | 3 |
| XMR (dual cath lab/MR facility) | | | | | | 1 |
| PET MR | | | | | | 1 |
| General Ultrasound | 8 | 8 | 2 | 10 | 9.5 | |
| MR Guided High Frequency Ultrasound | | | | | | 1 |
| Breast Ultrasound | | 2 | | 3 | 0.5 | |
| Mammography with tomosynthesis | | 2 | | 2 | | |
| Fluroscopy | 1 | 1 | 1 | 2 | 2 | |
| DEXA | | 2 | | 1 | 1 | |
| Gamma Cameras | 1 | 3 | | 1 | | |
| Interventional Radiology | 2 | 1 | | 4 | 1 | |
| GMP Radiopharmacy | | 1 | | | | |
| Cyclotron with radiochemistry facility | 1 | | | | | |
| Vascular Laboratory | | | | 5 | | |
| Hybrid Theatre | 1 | | | | | |
| Cardiact/IR Theatre | | | 1 | | | |
| General DR Rooms | 7 | 6 | 2 | 9 | 8 (3 are CR) | |
| In-patient beds for molecular radiotherapy | | 2 | | 1 | | |
| Out-patient beds/rooms for molecular radiotherapy | 1 | 2 | | | | |

Our PET Centre has an international reputation for patient care, high-quality academic research, and training. Our mission is to perform basic, translational and applied clinical PET research across all specialties including: oncology, neurology/psychiatry and cardiology. We welcome work with external collaborators, including industry, and aim to obtain the best possible quality and reliability for all studies we perform.



Imaging Services within King's College London

Within our KCL MRI service, we have a wide range of imaging equipment with capabilities that include specialist anatomical imaging (e.g. advanced cardiac, neonatal and fetal imaging), interventional MRI, functional and diffusion MRI, MR spectroscopy and elastography (a medical imaging modality that maps the elastic properties and stiffness of soft tissue). We use these comprehensive capabilities to conduct a broad range of research projects including

studies of cardiac function and disease, oncology, brain development in neonates and fetuses.

At King's College London and Guys and St Thomas' NHS Foundation Trust, we run an integrated clinical and research programme in cardiovascular Magnetic Resonance Imaging. This includes a 'fifteen minutes' research study that can be added on to standard clinical examinations, giving the opportunity to learn how to improve the clinical value of cardiovascular MRI and advance longer term research aims. In addition, we can combine MR imaging data with detailed information from patients' notes to get a more complete picture of patterns of disease progression. We may invite patients to participate in repeat imaging studies to enable more in depth studies, and to collect blood samples to obtain more comprehensive information.

Figure 4 | A state of the art X-MR facility which combines a 1.5 tesla magnet with a biplane catheter lab

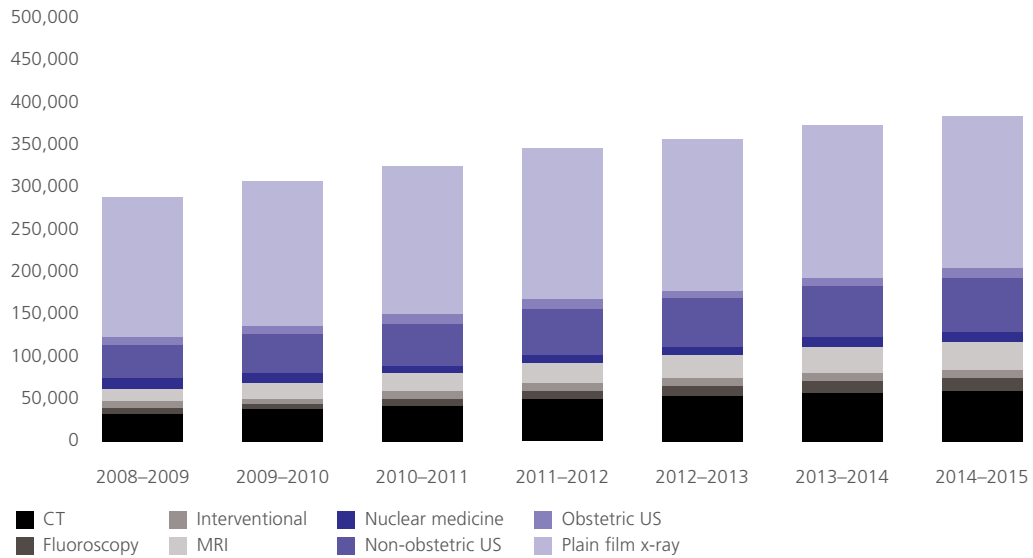


We are working closely with the NIHR BioResource and the blood samples are stored for future genotyping and phenotyping. The 'fifteen minutes' research study has enabled us to build cohorts (a bioresource) of patients who have had detailed assessment of their cardiovascular system by MRI. In cardiac MRI, the majority of clinical patients are invited to participate in this research and, if they consent, additional scanning is performed at the end of their clinical scan.

Activity

At GSTT, demand for imaging services has grown consistently year-on-year, and the total increase averages at around 6% per year with the greatest growth in CT and MRI (~10% per year).

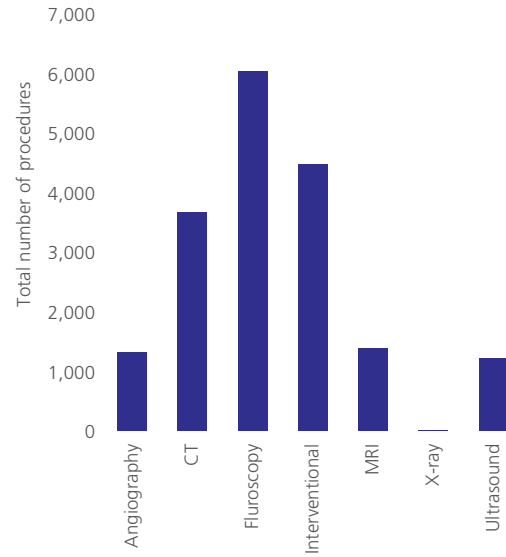
Figure 5 | Increase in activity observed over seven years at GSTT (2008/2009–2014/2015). Although the rate of growth varies across modalities, it is greatest in MRI with an approximate 10% increase year on year



Highlighted in this increase in imaging activity is the continued employment of imaging modalities to provide therapy for clinical conditions in nuclear medicine (see below table) and for interventional procedures (see below figure).

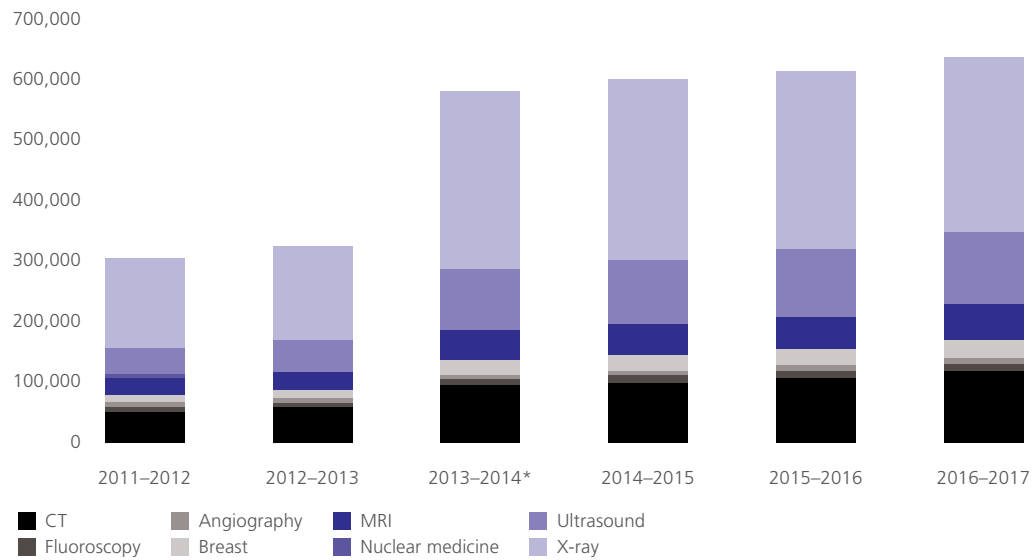
| Therapy/procedure | Number performed (April 2014–March 2015) |
|--------------------------------------|--|
| Radioiodine (benign thyroid disease) | 100 |
| Radioiodine (thyroid cancer) | 58 |
| Bone metastases (with strontium) | 0 |
| Bone metastases (with radium) | Started April 14, 78 |
| Haematology (P-32) | 0 |
| Radiosynovectomy (Y-90) | 4 |
| Radiosynovectomy (Re 186) | 1 |
| Lutetium dotatate | 58 |
| I-131 MIBG | 5 |

Figure 6 | Right number of therapies performed (2014/2015) and Interventional procedures (2016/2017) at GSTT



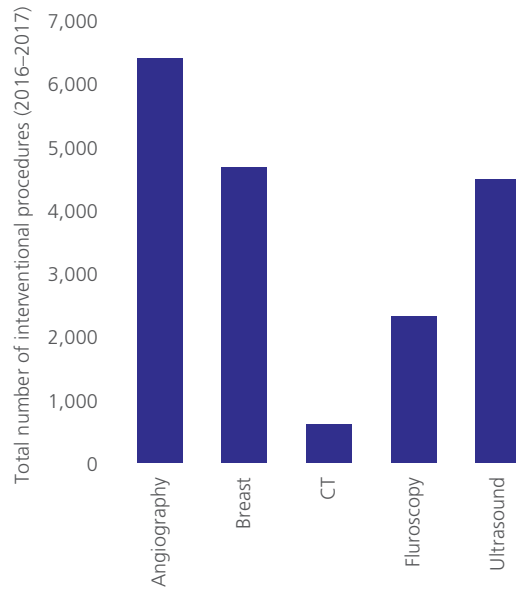
At KCH the demand for our imaging services have continued to increase similarly year on year.

Figure 7 | Year on year growth of imaging services at KCH. The large increase particularly in x-ray procedures in 2013/2014 is due to the acquisition of the Princess Royal University Hospital (PRUH) in October 2013



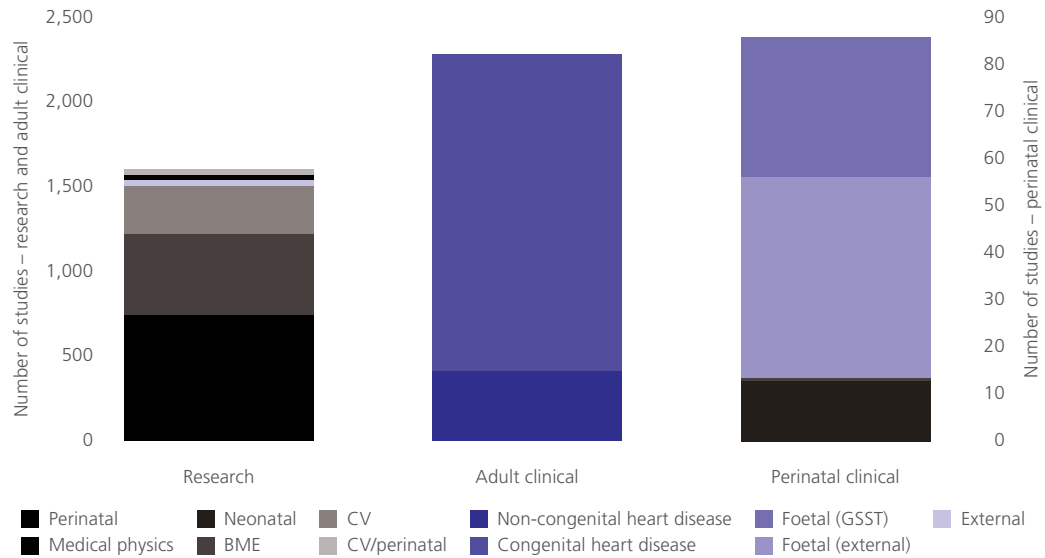
USS = Ultrasound, FI = Fluoroscopy, CT = Computer tomography

Figure 8 | Number of Interventional procedures (2016/2017) at King's College Hospital NHS Foundation Trust



The imaging services residing under King's College London have also been and continue to be employed for a wide variety of research and adult clinical studies.

Figure 9 | Studies performed using the KCL MRI services (2014/2015)



NB: The majority of clinical patients are invited to participate in research therefore the majority of the adult and perinatal clinical examinations are clinical research.



Patient
experience

Patient experience

How we shape patient experience within our services

Medical physics and engineering

The CAG is committed to improving the patient experience. Examples include modifying patient aids in rehabilitation engineering and constructing specialised immobilisation devices for patients having radiotherapy treatment. We also work to improve patient care by putting in place appropriate monitoring and safety measures, for example making sure x-ray installations minimise radiation doses to patients and staff and maintaining and inspecting equipment to make sure it is working correctly.

Enhancing the quality of imaging and other diagnostic procedures is one of our important contributions to better clinical outcomes and is vital in the diagnosis and treatment of patients using radiation imaging and therapy. We help to translate ideas into reliable and effective patient procedures through clinical trials and detailed implementation, in areas such as radiological

interventional treatments and advanced MR imaging.

Alongside standardisation of equipment and provision of effective training, staff contribute their expertise in the management of incidents involving non-optimal use of radiation exposure for patients and advise on corrective measures, as well as the reporting of incidents to external bodies.

As part of the focus on delivering and supporting quality, the King's Technology Evaluation Centre (KiTEC), established in 2011, works for NICE on the innovation agenda. Housed in the School of Biomedical Engineering and Imaging Sciences, KiTEC is a collaboration involving other KCL Departments (Health and Social Care Research and King's Health Economics) and the Medical Physics Departments of Guy's and St Thomas' Hospital and King's College Hospital.

KiTEC spans KHP, drawing upon staff and expertise across all disciplines and from all three NHS Foundation Trusts. The role of KiTEC is to support the work of the Medical Technologies Evaluation Programme (MTEP) and the Diagnostic Assessment Programme (DAP) of the National Institute for Health and Care Excellence (NICE). MTEP selects and evaluates innovative

medical technologies (including devices and diagnostics) and supports rapid and consistent adoption of efficient and cost effective medical devices and diagnostics into the NHS. KiTEC uses its specialist expertise to evaluate these technologies in order to inform MTEP decisions.

Projects undertaken by KiTEC include randomised controlled trials, systematic reviews, establishment of registers and databases and assessment of innovative medical technologies and diagnostic procedures. For example:

Heart Flow: A Nice report assessment report (www.nice.org.uk/guidance/mtg32/documents/assessment-report-2). The report fed directly into NICE guidance that recommends adoption of the technology in the NHS.

- Amyloid PET: Illustrating the breadth of KiTEC's work and linking to other aspects of the CAG, is a review performed for NICE: Morris, E., Chalkidou, A., Hammers, A. et al. *Eur J Nucl Med Mol Imaging* (2016) 43: 374.

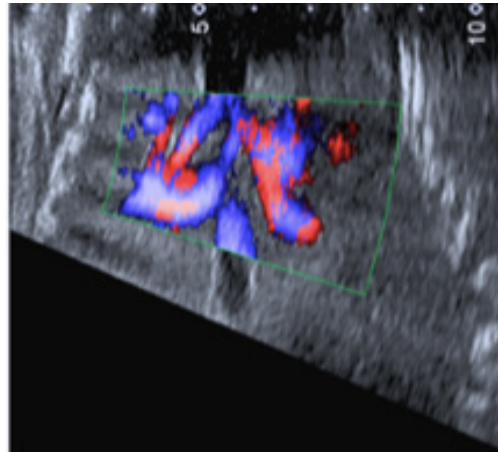
Specific case examples

The following case studies help to illustrate how Imaging dovetails with a range of clinical services and impacts on primary, secondary and tertiary care.

Case study 1

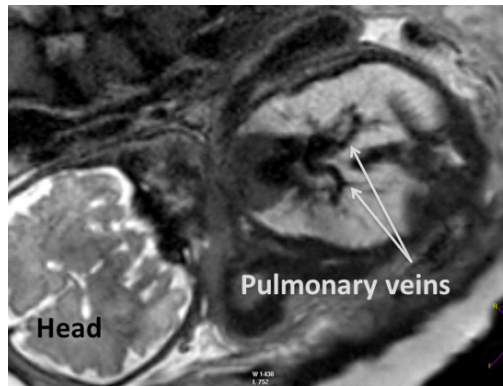
Emilia's mother was referred for a fetal cardiac assessment after her routine ultrasound had detected possible heart disease. A fetal echocardiogram confirmed a severe congenital heart malformation – hypoplastic left heart syndrome (see below figure).

Figure 10 | Fetal echocardiogram showing severe congenital heart disease



Hypoplastic left heart syndrome (HLHS) is a rare congenital heart defect in which the left aorta and ventricle is severely underdeveloped. In addition to this, Emilia's pulmonary venous system appeared abnormal and so she underwent a fetal cardiac MRI to delineate this further (see Figure 11).

Figure 11 | Fetal MRI showing unusual pulmonary venous drainage



Emilia (shown below with her parents and older brother and sister) was born at term and transferred to the paediatric intensive care unit. A chest x-ray showed clear lung fields and the echocardiogram confirmed the antenatal diagnosis. In order to help define the surgical strategy, Emilia underwent a cardiac MRI without anaesthetic.

This showed one large draining pulmonary vein on each side, with an acute angle noted where the left vein entered the heart (Figure 12).

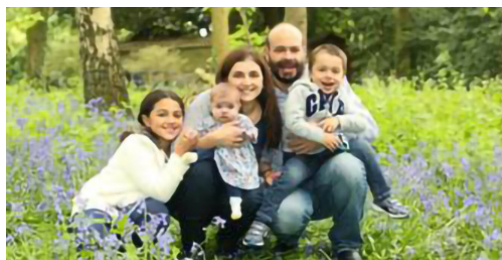
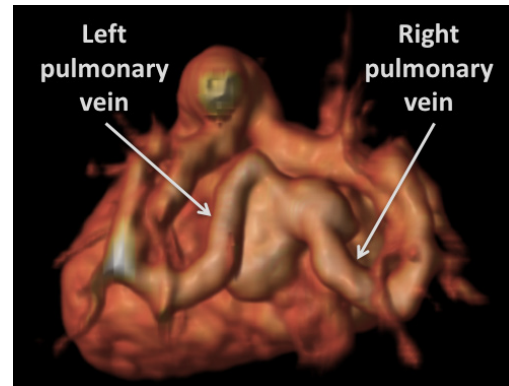


Figure 12 | MRI after birth showing the heart from behind and the abnormal pulmonary veins



Emilia underwent a palliative hybrid procedure at three days of age. This was done in the cardiac catheter laboratory under fluoroscopy guidance. Over the next two months, Emilia required several further open heart and keyhole procedures following complications detected by 2D transthoracic, trans-oesophageal and 3D echocardiography, CT and fluoroscopy.

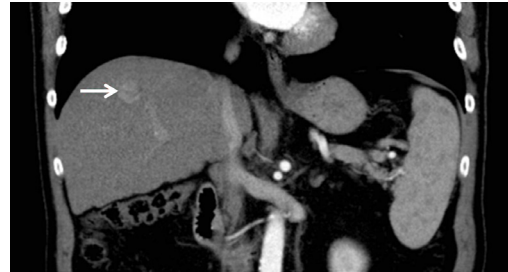
At three months of age, Emilia underwent the second stage of the four stages of her palliation and was finally discharged home. She was assessed using echocardiography and MRI and considered suitable to proceed with the third stage. Emilia is currently well at home with her parents – her most recent check-up with echocardiography and MRI showed good progress. If all remains well, Emilia will proceed to the fourth operation at around three years of age. She will continue to have regular check-ups with echocardiography and MRI for the rest of her life.

Case study 2

The liver transplant (LT) and hepato-pancreato-biliary (HPB) unit at King's College Hospital (KCH) receives around 2,500 new referrals every year. Patients are referred from all hospitals in the south of the UK. KCH also receives referrals from countries outside the UK such as Cyprus, Malta, Greece and the Middle East. The majority of referrals relate to patients with liver or pancreatic cancer. Patients with benign chronic liver disease are also referred for consideration of liver transplant. The Imaging service, both diagnostic and Interventional, is a crucial component of the HPB and Liver transplant service at KCH and the following case study illustrates the typical patient's journey after their referral and the critical role of imaging within the service.

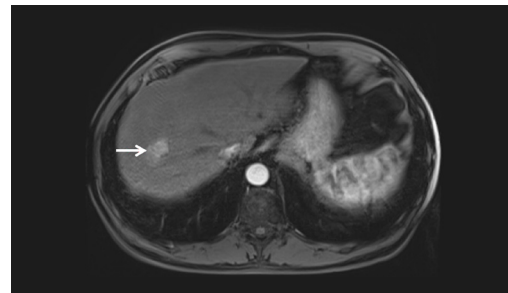
A 55 year old man was referred from Kent to the Hepatocellular Cancer (HCC) multidisciplinary team meeting (MDT) with suspicion of a liver tumour found during routine investigation for non-specific abdominal pain. The results of all investigations were attached to his referral letter and his CT scan was sent to KCH using the Image Exchange Portal (IEP) which enables transfer of imaging from all modalities between healthcare organisations. Following discussion at the MDT meeting, further imaging studies were arranged, including MRI with a specialist contrast agent, in order to confirm the number of lesions and size of each individual lesion. The extended imaging demonstrated three tumours in the liver, all measuring less than 3cm, without any evidence of spread outside the liver.

Figure 13 | Coronal CT image showing an arterialised lesion in the right liver (arrow)



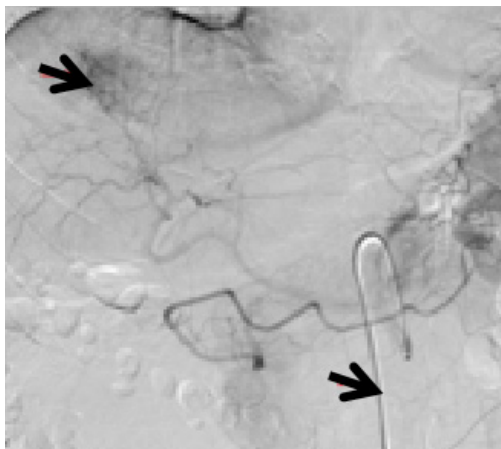
The CT section in the upper image and the MRI section in the lower image demonstrate one of the tumours. Diffuse liver disease was confirmed, secondary to alcohol overconsumption, with no evidence of viral hepatitis, autoimmune or metabolic liver disease

Figure 14 | Axial post-contrast T1 weighted MR image confirming the hepatoma in the right liver (arrow)



The MDT recommended liver transplantation, as the volume of disease was within liver transplant criteria and this is considered the best option for long term survival. As the waiting list for liver transplantation is long, the MDT recommended Transarterial Chemoembolisation (TACE) as a holding measure to halt tumour progression. The patient returned to the outpatient clinic to discuss the final diagnosis and treatment options, and was then admitted for the TACE procedure which is performed in Radiology by an Interventional Radiologist (see below figure).

Figure 15 | Arterial angiography done immediately prior to chemoembolisation (solid arrow shows one of the hepatomas and dashed arrow shows the catheter within the artery supplying the tumour)



Following the TACE procedure, the patient's recovery was uneventful and he was discharged the following day. A follow-up outpatient clinic visit was planned 6 weeks later, allowing for further blood tests and CT imaging to be performed to assess treatment response. The patient was again discussed at the MDT which recommended further treatment with TACE to maximise response. On completion of this second TACE procedure, subsequent follow up and imaging confirmed a good response. Repeat CT imaging and blood tests at 3 monthly intervals were performed to enable ongoing assessment of the patient and confirm that the HCC had not progressed or spread outside the liver.

18 months after initial presentation the patient received a liver transplant. Recovery from the transplant was good and the patient continues to be followed up in the outpatient clinic with serial blood tests and ultrasound imaging to ensure the new liver was not being rejected and there were no signs of cancer recurrence.

A typical patient referred to the Liver Service gets discussed in the MDT on 3 occasions prior to formulating a management plan. A typical patient with HCC undergoes three TACE procedures which are performed in Interventional Radiology in addition to an average of 5 CT scans and 2 MRI scans at KCH prior to discharge to his/her local hospital/service.



Examples
of service
innovations
and excellence

Examples of service innovations and excellence

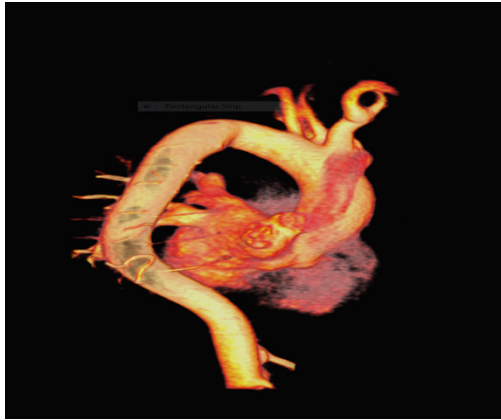
Endovascular aortic aneurysm repair programme

In April 2013, King's College Hospital and Guy's and St Thomas' interventional radiologists, nurses and radiographers began working together in the new state-of-the-art hybrid operating theatre with bi-plane x-ray fluoroscopy at St Thomas'. This is delivering the world's second largest endovascular aortic aneurysm repair programme. This includes a large research component including a new King's Health Partners start-up company, Cydar Ltd, which has developed innovative imaging tools to help guide these interventional procedures.

Cardiovascular MRI programme

Our integrated cardiovascular MR imaging clinical and research programme is one of the largest clinical programmes in the UK and the largest research programme internationally. The academic team supports the clinical service, both at Guy's and St Thomas' and King's College Hospital. The team are leading the largest international multi-centre randomised clinical trial funded by the National Institute for Health Research and industry which has recruited over 500 patients. A positive result would provide evidence that invasive cardiac catheterisation can be replaced by non-invasive MRI for deciding on the need for coronary interventions in patients with coronary artery disease.

Figure 16 | Mapping of a cardiac pathology through use of imaging techniques



MR Elastography

Various non-invasive methods have been proposed to assess the stage of liver fibrosis. These methods include liver imaging with MRI or Ultrasound and biochemical scores. The most common score is the so-called "aspartate to platelets ratio index" (APRI). Although those techniques certainly carry diagnostic value, their accuracy for staging intermediate fibrosis remains debated.

From clinical experience it is well known that liver stiffness changes with the degree of fibrosis. Here, MR-elastography (MRE) as a novel non-invasive method for measuring the visco-elastic properties of the liver, may play an important role. Preliminary reports suggest that MR elastography is a feasible method to stage

liver fibrosis. More recent clinical results clearly demonstrate that MRE can separate the three stages of liver fibrosis.

None of the commonly used non-invasive imaging techniques (ultrasound, CT and MRI) are directly sensitive to the physical parameters of elasticity or viscosity. Therefore, those properties can only be obtained indirectly. There is actually a close physical link between the propagation of mechanical waves in a viscoelastic medium and its viscoelastic properties. Thus, the general concept of elastography is:

- To somehow generate mechanical waves within the medium;
- To measure those waves via a non-invasive imaging technique, and finally;
- Reconstruct maps of the viscoelastic properties from the measured wave fields.

The last step, i.e. converting the measured wave fields into maps of elasticity and viscosity, necessitates utilization of rheology, i.e. the theory explaining the relationship between stress and strain and its evolution with frequency.

Breast cancer one-stop unit

The GSTT Breast Unit has recently successfully piloted a study using imprint cytology from

breast core biopsies to allow instant pathology results in the one stop clinic. Being able to give patients their biopsy results on the same day as their appointment would reduce patient anxiety for the majority of women who will have benign results, and will shorten the patient pathway for those patients with malignant biopsy results. Below are the team from the GSTT breast unit.



Here we provide a breakdown of the service provided by the unit:

Fine Needle Aspiration Cytology – involves inserting a fine needle syringe into the suspicious area or lump. A solid lump may be a benign tumour like a fibroadenoma or a breast cancer. A cell sample from the aspiration is placed on a slide and the pathologist categorises the cells accordingly.

Core biopsy – this takes out a small piece of breast tissue for analysis and provides histological (cell) information.

Cell samples are classified as follows:

C1 = inadequate cells for diagnosis, C2 = benign, C3 = equivocal, abnormal but more likely to be benign, C4 = suspicious of cancer, C5 = malignant.

- 28 patients had one or more biopsy procedures performed over the two pilot clinics, which were analysed by a pathologist on the day;
- 22 patients had core imprint biopsies;
- 4 patients had core imprint biopsies and a fine needle aspiration;
- 2 patients had a fine needle aspiration only;
- 18 patients had a benign diagnosis – of these 16 patients could have been told that their tests looked clear on the day. Insufficient cells were collected for 2 patients and further tests would have been needed;
- 7 patients had a malignant histology and would have been told on the day that their tests gave some initial reason for concern;
- 1 patient had a C3 diagnosis, indicating abnormal cells and would have required further tests.

The results showed that a significant change could have been made to patient experience, with earlier reassurance for patients with benign results, and a fast-track to next steps for those with a malignant histology, decreasing the

amount of time patients had to spend in a period of uncertainty, which is extremely stressful for patients and their families. The next steps are to present the new proposed model as a business case to the Trust.

GSTT has links with the King's College Hospital Breast Screening and Breast Care Unit (Seven consultants), with one Breast Radiology Consultants working within the screening unit and attending the Breast multi-disciplinary meeting for patients to be referred to Guys for surgery. There is also collaboration with King's College London on a research project investigating the potential clinical value of Breast MR elastography – elastography being a sub speciality of imaging that investigates the elastic materials (i.e. stretch, stiffness) of soft tissues.

Helping establish global standards in interventional oncology

The field of Interventional Oncology is fast becoming the fourth pillar of cancer care, alongside surgical, medical and radiation oncology. In 2017, interventional oncologists at KHP working in partnership with the Cardiovascular and Interventional Radiological Society of Europe (CIRSE), helped to develop the first global standards in Interventional Oncology. These have been adopted formally by CIRSE, which will launch the first global credentialing system in this field in early 2018.

Awards for the department of Radiology and Medical Physics (KCH)

The Department of Radiology and Medical Physics at KCH has been the recent recipient of several major health awards both from a team and individual perspective:

- Breast screening radiographers won regional team of the year 2016;
- Chris Roose won representative of the year from the Society of Radiographers 2017;
- Harry Smyth won the regional award of London Radiographer of the Year 2017;
- KCH Radiographers were the UK Overall Radiography Team of the Year 2016.

Transforming outcomes and health economics through Imaging – TOHETI



TOHETI is a large-scale, innovative programme of work funded by Guy's and St Thomas' charity. By changing the use of imaging in the patient pathway, and through the introduction of cutting-edge new technology, TOHETI aims to show how imaging can be used more effectively as a diagnostic and therapeutic tool across a range of common patient pathways, as well as contributing to cost-effectiveness across King's Health Partners.

TOHETI is engaging NHS partners across the London boroughs of Lambeth and Southwark to co-design, transform and improve services across a number of patient pathways, leading to improved patient experience and outcomes and contributing to cost-effectiveness. By addressing whole pathways rather than focussing on small, piecemeal change, TOHETI asks "are we enabling the right imaging test to be done at the right point in time?"

The programme works across the Clinical Imaging and Medical Physics (CLIMP) Directorate at Guy's and St Thomas' and is facilitated by £13.3m funding from Guy's and St Thomas' Charity. This funding has enabled the installation in 2016 of a replacement

Emergency Department CT scanner, and additional 3T-MRI and CT scanners, delivering increased capacity and providing the ability to introduce and measure innovations outside of 'normal practice'.

Changes to practice and ways of working

Phase 1

Between April 2013–June 2014, funding from Guy's and St Thomas' Charity allowed the TOHETI team to work with clinical teams and imaging staff across King's Health Partners and primary care providers throughout Southwark and Lambeth and facilitated visits to the Virginia Mason Medical Centre in Seattle. Efforts focused primarily on engaging stakeholders to identify appropriate pathways that could realise benefits from the outcome, patient experience and health economics perspectives. Teams worked together to develop models for the proposed changes, taking into account the entire patient journey. Pathways identified include breast, colon, prostate and lung cancers, persistent headache, acute chest pain, uterine fibroids and scaphoid fractures – all prevalent in the King's Health Partner's local population.

Phase 2

A further £9.9m funding from Guy's and St Thomas' Charity is allowing the pilots/research studies co-designed during phase 1 to be implemented across each of the pathways during phase 2 (September 2014–September 2018).

TOHETI has also introduced the advanced technologies of PET-MR and MR-guided High Intensity Focussed Ultrasound to KHP. By harnessing these cutting edge technologies, TOHETI aims to enable imaging potential to be fully realised for patient benefit, to help improve and personalise care.

Figure 17 | Operations of the Siemens PET/MR Scanner

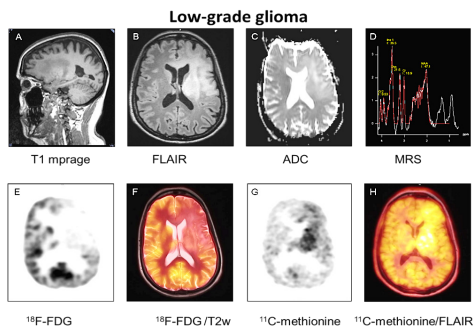


Analysis of the benefits to patient experience, outcome and health economics across KHP will form a core part of TOHETI's work during phase 2, which is focused on the following four major transformational programmes:

1. Improve accessibility to imaging and streamlining diagnostic pathways

Embarking on phase 2, the aim of these pathway re-designs is to enable more effective application of imaging techniques, or to take out unnecessary steps between presentation and diagnosis/discharge by utilising the optimum imaging technology much earlier in the patient's pathway. This will improve overall care whilst reducing costs to the wider health economy thereby increasing value (outcomes that are important to patient, divided by the cost of delivering the outcomes over the complete pathway of care). Value based healthcare is a key theme of KHP.

Figure 18 | F-18 FDG and C-11 Methionine PET-MRI in a patient with a low grade left hemispheric glioma: (A) high tissue contrast is obtained using a T1w 3D isotropic mprage sequence (B) axial T2w fluid suppressing sequence (FLAIR), (C) ADC (shows cellular density), (D) MR spectroscopy is used to map out different metabolites, (E) axial F-18 FDG PET images (shows glucose metabolism), (F) axial fused T2w/F-18 FDG PET, (G) axial C-11 methionine PET images (shows amino acid metabolism) (H) axial fused T2flair/C-11 methionine



- Compare PET/MR to current standard imaging and assess where it provides improvements in patient experience, outcomes and efficiency;
- Assess cancer therapy response early to discontinue ineffective treatments, eliminating the risk of side effects and morbidity, and enabling alternative treatments to be tested;
- Investigate opportunities to streamline imaging, reducing patient visits and maximising diagnostic information.

3. Increasing therapeutic options for patients

Access to a £450K MR-guided High Intensity Focussed Ultrasound (MRgHIFU) system (from January 2015) is enabling in-depth research into new applications of minimally-invasive, image-guided interventions.

2. Identifying applications for new technology

TOHETI funding has enabled a new £3.3m PET-MR scanner to be installed at Guy's and St Thomas'. PET/MR brings together two powerful imaging modalities; providing anatomical, functional and metabolic information in one examination. The new PET-MR scanner will allow clinicians to:

HIFU uses focused ultrasound waves to destroy pathological tissue by rapid heating. The efficacy of HIFU treatments is well proven; they are less invasive and outcomes are often much better than surgery. The HIFU system is incorporated into a specially designed bed (below) which can be placed into the MRI scanner, in place of the standard imaging couch, allowing imaging data to be collected whilst the treatment is being delivered. Thus, MRgHIFU affords additional imaging capability through high-quality MR

to plan, deliver and monitor the non-invasive ultrasound therapy.

The new MRgHIFU system will allow clinicians to:

- Investigate new clinical applications for MRgHIFU;
- Provide options for patients where other treatments have been excluded or failed.

Figure 19 | MRI-Ultrasound design MRgHIFU



4. Transforming our ways of working

Collaborative working and strong partnerships are at the heart of the TOHETI programme. Meaningful engagement with our stakeholders is essential to ensure the long-term success and viability of this ambitious programme of work – which not only aims to change how we use imaging in care pathways across primary and secondary care, but to transform the way we work.

TOHETI is all about empowering change across primary and secondary care, and we want these changes to be owned and led by those on the frontline. Continued engagement, input and feedback is being sought over the programme's duration from all our stakeholder groups: patients and patient groups, clinicians and imaging staff, GPs, nurses, commissioners and other healthcare staff.

TOHETI also aims to learn from best practice nationally and internationally. We have built a strong working relationship with colleagues from the Virginia Mason Medical Centre, Seattle and with Sunderland NHS Trust to explore new methodologies of working, taking on learning to act as a catalyst for change.



Transforming Outcomes and Health Economics Through Imaging (TOHETI)

INTRODUCTION: The Transforming Outcomes and Health Economics Through Imaging (TOHETI) programme is engaging NHS partners across the London boroughs of Lambeth and Southwark to co-design, transform and improve services across a number of patient pathways, leading to improved patient experience and outcome and contributing to cost-effectiveness. By addressing whole pathways rather than focusing on small, piecemeal change, TOHETI asks *'are we enabling the right imaging test to be done at the right point in time?'* The programme works particularly closely with the Clinical Imaging and Medical Physics (CLIMP) Directorate at Guy's and St Thomas' NHS Foundation Trust.

This programme of work is facilitated by £13.3M funding from Guy's and St Thomas' charity, which will enable the installation in 2016 of a replacement Emergency Department CT scanner, and additional 3T-MRI and CT scanners, delivering increased capacity and providing the ability to introduce and measure innovations outside of 'normal practice'.

IMPROVING PATHWAYS:

Redesign of pathways aims to identify and remove inefficiencies. Through a mixture of research studies and short term service improvement projects, TOHETI impacts widely across the Trust and local community, through the different clinical specialities, emergency medicine, primary care, patients, families and carers.

| Research Study | Study Question/Design | Proposed benefits |
|---------------------|--|--|
| Chronic Headache | Evaluating direct access from GPs to MRI imaging services for patients with chronic headache | <ul style="list-style-type: none"> Reduction in waiting times Reduction in Neurology appointments Supports patient management within the primary care setting due to MRI reassurance effect |
| Colon Cancer | Replacing colonoscopy with CT colonography for patients symptomatic for colon cancer. | <ul style="list-style-type: none"> Increase early detection and improve prognosis. Lower risks and discomfort to patient. Address capacity issues, and release optical colonoscopy capacity to focus on high-risk patients. |
| Lung Cancer | To identify high-risk patients in the smoking population aged between 55-80 years (current and former smokers) and offer low-dose CT scans. Patient identification and engagement methods will include GP records & Community Pharmacies. | <ul style="list-style-type: none"> Increase engagement and enable early detection Explore possibility of direct access for GPs to low dose CT. Increase understanding of non-compliance, and potential barriers to uptake of low-dose CT screening |
| Acute Chest Pain | To assess the use of CT Coronary Angiography (CTCA) in patients with Acute Chest Pain (ACP) and no myocardial ischaemia referred from the A&E department to the Rapid Access Chest Pain Clinic (RACPC). | <ul style="list-style-type: none"> Increase the efficiency associated with the management of patients discharged from A&E following a non-ischaemic ACP episode Improve clinical care by enhancing the completeness of diagnosis, ruling in or ruling out Coronary Artery Disease (CAD) as the underlying cause of ACP |
| Scaphoid Fractures | Assessing MRI, alongside plain x-rays, on presentation for patients with suspected scaphoid fracture | <ul style="list-style-type: none"> Improves the diagnostic pathway for suspected scaphoid fractures, to enable appropriate and timely treatment Cost of additional MRI scan predicted to be offset by savings made in decreasing the amount of unnecessary diagnostic and treatment procedures |
| Service Improvement | Service Improvement | Proposed benefits |
| Breast Cancer | Introducing a new way of running the Breast One-Stop clinic, so that biopsies can be analysed in parallel to clinic. | <ul style="list-style-type: none"> All patients able to find out results of all tests on same day Earlier reassurance where biopsies are normal, and faster route to treatment if needed |
| Uterine Fibroids | <ul style="list-style-type: none"> Improving patient access to information on treatment options. agree a joint clinical approach for patient assessment, referrals and follow-up across Gynaecology and Interventional Radiology | <ul style="list-style-type: none"> Better informed, engaged patients who are aware of their treatment options and useful questions to ask. More joined up services between Gynaecology and Interventional Radiology to improve patient flow and management |
| Prostate Cancer | Shortening the urgent suspected cancer pathway by improving workflow and access to MRI | <ul style="list-style-type: none"> Earlier diagnosis and treatment where needed, improved patient experience Reducing number of DNAs by enabling scans to take place on same day as clinic |

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Education
and training

Education and training

The establishment of King's Health Partners and its Education Academy has been tremendously beneficial to education and training in our disciplines, enabling us to establish collaborations across the KHP organisations that have real impact at national level, and to tender for contracts as an established partnership with demonstrable excellence in breadth and depth.

Our CAG hosts one of only three MSc programmes in England accredited to provide the academic component of NHS training for Medical Physicists, and the only such programme for Clinical Engineers. A great deal of the teaching is provided by NHS staff from the KHP Trusts, ensuring that it is relevant to current clinical practice. There are now 120 students on these three year part-time programmes, the largest in the UK.

The BEng/MEng Biomedical Engineering course was successfully accredited by the Institution of Engineering and Technology (IET) granting all previous cohorts (since 2011) and current students exemptions from the education requirements of the Chartered Engineer status. The MSc Radiopharmaceutics and PET Radiochemistry course was also accredited by the European Association of Nuclear Medicine (EANM)

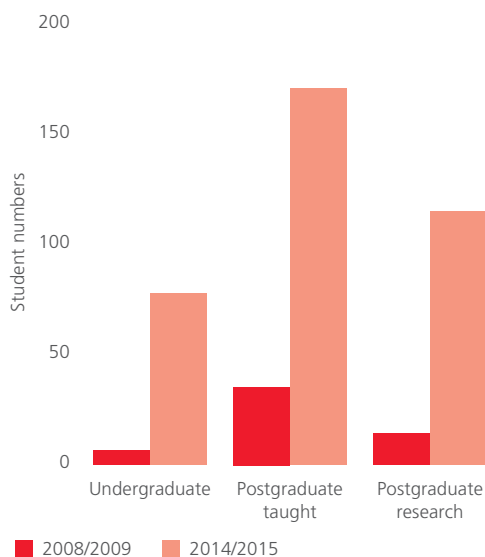
adding to its existing accreditation with the Royal Society of Chemistry, enabling students to take the exam for the EANM Radiopharmacy Certificate.

In 2017, the KCL School of Biomedical Engineering and Imaging Sciences launched a Centre for Education, a hub that seeks to enhance learning and teaching practice through innovation and professional development support to academics. A range of useful resources including the new Module Leader's handbook, tips on exam setting, embedding sustainability, CPD opportunities are accessible. To celebrate its launch the centre introduced an Annual Teaching Fund of £2,000 for staff to assist in delivering substantial teaching.

In the Postgraduate Research Experience Survey (PRES) we achieved 72% overall satisfaction for our department within KCL whilst in the postgraduate Taught Experience Survey (PTES) we achieved 89%. The MRes in particular achieved its highest rating of 92% overall satisfaction and was the top programme in the Faculty of Life Science and Medicine at King's, improved in every area of the survey and achieved higher ratings than both the overall Faculty and College. Whilst satisfaction

remains high overall across programmes we are still striving to innovate teaching and address areas of need including providing more timely assessment and feedback to students.

Figure 20 | Student numbers for 2008/2009 (purple) and 2014/2015 (green) for BE&IS division



UG – Undergraduate, PGT – Postgraduate taught, PGR – Postgraduate research

Postgraduate Radiology training across South East London is also now provided by a KHP-based consortium, one of the largest integrated programmes in the UK. This runs alongside the largest training programme for Nuclear

Medicine, including the UK's leading MSc for postgraduate training.

Our EPSRC Centre for Doctoral Training in Medical Imaging (joint with Imperial College) is one of only three such centres nationally, funding over 70 four-year MRes/PhD studentships over a five-year period.

New successful Masters and Bachelors programmes have been developed over the last few years, including a new BEng and MEng in Biomedical Engineering. These programmes build on our long-established intercalated BSc in Imaging Sciences and are recruiting record numbers of students. Once again, involvement of NHS staff in relevant modules ensures linkage between basic science material and the clinical interface.

Professor Kawal Rhode was appointed as Head of Education in November 2016 to provide strategic academic leadership to our staff and curriculum, working with the Education Manager and has also been instrumental in gaining support for two new senior teaching fellows; Dr. Marta Varela and Dr. Richard James Housden who were appointed on 1st August 2017, on a part time basis for a two year term. They will carry out their duties alongside their role of researchers in the Division and are excellent ambassadors. They will be involved in teaching on core modules on the BEng Biomedical Engineering degree and supporting learning and teaching initiatives on all programs.

The Assistant Clinical Technologist Apprenticeship Scheme, developed within the Medical Engineering and Physics Department at KCH, has won two national awards and is informing developments in this area nationally.

Short course provision has expanded too. For example, King's Technology Evaluation Centre (KiTEC), established following a competitive tendering process in which the successful bid was explicitly KHP-wide, runs an annual course on CT for multimodality imaging, which has been oversubscribed each year so far.

Other examples of training delivered include:

Medical physics and engineering

Initiatives include our apprenticeship scheme (£0.5m grant income to deliver scheme). This is designed to enhance public and school engagement with apprentices employed within the Trusts. This scheme is now expanding to other trusts and won an award in 2014 (see below figure).

Figure 21 | Apprentice awards 2014



Working with London South Bank University to develop Lambeth University Technical College for Engineering in Healthcare and the Built Environment. Delivering one of three MSc Clinical Sciences (Medical Physics) courses and the only MSc (Clin Eng) course accredited by National School of Healthcare Science (NSHCS). Medical Physics also teaches and trains medical, nursing and other clinical staff, in addition to a range of scientific and technical staff. A number of courses are offered in the safe use of ionising radiation, lasers, UV equipment and medical devices.

Nuclear medicine and molecular radiotherapy

The department is an accredited site for trainees on the *Modernising Scientific Careers* – Scientist Training Programmes (STP) or Practitioner Training Programmes (PTP). Staff within the department provide supervision and support to the next generation of healthcare scientists and participate in the national recruitment programme to ensure the future workforce reflect the requirements of the speciality.

Radiology

The Departments of Radiology at Guy's and St Thomas' NHS Foundation Trust and King's College Hospital NHS Foundation Trust undertake training for Radiographer and Radiology students.

The Department of Radiology at Guy's and St Thomas' NHS Foundation Trust undertakes the clinical training of Student Radiographers as part of the BSc (Hons) Diagnostic Radiography qualifications offered by the London South Bank University (12 students per cohort) and Kingston University (4 students per cohort). In addition, Student Radiographers from other universities elect to undertake a placement at Guy's and St Thomas' Foundation Trust.

At Guy's and St Thomas', the clinical training is facilitated by the radiographers and closely supported by the superintendent radiographers. There is also additional support from a Lecturer Practitioner (a joint appointment role by Guy's and St Thomas' and LSBU) who assists the student whilst in the clinical environment.

Throughout the clinical placement, students will generally progress from observation/assisted practice to being more independent and taking responsibility for conducting an examination whilst under the supervision of a qualified member of staff. Student teaching and supervision is embedded in the defined responsibilities of all clinical staff.

Student radiographers rotate through all our Imaging modalities (Plain Imaging, CT, MRI, Ultrasound, Mammography, Cardiac Catheter Labs, Nuclear Medicine and Interventional Radiology) as part of their clinical placements and to all three sites.

Guy's and St Thomas' offers a comprehensive programme for Trainee Radiologists, with a broad range of placements that include Evelina London Children's Hospital and University Hospital Lewisham. There is access to general and subspecialty diagnostic imaging alongside Interventional Radiology. In 2015, Guy's and St Thomas' further increased the availability of consultant-led training and has given Trainee Radiologists the opportunity to become involved in transformational change projects as part of the Transforming Outcomes and Health Economics Through Imaging (TOHETI) programme. This ensures an innovative, comprehensive and exciting learning experience.



Research
and innovation
across the CAG

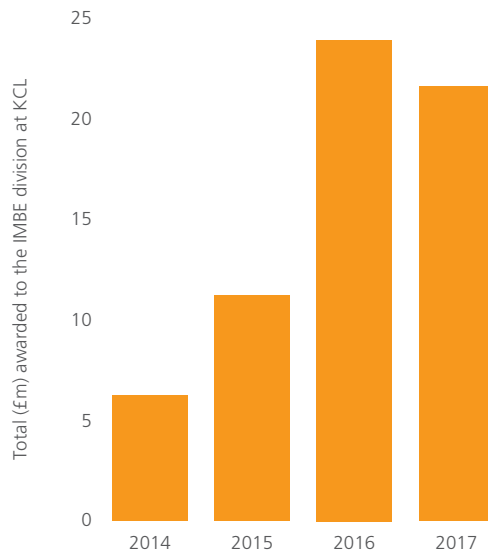
Research and innovation across the CAG

We have one of the leading research groups in imaging and biomedical engineering with over 150 grants awarded to researchers within the King's College London School of Biomedical Engineering and Imaging Sciences since 2014. Across the CAG there has been a number of commercial trials supported by the King's Health Partners commercial trials office with 4 contracts signed to the CAG since 2014 worth over £100,000. Additionally, the CAG has the largest integrated clinical cancer PET programme in the UK, integrated with a large programme of research that is being expanded with recent international recruitments.

In total, our current grant income exceeds £50m and includes:

- 12 EPSRC Programme and fellowship grants;
- 8 MRC grants;
- 8 British Heart Foundation Programme and fellowship grants;
- 7 EU Programme grants including £4.3m for Imaging the Force of Cancer Project (FORCE);
- 5 Guy's and St Thomas' Charity grants including £13M for Transforming Outcomes and Health Economics Through Imaging (TOHETI) programme;
- 1 NICE grant of £2.2m for the Kings Technology Evaluation Centre (KiTEC);
- 3 NIHR grants and 6 Wellcome Trust grants.

Figure 22 | Research grants processed through the King's College London (KCL) School of Biomedical Engineering and Imaging Sciences



Programmes of work

Basic science – We have a large basic science research programme in physics, chemistry, mathematics, computer science and engineering with 100 PhD students. Substantial year-on-year increase in research spend – up 40% in 2011/2012 and 30% in 2012/2013.

Operational efficiency – Since 2009/2010, radiology activity in both King's College Hospital and Guy's and St Thomas' has increased by

a minimum of 10% per year, whilst unit costs in both have been reduced by at least 2%.

Information technology – There is agreement to proceed with the replacement of PACS (Picture Archiving and Communications System)/RIS (Radiology Information System), as a King's Health Partners' solution has been reached. In the medium-term, we are seeking immediate improvements to cross-site working and improved image storage resilience. Longer-term, we will put in place a PACS solution which operates seamlessly across all sites and integrates with our sector partners.

Innovation and research at our health trusts

At King's College Hospital, radiology continually works with our referral partners to look at innovative ways to shorten and improve patient pathways, not just through radiology but the entire patient journey. A programme of initiatives run concurrently and all the services provided by radiology are continually revisited to look for improvements. The clinical governance structure within radiology ensures that any new capabilities and lessons learnt in one imaging modality are shared across all specialties in radiology for maximum impact. Examples include fine-tuning orthopaedic outpatient clinic appointment times at King's College Hospital, to reduce the length of time patients wait for x-ray and hence the amount of time the patient has to spend in clinic. Large scale transformational

changes include a piece of work to completely redesign the CT service at the Princess Royal University Hospital. This involves improving access to imaging and redesigning CT pathways, identifying areas for improvement, such as quality of scans and reporting backlogs and engaging in a process of transformation.

Guy's and St Thomas' radiology has a high level of research activity. Services and facilities across imaging are critical to enabling research and development activity across the trust and King's Health Partners. Nearly 400 studies are currently underway and require support from imaging or other Clinical Imaging and Medical Physics division (CLIMP) services, of which 87 commenced during the financial year 2013–2014 and over 60 in the first nine months of 2014/2015 alone. The number of these studies that are led from within the Radiology Department itself has also increased, reflecting recent clinical academic appointments in collaboration with King's College London. To strengthen our support for research and development, the CLIMP directorate as a whole has established a research support unit, with a view to giving research activity within the directorate a higher profile and level of attention.

Medical Physics and Engineering is involved in research and innovation in two distinct ways:

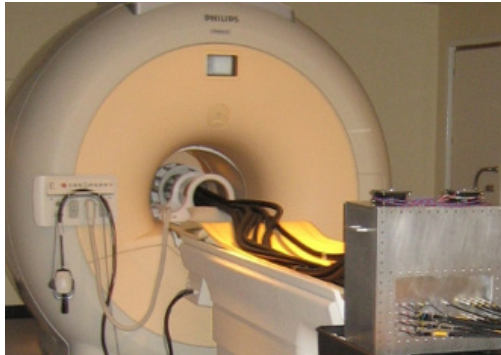
1. We provide resources and expertise to support research and innovation activity led by others. Members of the department provide regulatory and scientific expertise to support trials involving medical devices and radiation, including statutory roles

such as the Radiation Protection Adviser (RPA) and Medical Physics Experts (MPEs), with dedicated posts to support this work in Radiation Safety and Radiotherapy Physics. We also provide safety and quality assurance services for research equipment and new clinical techniques across KHP, including imaging and radiotherapy.

2. We have a growing portfolio of research and innovation of our own. We encourage staff to undertake clinically-relevant research: several are registered for part time PhDs, whilst others supervise PhD students at KCL and other institutions. We actively pursue external grant funding for our work: two members of the department were the first medical physicists nationally to hold prestigious NIHR/HEE Senior Clinical Lectureships. Dr Coleman in the Non-Ionising Radiation Physics Section has secured over £1.25m in grant support since 2013 and is working in partnership with the St John's Institute of Dermatology and industry to develop innovative approaches to skin imaging and cancer diagnosis and treatment.

Behind this activity, we have excellent workshop facilities which we use to develop and manufacture prototype medical and other devices in support of clinical services, research and teaching across KHP (see below figure). We have also developed effective relationships with other centres to enhance what we can provide, and seek to encourage and develop innovative ideas from clinical staff in partnership with charitable and commercial funding.

Figure 23 | Example of a prototype MRI/PET scanner developed by the team



The Nuclear Medicine department at Guy's and St Thomas' Hospital is active in research and innovation. Nuclear Medicine delivers routine nuclear medicine procedures to monitor the progress of patients on drug or interventional trials where the principal investigator (PI) sits outside of Nuclear Medicine. In addition, several studies a year involve innovative use of Nuclear Medicine techniques in research and require close collaboration of the multidisciplinary team with the researchers.

The department has completed a CRUK project with Breast Cancer Surgery (PI: Prof Purushotham) studying breast cancer-related lymphoedema using Nuclear Medicine techniques and has ongoing projects with the same team investigating the use of Cerenkov Imaging to assess tumour margins in breast cancer surgery. In all types of research, Nuclear Medicine staff provide Medical Physics Expert and Clinical Radiation Expert advice for

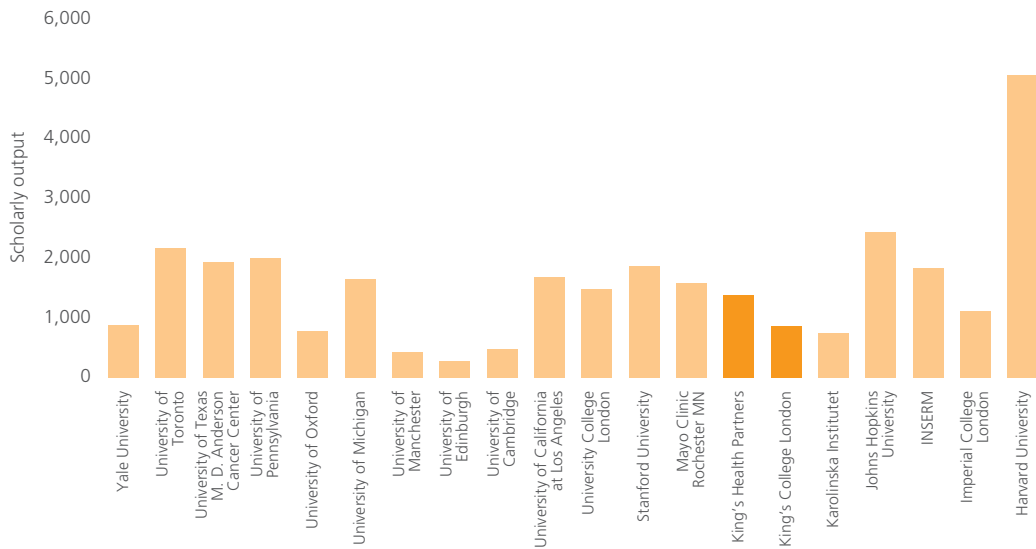
completion of ethics and ARSAC applications for around 20 applications a year. Other areas of research include the use and effectiveness of Molecular Radiotherapy treatments; the department was involved in the phase IV trial for ^{223}Ra -Chloride for treatment of bone metastases from prostate cancer, a trial that led to the successful introduction of this treatment into clinical practice when the product was licensed.

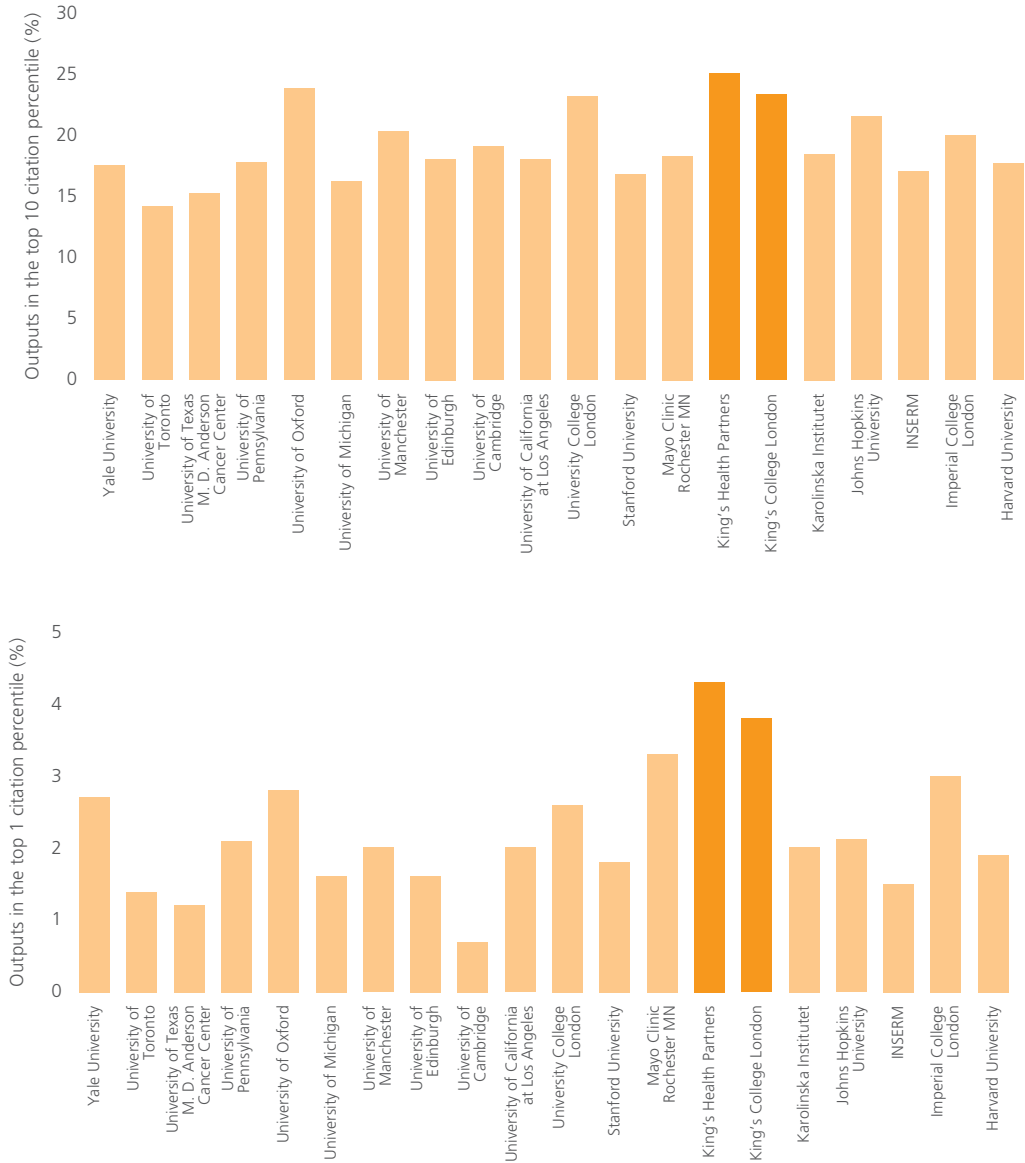
Nuclear Medicine has been an early adopter of new and innovative Molecular Radiotherapy treatments and now provides patients with a wide range of targeted Molecular Radiotherapy for benign and malignant conditions. The department is part of the KHP NET (Neuroendocrine Tumour) centre, accredited by the European Neuroendocrine Tumour Society (www.enets.org) as a centre of excellence for the treatment of patients with neuroendocrine tumours.

The Nuclear Medicine team also works closely with colleagues in the KCL School of Biomedical Engineering and Imaging Sciences on translational aspects of research into new radiopharmaceuticals for diagnostics, "theranostics" and therapies using radiopharmaceuticals. Examples include cell tracking in asthma and the implementation of ^{68}Ga -THP-PSMA. The department of Nuclear Medicine at KCH principally supports haematological clinical trials, movement disorders studies in collaboration with the Maurice Wohl Clinical Neurosciences Institute, and King's HIV Research Centre.

Research in focus

Figure 24 | Reproduced using Elsevier's Scival Database with ASJC journal category selection: Radiology, Nuclear Medicine and Imaging on 31 October 2017, with the time capture of 2012–2016. Output metrics were field weighted and self-citations were excluded. Only article, reviews and conference papers were included as implemented in the Times Higher Education institution rankings. KHP with KCL additionally separated to show the partnerships contribution highlighted in orange





The Imaging and Biomedical Engineering CAG's research has supported research development in nearly all of the 22 CAGs of King's Health Partners, authoring over 1,500 research articles since the creation of the CAG's in 2010.

The group has demonstrated particular academic prowess in the areas of cancer imaging, cardiovascular and perinatal imaging, as well as contributing to the basic sciences (chemistry, physics and biology) through the innovation of new imaging techniques and bioengineering advances. Such advances have attracted the attention of media and investors, deepened our understanding of disease processes and pioneered new surgical techniques.

Using the Scival analysts tool, compared to other leading centres of excellence within the identified journal field of Imaging, Radiology and Nuclear Medicine, work from King's Health Partners has resulted in moderate amount of publications, but an exceptional high yield of citations (see below).

To provide a focus on the research endeavours of the group below are abstracts from some of the highlighted publications of the group that have shaped the development of clinical guidelines, imparted education outcomes and pioneered first in man procedures.

Examples of contributions to guideline and training development

EFSUMB Guidelines on Interventional Ultrasound (INVUS), Part VI – Ultrasound-guided vascular interventions, *Ultraschall in der Medizin*, 2016

Jenssen, C., Brkljacic, B., Hocke, M., Ignee, A., Piscaglia, F., Radzina, M., Sidhu, P. S., Dietrich, C. F.

The sixth part of the Guidelines on Interventional Ultrasound produced under the auspices of the European Federation of Societies for Ultrasound in Medicine and Biology (EFSUMB) assesses the evidence for ultrasound guidance and assistance in vascular interventions. Based on convincing data, real-time sonographic guidance for central venous access is strongly recommended as a key safety measure. Systematic analysis of scientific literature shows that in difficult situations and special circumstances US guidance may also improve the efficacy and safety of peripheral venous and arterial access and endovascular interventions. Moreover, the recommendations of this guideline endorse the use of ultrasound to detect complications of vascular access and US-guided interventional treatment of arterial pseudoaneurysms.

Nuclear medicine training and practice in the UK, *European Journal of Nuclear Medicine and Molecular Imaging*, 2016

Neilly, B., Dizdarevic, S., Prvulovich, L., Buscombe, J., Lewington, V.

Training in the field of nuclear medicine (NM) in the UK commenced during the 1960s and the first consultant appointment was made in 1965. The British Nuclear Medicine Society (BNMS) came into being in 1966 and will be celebrating its 50th Anniversary in 2016. However, the development of structured training and assessment came only with the publication in 1993 of the Calman working party document on specialist medical training in the UK. NM was recognized as a monospecialty in the UK when the European Specialist Medical Qualifications Order 1995 came into force on 12 January 1996. The number of NM specialists (consultant NM physicians) in the UK has risen slowly over the past decade. The Federation of Royal Colleges of Physicians' 2013/2014 consultants census report for NM reported 80 consultants across the UK, which reflects an expansion of 6.7% since the previous census in 2012. About one-third of NM specialists are also specialists in clinical radiology (CR) and a few NM specialists are also specialists in internal medicine. It is anticipated that about one-quarter of the UK workforce of NM specialists will retire in the next 10 years.

Standardized cardiovascular magnetic resonance (CMR) protocols 2013 update, *Journal of Cardiovascular Magnetic Resonance*, 2013

Kramer, C. M., Barkhausen, J., Flamm, S. D., Kim, R. J., Nagel, E.

This document is an update to the 2008 publication of the Society for Cardiovascular Magnetic Resonance (SCMR) Board of Trustees Task Force on Standardized Protocols. Since the time of the original publication, 3 additional task forces (Reporting, Post-Processing, and Congenital Heart Disease) have published documents that should be referred to in conjunction with the present document. The section on general principles and techniques has been expanded as more of the techniques common to CMR have been standardized. There is still a great deal of development in the area of tissue characterization/mapping, so these protocols have been in general left as optional. The authors hope that this document continues to standardize and simplify the patient-based approach to clinical CMR. It will be updated at regular intervals as the field of CMR advances.

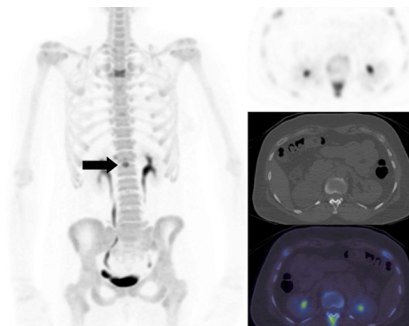
Examples of original research

Imaging bone metastases in breast cancer: Staging and response assessment, *Journal of Nuclear Medicine*, 2016

Cook, G. J. R., Azad, G. K., Goh, V.

Bone metastases are common in patients with advanced breast cancer. Given the significant associated morbidity, the introduction of new, effective systemic therapies, and the improvement in survival time, early detection and response assessment of skeletal metastases have become even more important. Although planar bone scanning has recognized limitations, in particular, poor specificity in staging and response assessment, it continues to be the main method in current clinical practice for staging of the skeleton in patients at risk of bone metastases. However, the accuracy of bone scanning can be improved with the addition of SPECT/CT. There have been reported improvements in sensitivity and specificity for staging of the skeleton with either bone-specific PET/CT tracers, such as ^{18}F -NaF, or tumor-specific tracers, such as ^{18}F -FDG, although these methods are less widely available and more costly.

Figure 25 | A 48-yr-old woman with metastatic breast cancer. Maximum-intensity projection ^{18}F -NaF (left) and axial ^{18}F -NaF PET, CT, and fused PET/CT slices (right, from top to bottom) at level of T12 showing a metastasis in the spinous process (arrow). A further metastasis is visible at T4. Copyright *Journal of Nuclear Medicine*



There is a paucity of data on the use of ^{18}F -NaF PET/CT for response assessment in breast cancer, but there is increasing evidence that ^{18}F -FDG PET/CT may improve on current methods in this regard. At the same time, interest and experience in using whole-body morphologic MRI augmented with diffusion weighted imaging for both staging and response assessment in the skeleton have been increasing. However, data on comparisons of these methods with PET methods to determine the best technique for current clinical practice or for clinical trials are insufficient. There are early data supporting the use ^{18}F -FDG PET/MRI to assess malignant disease in the skeleton, with the possibility of taking advantage of the synergies offered by combining morphologic, physiologic, and metabolic imaging.

Reproducibility of 2D and 3D fractal analysis techniques for the assessment of spatial heterogeneity of regional blood flow in rectal cancer, *Radiology*, 2012

Kramer, C. M., Barkhausen, J., Flamm, S. D., Kim, R. J. and Nagel, E.

To characterize the two-dimensional (2D) and three-dimensional (3D) fractal properties of rectal cancer regional blood flow assessed by using volumetric helical perfusion computed tomography (CT) and to determine its reproducibility. Institutional review board approval and informed consent were obtained.

Ten prospective patients (eight men, two women; mean age, 72.3 years) with rectal adenocarcinoma underwent two repeated volumetric helical perfusion CT studies (four-dimensional adaptive spiral mode, 11.4-cm z-axis coverage) without intervening treatment within 24 hours, with regional blood flow derived by using deconvolution analysis. Two-dimensional and 3D fractal analyses of the rectal tumor were performed, after segmentation from surrounding structures by using thresholding, to derive fractal dimension and fractal abundance. Reproducibility was quantitatively assessed by using Bland-Altman statistics. Two-dimensional and 3D lacunarity plots were also generated, allowing qualitative

assessment of reproducibility. Statistical significance was at 5%.

Mean blood flow was 63.50 mL/min/100 mL \pm 8.95 (standard deviation). Good agreement was noted between the repeated studies for fractal dimension; mean difference was -0.024 (95% limits of agreement $-0.212, 0.372$) for 2D fractal analysis and -0.024 (95% limits of agreement $-0.307, 0.355$) for 3D fractal analysis. Mean difference for fractal abundance was -0.355 (95% limits of agreement $-0.869, 1.579$) for 2D fractal analysis and -0.043 (95% limits of agreement $-1.154, 1.239$) for 3D fractal analysis. The 95% limits of agreement were narrower for 3D than 2D analysis. Lacunarity plots also visually confirmed close agreement between repeat studies.

Regional blood flow in rectal cancer exhibits fractal properties. Good reproducibility was achieved between repeated studies with 2D and 3D fractal analysis.

Specialization and integration of functional thalamocortical connectivity in the human infant, *Proceedings of the National Academy of Sciences of the United States of America*, 2015.

Toulmin, H., Beckmann, C. F., O'Muircheartaigh, J., Ball, G., Nongena, P., Makropoulos, A., Ederies, A., Counsell, S. J., Kennea, N., Arichi, T., Tusor, N., Rutherford, M. A., Azzopardi, D., Gonzalez-Cinca, N., Hajnal, J. V. & Edwards, A. D.

Connections between the thalamus and cortex develop rapidly before birth, and aberrant cerebral maturation during this period may underlie a number of neurodevelopmental disorders. To define functional thalamocortical connectivity at the normal time of birth, we used functional MRI (fMRI) to measure blood oxygen level-dependent (BOLD) signals in 66 infants, 47 of whom were at high risk of neurocognitive impairment because of birth before 33 wk of gestation and 19 of whom were term infants. We segmented the thalamus based on correlation with functionally defined cortical components using independent component analysis (ICA) and seed-based correlations.

After parcellating the cortex using ICA and segmenting the thalamus based on dominant connections with cortical parcellations, we observed a near-facsimile of the adult functional parcellation. Additional analysis revealed that BOLD signal in heteromodal association cortex

typically had more widespread and overlapping thalamic representations than primary sensory cortex. Notably, more extreme prematurity was associated with increased functional connectivity between thalamus and lateral primary sensory cortex but reduced connectivity between thalamus and cortex in the prefrontal, insular and anterior cingulate regions.

This work suggests that, in early infancy, functional integration through thalamocortical connections depends on significant functional overlap in the topographic organization of the thalamus and that the experience of premature extrauterine life modulates network development, altering the maturation of networks thought to support salience, executive, integrative, and cognitive functions.

Retrospective Analysis of the Safety and Cost Implications of Pediatric Contrast-Enhanced Ultrasound at a Single Center, *American Journal of Roentgenology*, 2016

Yusuf, G. T., Sellars, M. E., Deganello, A., Cosgrove, D. O. and Sidhu, P. S.

Because of concern over medical ionizing radiation exposure of children, contrast-enhanced ultrasound (CEUS) has generated interest as an inexpensive, ionizing radiation-free alternative to CT and MRI. CEUS has received

approval for paediatric hepatic use but remains off-label for a range of other applications. The purposes of this study were to retrospectively analyse adverse incidents encountered in paediatric CEUS and to assess the financial benefits of reducing the number of CT and MRI examinations performed.

All paediatric (patients 18 years and younger) CEUS examinations performed between January 2008 and December 2015 were reviewed. All immediate reactions deemed due to contrast examinations were documented in radiology reports. Electronic patient records were examined for adverse reactions within 24 hours not due to an underlying pathologic condition. With tariffs from the U.K. National Institute of Clinical Excellence analysis, CEUS utilization cost (\$94) was compared with the CT (\$168) and MRI (\$274) costs of the conventional imaging pathway.

The records of 305 paediatric patients (187 boys, 118 girls; age range, 1 month–18 years) undergoing CEUS were reviewed. Most of the studies were for characterizing liver lesions (147/305 [48.2%]) and trauma (113/305 [37.1%]); the others were for renal, vascular, and intracavitary assessment (45/305 [14.8%]). No immediate adverse reactions occurred. Delayed adverse reactions occurred in two patients (2/305 [0.7%]). These reactions were transient hypertension and transient tachycardia. Neither was symptomatic, and both were deemed not due to the underlying disorder. The potential cost savings of CEUS were \$74 per examination over CT and \$180 over MRI.

Paediatric CEUS is a safe and potentially cost-effective imaging modality. Using it allows reduction in the ionizing radiation associated with CT and in the gadolinium contrast administration, sedation, and anesthesia sometimes required for MRI.

In vivo super-resolution and super-resolved velocity mapping, *IEEE Transactions on Medical Imaging*, 2015

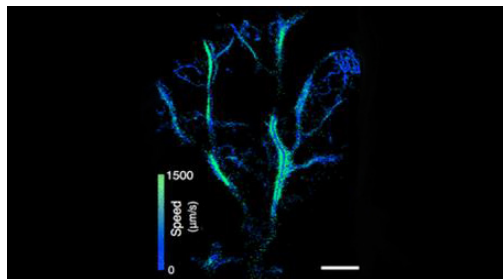
Christensen-Jeffries, K., Browning, R. J., Meng-Xing T., Dunsby, C., Eckersley, R. J.

The structure of microvasculature cannot be resolved using standard clinical ultrasound (US) imaging frequencies due to the fundamental diffraction limit of US waves. In this work, we use a standard clinical US system to perform in vivo sub-diffraction imaging on a cluster of differentiation1 (CD1 [glycoproteins]), female mouse aged eight weeks by localizing isolated US signals from microbubbles flowing within the ear microvasculature, and compare our results to optical microscopy.

Furthermore, we develop a new technique to map blood velocity at super-resolution by tracking individual bubbles through the vasculature. Resolution is improved from a measured lateral and axial resolution of 112 μ m and 94 μ m respectively in original US data, to super-resolved images of microvasculature where vessel features as fine as 19 μ m are clearly visualized.

Velocity maps clearly distinguish opposing flow direction and separated speed distributions in adjacent vessels, thereby enabling further differentiation between vessels otherwise not spatially separated in the image. This technique overcomes the diffraction limit to provide a noninvasive means of imaging the microvasculature at super-resolution, to depths of many centimeters. In the future, this method could noninvasively image pathological or therapeutic changes in the microvasculature at centimeter depths in vivo.

Figure 26 | Corresponding speed of flow through the vessels, where speeds above 1,500 formula milliseconds are set to the maximum on the colour bar. Copyright *IEEE Transactions on Medical Imaging*



65 – First in man: real-time magnetic resonance-guided ablation of typical right atrial flutter using active catheter tracking – Poster Presentation, *EP Europace*, 2014

Chubb H., Harrison J., Williams S. E., Weiss S., Krueger S., Rhode K., O'Neill M., Schaeffter T., Razavi, R.

MR-guided electrophysiology (MR-EP) has the potential to improve catheter navigation, to visualize ablation injury and to avoid ionizing radiation. This study investigated the feasibility of an actively-tracked, fully MR-guided, electroanatomical mapping and ablation system. This represents first such system used in humans.

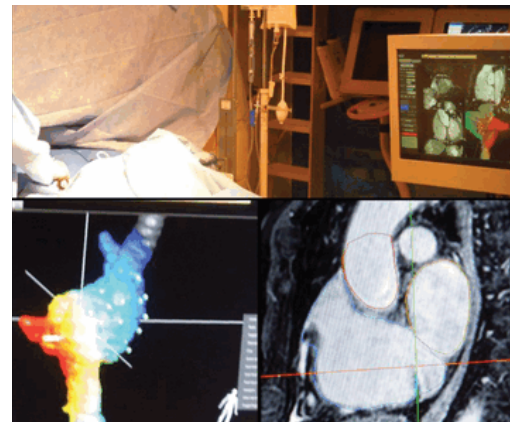
Two patients with typical right atrial flutter underwent cavotricuspid isthmus (CTI) ablation under MR guidance. The MR-EP suite integrated a Philips 1.5T Achieva scanner (Philips, Best, The Netherlands), an EP recording system (Horizon System, Imricor, Burnsville, MN, USA), an RF generator (St Jude Medical, St Paul, MN, USA), and a real-time image guidance platform (iSuite, Philips). Under anaesthesia, a baseline MRI was performed. 3D right atrial shells were created by automated segmentation of a whole-heart MR scan (3D BTFE) and CTI anatomy delineated. Using the shell for guidance, deflectable MR-EP RF Vision catheters (Imricor) were placed in the CS and RA using MR-guided active tracking alone. Isochronal

activation maps were created prior to ablation. RF ablation of the CTI was performed under active MR-guidance, with brief cine sequences for catheter position confirmation (35–40W for 40–60sec). Post ablation, activation maps were repeated and native-T1 weighted, T2 weighted and LGE imaging of the lesions was performed prior to removal from the scanner.

Both patients underwent ablation of the CTI without use of fluoroscopy, with no complications. High fidelity electrograms were recorded with minimal MR interference. Active tracking of the catheter tip was accurate, with tracking position corroborated by conventional imaging sequences prior to each energy delivery. Total procedure times were 307min and 315min. Septal to lateral transisthmus conduction interval was lengthened to 142ms and 134ms respectively, and atrial flutter was uninducible post-ablation. Imaging confirmed both T2 weighted and late gadolinium enhancement of the CTI with no gaps identified. The patients remain free of atrial flutter at 44 days and 23 days respectively.

This study confirms feasibility in man of active-tracked MR-guided ablation of typical atrial flutter in man.

Figure 27 | MR-EP suite set-up. The MRI scanner is covered by sterile drapes on the left, with iSuite mapping system displayed on right. (bottom left) Localised activation time shell on pacing from CS prior to ablation. (Bottom right) Single slice of multi planar reconstruction demonstrating catheter position adjacent to CTI. Copyright *European Society of Cardiology*



Whole left ventricular functional assessment from two minutes free breathing multi-slice CINE acquisition, *Physics in Medicine and Biology*, 2015

Usman, M., Atkinson, D., Heathfield, E., Greil, G., Schaeffter, T., Prieto, C.

Two major challenges in cardiovascular MRI are long scan times due to slow MR acquisition and motion artefacts due to respiratory motion. Recently, a Motion Corrected-Compressed Sensing (MC-CS) technique has been proposed for free breathing 2D dynamic cardiac MRI that addresses these challenges by simultaneously accelerating MR acquisition and correcting for any arbitrary motion in a compressed sensing reconstruction.

In this work, the MC-CS framework is combined with parallel imaging for further acceleration, and is termed Motion Corrected Sparse SENSE (MC-SS). Validation of the MC-SS framework is demonstrated in eight volunteers and three patients for left ventricular functional assessment and results are compared with the breath-hold acquisitions as reference.

A non-significant difference ($P > 0.05$) was observed in the volumetric functional measurements (end diastolic volume, end systolic volume, ejection fraction) and myocardial border sharpness values obtained with the proposed and gold standard methods.

The proposed method achieves whole heart multi-slice coverage in 2 min under free breathing acquisition eliminating the time needed between breath-holds for instructions and recovery. This results in two-fold speed up of the total acquisition time in comparison to the breath-hold acquisition.

Assessment of atherosclerotic plaque burden with an elastin-specific magnetic resonance contrast agent, *Nature Medicine*, 2015

Makowski M., Wiethoff A. J., Blume U., Cuello F., Warley A., Jansen C. H., Nagel E., Razavi R., Onthank D. C., Cesati R. R., Marber M. S., Schaeffter T., Smith A., Robinson S. P., Botnar R. M.

Atherosclerosis and its consequences remain the main cause of mortality in industrialized and developing nations. Plaque burden and progression have been shown to be independent predictors for future cardiac events by intravascular ultrasound. Routine prospective imaging is hampered by the invasive nature of intravascular ultrasound. A noninvasive technique would therefore be more suitable for screening of atherosclerosis in large populations. Here we introduce an elastin-specific magnetic resonance contrast agent (ESMA) for noninvasive quantification of plaque burden in a mouse model of atherosclerosis.

The strong signal provided by ESMA allows for imaging with high spatial resolution, resulting in accurate assessment of plaque burden. Additionally, plaque characterization by quantifying intraplaque elastin content using signal intensity measurements is possible. Changes in elastin content and the high abundance of elastin during plaque development, in combination with the imaging properties of ESMA, provide potential for noninvasive assessment of plaque burden by molecular magnetic resonance imaging (MRI).

Reproducibility of 2-Dimensional Shear Wave Elastography Assessment of the Liver: A Direct Comparison With Point Shear Wave Elastography in Healthy Volunteers, *Journal of Ultrasound Medicine*, 2017

Fang, C., Konstantatou, E., Romanos, O., Yusuf, G. T., Quinlan, D. J., Sidhu, P. S.

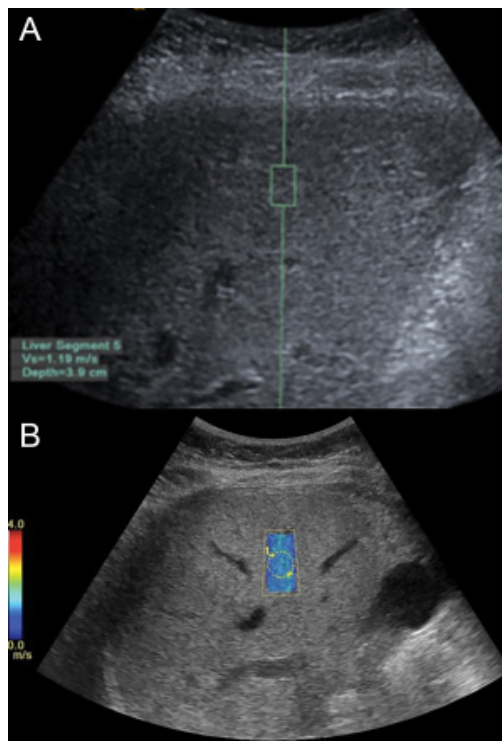
Two-dimensional shear wave elastography (2D-SWE) imaging for the noninvasive assessment of tissue stiffness was assessed for reproducibility in healthy volunteers in quantifying liver elasticity, compared with an established point shear wave elastography (p-SWE) technique also known as virtual touch quantification (VTQ) (SIEMENS).

Eleven healthy volunteers were examined by four experienced operators on two occasions, separated by two weeks (sessions A and B). Ten 2D-SWE using LOGIQ E9 and p-SWE measurements using VTQ (in meters per second) were consecutively taken from deep portions of liver segments 5 or 6 away from vascular structures, using standard techniques. Inter – and intra-observer agreement was assessed by intraclass coefficient (ICC).

A total of 880 2D-SWE and p-SWE velocities were recorded. Mean values from the four operators ranged between 1.188 and 1.196 m/s for 2D-SWE and 1.170 to 1.207 m/s for p-SWE. Interobserver reproducibility was good for both sessions with ICCs of 0.88 and 0.93 (2D-SWE) and 0.87 and 0.93 (p-SWE). The overall intra-operator reproducibility between sessions A and B was good for both p-SWE and 2D-SWE with ICC of 0.87 and 0.83, respectively. For inter – and intra-observer variability, the ICC was more than or equal to 0.71, indicating that the results were reliable. There was a strong and significant correlation between the 2D-SWE and p-SWE measurements ($r=0.87$, $P=.0006$), but their velocities did not agree equally across different velocities.

Two-dimensional SWE using LOGIQ E9 is a reliable and reproducible method for measuring elasticity in healthy volunteers and has a similar degree of reliability as p-SWE using VTQ, but absolute measurements from the two techniques should not be used interchangeably.

Figure 28 | A, Point SWE measured through an intercostal space of the liver using VTQ. The rectangular indicates the ROI where the average SWE is calculated. B, Real-time 2D-SWE images performed through an intercostal space of the liver using LOGIQ E9. The rectangular box is the field of view where the shear wave measurements are taken. The machine provides the mean, median minimum and maximum, and standard deviation of the elastography measurements within the region of interest, which is shown in (B) as the dotted circle within the field of view. Copyright *Journal of Ultrasound Medicine*



Mitochondria: hub of injury responses in the developing brain, *Lancet – Neurology*, 2014

Hagberg H., Mallard C., Rousset C., Thornton C.

Progress in the field of mitochondrial biology in the past few years has shown that mitochondrial activities go beyond bioenergetics. These new aspects of mitochondrial physiology and pathophysiology have important implications for the immature brain. A picture emerges in which mitochondrial biogenesis, mitophagy, migration, and morphogenesis are crucial for brain development and synaptic pruning, and play a part in recovery after acute insults. Mitochondria also affect brain susceptibility to injury, and mitochondria-directed interventions can make the immature brain highly resistant to acute injury.

Finally, the mitochondrion is a platform for innate immunity, contributes to inflammation in response to infection and acute damage, and participates in antiviral and antibacterial defence. Understanding of these new aspects of mitochondrial function will provide insights into brain development and neurological disease, and enable discovery and development of new strategies for treatment.

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