Institution: King's College London

Unit of Assessment: UoA 15

a. Context

Background: The Division of Imaging Sciences and Biomedical Engineering, which forms this unit of assessment return, is made up of 60 academics from multidisciplinary backgrounds that are focused on engineering and physical science research and its application to biological and clinical problems. The Division is dual-affiliated to the KCL Schools of Natural and Mathematical Sciences and Medicine and is based at St Thomas's Hospital. It is embedded within a Clinical Academic Group (CAG) of King's Health Partners (KHP), the Academic Health Science Centre, which describes itself as "a Centre where world-class research, teaching and clinical practice are brought together for the benefit of patients". The Imaging and Biomedical Engineering CAG, alongside other CAGs, are the main vehicles within KHP of delivering this, as the Division and CAG have the same leadership and strategy.

The main beneficiaries of the impact of the Division's research are patients and the wider NHS. There are additional economic benefits via industrial partners and spinout companies, as well as societal benefits through influence on healthcare policy. Healthcare impact can only be achieved if the research is incorporated by industry into clinical products. Therefore, the imaging and device industries are not only the main routes to impact but also direct beneficiaries of the Division's research output, as reflected in all 6 of our impact case studies.

The wider NHS, via the National Institute for Health Research (NIHR) and National Institute for Health and Care Excellence (NICE), support the Division's aim of translating research for patient benefit. NIHR fund a Biomedical Research Centre, with the Division hosting the imaging and biomedical engineering theme, and also support the Division's Imaging Clinical Research Facility. The NIHR Health Technology Cooperative for Cardiovascular Technologies and NICE funded King's Imaging Technology Evaluation Centre are also based within the Division.

- **Benefit to Local And National Health Services:** The creation of the Imaging and Biomedical Engineering CAG, which places KCL and NHS employees in the same organisational structures, has ensured that important clinical questions drive the direction of our research. The environment is also conducive for the evaluation of potential innovations and the implementation of findings within the NHS partner trusts. Many research ideas quickly become prototypes that are evaluated clinically and, in many cases, become important new tools in diagnosis and treatment of patients locally. This is facilitated by over 20 NHS employed clinical, and medical engineering & physics staff having honorary positions within the Division and spending between 4 and 12 hours a week (funded by the NHS trusts) working on research at the academic clinical interface. Impact case studies where we have shown local impact first include: improving diagnosis of patients with ischaemic heart disease (4); the diagnosis and treatment of children with congenital heart disease (3); treatment of patients with cardiac arrhythmias (2); and finally the treatment of patients with abdominal aortic aneurysms (6). In addition, all of our case studies show national and international impact beyond the local benefit.
- **Benefit to Industry:** We work closely with many leading medical technology companies and many of the scientific ideas and initial prototypes built within the Division have been taken up by them as a model for their product development, as shown in the impact case studies 1, 3, 4 and 5. Our teams have also taken their research ideas and prototypes into university start-up companies, developing and marketing product versions as in impact case studies 1 and 6.
- **Influencing Policy, Practice and Public Perception:** Our NICE funded King's Imaging Technology Evaluation Centre has significant impact on NHS policy and practice. The Centre carries out technical, clinical, and health economic evaluations of new imaging technologies, which form the basis of the guidance, given by NICE to the NHS for their use. Many of our academics hold leadership positions in national and international societies that influence guidelines and clinical practice in the use of imaging for diagnosis and treatment. Our PI's also participate in a wide range of outreach activities influencing public awareness of biomedical engineering and imaging. For example, our image guided surgery system (impact case study 6) was chosen to be one of the 24 exhibits at the week-long Royal Society Summer Science exhibition in 2011, which attracted over 14,000 visitors including school pupils, general public, media and Royal Society Fellows.

b. Approach to impact

Our submitted impacts are built on a platform of excellent research, informed by early engagement and dialogue with key stakeholders: the NHS, patients, and industry.

Interactions with the NHS are greatly enhanced as the Division is based at St Thomas' Hospital. One third of the academics in the Division spend half of their time looking after patients and yet are still completely integrated with the engineers and physical scientists. Our engineers and physical scientists in turn hold honorary contracts with KHP hospitals and spend varying amounts of time interacting in clinical settings. The Division also employs approximately 30 staff members who work within the Imaging Clinical Research Facility (CRF) as research radiographers, nurses, and technicians. Our Imaging CRF includes 5 research MRI systems (2 with combining x-ray fluoroscopy catheterisation laboratories), 2 research PET-CT's, and research ultrasound systems. A clinical PET-MR system, the second available in the UK, has been purchased during the REF period and is currently being installed. These imaging research facilities have been substantially renewed and expanded as part of an investment of more than £40m in the Division's infrastructure since the end of 2007. This environment provides our researchers with leading edge imaging technologies in a hospital environment supported by a comprehensive engineering, computing, laboratory and pre-clinical infrastructure that encourages innovation and rapid clinical translation. In addition, the Division has research time on most clinical imaging equipment within the hospital so that it can also bring its science and engineering capabilities directly to clinical care pathways. Many patients are enrolled in ethically approved studies of new engineering techniques. For example, almost all of the 2000 clinical cardiovascular MRI scans performed annually have a 15 minute additional research time added where new sequences developed by the MR physics team are tested. Facilitated by the CAG structure, many NHS employed clinicians, medical physicists, engineers and other staff spend significant amounts of time doing research and are completely integrated with the Division. **The result of this very close integration with the local NHS Trust is that potential clinical impact drives the great majority of the research questions being investigated. This is reflected in the engineering and physical sciences grants held by the Division which nearly all have clinicians as co-applicants. There is also a programme of very early testing of research ideas and prototypes within the clinical setting with a close-coupled feedback loop in order to adapt and improve the technologies so that they are fit for their clinical purpose.**

In order to gauge the success of the technologies we are developing, we maintain strong links to the patient community. Patient involvement starts from the initial research ideas and continues throughout the development stage. We have built these links via the hospital and BRC initiatives around patient and public engagement. We host patient group meetings in which new research ideas and potential grant proposals are discussed. Patient representatives join the steering groups of major grants and continue to input as the research develops. Finally, we get important feedback from patients who take part in clinical trials of our new technologies and prototypes.

The Division has particularly strong links with the imaging and device industries. There are also links with pharmaceutical companies that are either developing imaging agents or use imaging as part of their drug discovery pipeline. Industrial interactions by our academics are strongly encouraged and are an integral part of their appraisal and promotion criteria. Fostering industrial links and the exploitation of assets for licensing, as well as support for start-up companies, are facilitated by two dedicated Divisional Business Development Managers who also have access to strategic funds in order to overcome any bottlenecks obstructing valued research assets. For example, as outlined in impact case study 6, Cydar Ltd. was incorporated last year with a prototype product to assist vascular surgeons performing endovascular stent implantations for complex abdominal aortic disease. Institutionally, the King's Commercialisation Institute provides expertise on intellectual property, patenting, technology transfer, and commercialism. The specific companies that have a substantial research relationship with the Division, governed by a research agreement and significant financial commitments, are outlined in the table below:

Company Name	Funding (£)	No. of Projects	No. of Prototypes
Philips	1,974,962	14	9
St Jude Medical	602,738	5	3
GE Healthcare	265,100	5	3
Siemens Healthcare	450,000	2	0

Medtronic	285,064	2	1
Bayer-Schaering	1,475,000	3	2
Lantheus Medical Imaging	115,073	2	0
Imaging Equipment Ltd.	90,000	2	1
Primal Pictures	209,000	1	1
Boston Scientific	150,000	1	1
Alliance Medical Ltd.	110,000	1	0
Cook Medical	150,000	1	0
Eli Lilly & Co Ltd	80,191	1	0
Ixico Ltd	62,298	1	1
Biosense Webster	58,873	1	1
Bracco	50,000	1	0
Microsoft	39,323	1	1
Chugai Pharma	30,000	1	0
Roche	20,000	1	0
Volcano Corp	10,000	1	0

For the Division, the main reason to build and maintain these relationships is to ensure wide impact of our research. From the companies perspective it allows an opportunity to work with some of the leading scientists in the field in a clinical setting, gain clinical and technical input into their own related R&D programs and, more importantly, access to the Divisional research portfolio, particularly in areas where they do not have internal R&D expertise or focus. It also provides opportunities for leveraging their R&D resource with joint external grants. For example, 3 of the successful industry led proposals from the recent Technology Strategy Board call on Medical Imaging will have all, or a very substantial part, of the research carried out within the Division and involve all 3 major imaging technology companies (Siemens, Philips and GE). Companies such as Philips, GE and Mediso have also placed their scientists on site, with Siemens planning to do so shortly, to help facilitate the relationship and opportunities outlined above. For example, Philips have 3 scientists based within the Division: 1 from their MR business unit and 2 from Philips Global Research working on joint projects in quantitative MRI and next generation PET MR systems (impact case study 3).

The PET-MR collaboration with Philips is also a good example of how industrial interactions allow us to leverage substantial external grant funding. For example we now have 3 substantial awards from EU (Hyperimage and Sublima) and Wellcome Trust/EPSRC (a large program within our Medical Engineering Centre). In addition, two KCL researchers are also embedded within the Philips global research laboratories working with Philips scientists to build working prototypes of the new PET MR technology. The first prototype was brought to KCL for phantom and preclinical testing and the lessons learnt by the joint research team have been incorporated into the next version, which has just been moved to KCL. These prototypes will form the basis for the next generation of clinical systems that will be built by Philips. This clearly demonstrates that strong academic industrial collaborations make a significant impact on the R&D process. There are also strong interactions with industry by individual researchers from within the Division, which includes providing consultancy and sitting on industrial advisory boards; Schaeffter and Nagel (Philips), Gee (GSK), Hajnal (Ixico), and Penney (Cydar).

Bringing our researchers, the NHS, and industry together with a strong patient and public engagement policy is key to delivering impact from our research. We have dedicated structures, such as our NIHR funded Health Technology Cooperative in Cardiovascular Technologies, which help facilitate these interactions. Finally influencing NHS policy and guidelines is best demonstrated by the work of our NICE funded King's Imaging Technology Evaluation Centre. For example, by drawing on the expertise of academic staff and affiliated NHS scientists and clinicians we have developed an implementation guide to support the NICE guidelines on use of cardiac CT scanners which will help the NHS to make informed choices when purchasing CT equipment. In another recent project we advised NICE on how they should approach the evaluation of PET amyloid tracers in the early diagnosis of Alzheimer's disease. This report drew on the expertise of a number of clinical and non-clinical academics in imaging, clinical trials and health economics, representing collected expertise that it would be difficult to match elsewhere and ensures the best possible scholarly input to a question with very wide healthcare and societal implications.

c. Strategy and plans

The most important part of our strategy for impact is **to use the close interaction between academia, the NHS, and industry to develop specific projects that bring together the scientific expertise within the Division and real clinical problems that need technological solutions.** This strategy is bearing fruit with many recent awards from major funders such as a £10maward (July 2013) from the EPSRC/Wellcome Trust Innovative Engineering for Health scheme to develop new ultrasound technologies for prenatal diagnosis of congenital abnormalities in partnership with Philips Healthcare.

Delivery of our strategy relies on scientific excellence, interdisciplinary working, and focus on clinical translation. We have been able to attract leading scientists from the UK and abroad who share our vision for their research to have major impact on healthcare. These strategic appointments have consolidated and advanced existing areas and broadened the scope of our translational research. Research impact is central to our recruitment strategy with Professorial appointments during this REF period designed to enhance our activities in: computational modelling (Smith); biostatistics (Montana); MR physics (Sinkus, Kozerke and Hajnal); PET chemistry (Gee); cancer imaging (Cook and Goh); neuroimaging (Hammers) and perinatal imaging (Edwards, Counsell and Rutherford). Nurturing early career researchers, who form 45% of our REF return, is also vital to our impact agenda and we introduce them to a culture of innovation and commercialisation though workshops provided by the KCL Researcher Development Unit covering topics such as leadership, management, entrepreneurial skills, and becoming a PI.

One of the most important ways that we can ensure future impact is in the way that we train the next generation of scientists. We have an extensive track record of industry-sponsored PhD studentships whereby the research projects have been defined together with the industrial partner and the PhD student spends 20% of their time at industrial R&D departments. We will expand this successful model through our recently awarded EPSRC Centre for Doctoral Training (CDT) to provide PhD students with access to industrial training, facilities, and expertise. 18 industrial partners have committed to 50% co-funding of 39 CDT studentships and will provide student placements and industry workshops to allow the students to see the potential impact of their innovation. We regularly invite successful med-tech entrepreneurs to spend time with us to engage with our PhD students and young post-docs and to share their experiences and expertise.

d. Relationship to case studies

The case studies presented illustrate the different facets of the approach outlined above. For example, the development of the EP navigator (in case study 2) started as EPSRC funded basic research to develop technologies for image guidance and fusion. The outputs from this were translated into a research prototype jointly funded by TSB and Philips. The development work was carried out by researchers within the Division in the Philips Development Software Environment. Philips then moved this to a commercial prototype, and clinical evaluations were conducted within the hospital by teams in the Division to show efficacy. Finally, a commercial product was produced and has been deployed successfully in many hundreds of units around the world; and therefore has had major impact on the care of patients undergoing treatment for cardiac arrhythmias.

Case studies 1 and 6 follow a different pathway. Spinout companies were created to achieve translational impact from core EPSRC funded research. The researchers have developed a business model converting advanced image registration and image management methods into products and have started to explore their direct healthcare impact. Case studies 2 and 3 demonstrate how advanced engineering capacity within a clinical context can lead to innovative solutions that can then be directly validated by the same research teams to gather the evidence needed for subsequent clinical uptake. Case studies 4 and 6 show how developments in computing and reconstruction can be converted to clinical capabilities. Case study 5 describes the fruits of a classic instrumentation development programme.

1	Image Registration and Data Curation for Digital Healthcare
2	Platform for Image-Guided Treatment of Arrhythmia
3	MRI-Guided Cardiovascular Catheterisation in Children
4	Spatiotemporal Undersampling for Highly Accelerated MRI
5	Simultaneous PET & MRI
6	Robust and Accurate 2D-3D Image Registration