Institution: University of Edinburgh (UoE)

Unit of assessment: UoA1 WORD LIMIT 23,200

Section 1. Unit context and structure, research and impact strategy

1.1 Vision

The vision of Edinburgh Medicine is *to improve lives through the understanding of human health and disease.* Our research, within the College of Medicine and Veterinary Medicine (CMVM), spans molecular biology to population sciences, bringing together an interactive community of 377 clinician scientists and other researchers (representing 47% staff growth over the REF period) who have been awarded £540m research income (16% average annual growth rate), and whose work has transformed lives globally though discovery, translation and clinical research.

1.2 Strategy

To deliver this vision, our strategy is for scientists, clinicians, industrial and NHS colleagues to work side by side in interdisciplinary research institutes, bringing together externally-supported and core-funded (MRC, BHF, CRUK) Centres to drive our research themes (Figure 1) and respond to global needs. Each Institute has state-of-the-art infrastructure and, with over 500 Principal Investigators, post-doctoral research assistants and graduate students, has critical mass to drive innovative interdisciplinary research and transform the understanding and treatment of disease. Four such research institutes form Edinburgh Medicine and are sited on one of our two core campuses (Edinburgh BioQuarter and Western General Hospital), each co-locating a major teaching hospital, advanced medical education, state-of-the-art preclinical and clinical investigation facilities and translational and commercialisation space.

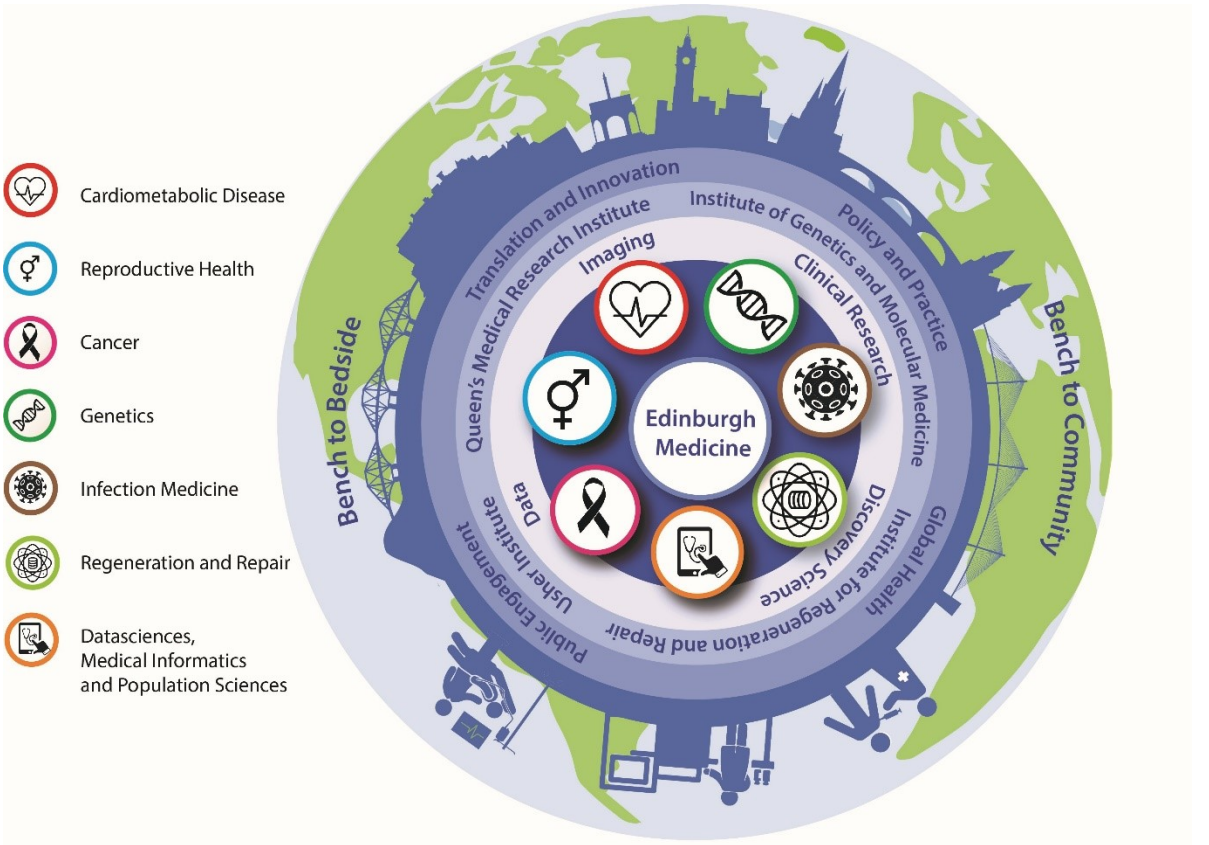

Figure 1: Our interdisciplinary themes, strategies and infrastructure that together improve lives throughout the world

Our two new Institutes for REF2021 exemplify this approach to deliver world-leading research and innovation. The Institute for Regeneration and Repair (IRR) was created in 2019, bringing together the existing Centres for Regenerative Medicine (MRC centre status 2008-2020), Inflammation Research (MRC centre status 2000-2018) and the MRC Capital Award, "Computational and Chemical Biology of the Stem Cell Niche", to accelerate our research in this field. IRR will coalesce its centres in a new building (£90.7m, opening 2022) creating the largest institute for regeneration globally, to facilitate translation of discovery to therapy. Adding further strength, our Centre-in-development for Infection Medicine will strategically locate to IRR to explore the important links between infection and inflammation.

The Usher Institute was created in 2014 by melding the Centres for Population Health Sciences, Global Health Research, Medical Informatics and the Edinburgh Clinical Trials Unit, to create synergies in the studies of people, populations and data science. Evidencing success, Usher has become a designated Innovation Centre, delivering health & social care data-driven innovation (DDI) as part of the £661m Edinburgh City Region Deal (2018) that has created a major new strand in medical informatics. The Institute will expand into the new Usher II Institute building (£68m, opening 2023), co-locating 950 medical data researchers who collaborate with data scientists in the Turing Institute (UoA11), social scientists in the Wellcome Trust funded (£1.2m) Centre for Biomedicine, Self and Society (returned UoA20), and the £82m national supercomputer ARCHER2, aiming to transform health in global societies.

Once formed, our Institutes remain responsive to global need and our two other Institutes (returned in REF2014) have evolved their research strategy to meet key challenges. The MRC Human Genetics Unit (MRC HGU), CRUK Edinburgh Cancer Research Centre (ECRC) and the Centre for Genomic and Experimental Medicine (CGEM) together form the MRC Institute of Genetics and Molecular Medicine (IGMM). A £27.2m investment in infrastructure created a single IGMM building with collaboration space to drive interaction. The Queen's Medical Research Institute that houses our Centres in cardiometabolic disease and reproductive health will, as detailed in Future Aims, evolve by adding our Neuroscience community (returned UoA4) to the BHF Centre for Cardiovascular Science, generating the interlinking of brain and body required for 21st century physiology and medicine.

Since REF2014 this dynamic institute structure has driven a greatly enhanced level of achievement and major capital investment. In addition to the growth in research staff and awards above, highlights include:

Infrastructure

- IRR: New Centre for Tissue Repair building constructed, with expansion work approved and ongoing (£90.7m opening 2022)
- Anne Rowling Regenerative Neurology Clinic Phase 2 (£15m 2019)
- New Usher Institute Building and supporting infrastructure (£68m, £49m from data-driven innovation component of the Edinburgh City Region Deal; opening 2023)
- IGMM New Institute building (£27.2m 2016)
- City Region Deal investment to deliver enabling infrastructure at the Edinburgh BioQuarter campus (£13m)

Major Funding

- MRC HGU core renewal (£53m 2017-2022): largest MRC Unit in the UK
- UKRI HDR-UK (Health Data Research) core (£5.2m, 2018-2023) and BREATHE Hub (£6.9m, 2019-2022)
- UKRMP Engineered Cell Environment Hub (£5.1m 2018-2023)
- CRUK Core and Training Centre Award (£7.7m renewed 2017)
- CRUK Training Award joint with Glasgow - TRACC programme (£6m 2019-2024)
- Wellcome Trust Edinburgh Clinical Academic Training Programme (£10.2m 2017-2025)
- Administrative Data Research Centre Scotland (£7.7m ESRC)
- BHF Centre awards (£5.5m 2017-2019)

- Scottish Genomes Partnership (£15m 2015-2020)
- Generation Scotland (£15m SFC, CSO, MRC and Wellcome Trust)
- RESPIRE:NIHR Global Health Research Unit on Respiratory Health (£7.7m 2017-2021)

People

- 73 new appointments to Personal or Established Chairs
- 32 new tenure-track Chancellor's Fellows/ESAT

Fellowships & Awards

- 4 Fellows of the Royal Society
- 34 Fellows of the Royal Society of Edinburgh
- 26 Fellows of the Academy of Medical Sciences
- 30 Clinical Training Fellowships
- 10 Intermediate Clinical Fellowships
- 11 Senior Fellowships
- Athena Swan (Silver)
- 2 Queen's Anniversary Prizes (2015, 2017)

Translation

- 6 new companies formed attracting £38.7m initial investment

Impact

- Determining that computer tomography coronary angiography imaging is the most accurate and cost-effective way to diagnose ischaemic heart disease, changing guidelines and routine practice in the UK, Europe and USA
- Developing an integrated model of delivering palliative care in resource-poor settings which has resulted in a 5-fold increase in morphine availability in parts of sub-Saharan Africa since 2012
- Demonstrating the effectiveness and superiority of ulipristal acetate as emergency contraception, leading to its usage in 23 EU countries without prescription, empowering women to take charge of their own fertility

Interdisciplinarity

- PROTEUS (£11.3m EPSRC) bringing together clinician scientists, chemists and optical physicists to devise real-time solutions to the diagnosis of lung infection
- The Chemistry and Computational Biology of the Niche facility (£5.1m MRC) exploits the interface of stem cell biology, chemical engineering and bioengineering to develop 3D models of stem cell microenvironments that enhance regeneration
- Advanced Care Research Centre (£20m Legal & General collaboration 2020) brings together clinician scientists working in primary and hospital care with engineers working on biosensors, social care researchers and ethicists to develop new models for care of the elderly
- The Wellcome Trust Centre for Biomedicine, Self and Society (£1.2m, returned UoA20) conducting interdisciplinary humanities and social science research in biomedicine, public health and health care, bringing together clinicians and social scientists to address the wider social and ethical issues in medicine early on in the research and development trajectory

1.3 Research Themes

Genetics: 66 UoA1 Staff Returned

The MRC Human Genetics Unit (MRC HGU, £53m; Director **Bickmore**) that nucleates this research theme combines the latest computational and experimental technologies to investigate how our genomes work to control the function of molecules, cells and tissues in people and populations. MRC HGU applies clinical and scientific expertise, harnessing the power of complex data, to improve

health, and the lives of patients and their families. This is facilitated through strong collaboration with the NHS: powerful genetic analytical pipelines and subsequent mechanistic research allow diagnostics and biological insight to be returned to the clinic. For example, in the Deciphering Developmental Disorders study clinical recruitment of >13,000 affected individuals, mostly children with severe undiagnosed developmental disorders, was achieved *via* all 23 of the NHS regional genetics services in the UK. This study has reported a confident genetic diagnosis in 35% of the research participants and has directly informed clinical practice, by limiting unnecessary invasive diagnostic procedures, clarifying reproductive risks and, in some cases, changing therapy. In addition to MRC programme grant support to **Ponting** (£3.5m), senior fellowships awarded within this research theme include **Kudla** who was awarded a Wellcome Trust Senior Research Fellowship in Basic Biomedical Science (£1.4m).

Our *genome regulation* research addresses the mechanisms of genome stability, gene expression and relationship to disease: **Bickmore** and **FitzPatrick** linked gene control and enhancers to rare diseases (Nat Genet 2018). **A. Wood** and **Bickmore** (Figure 2) showed that chromatin decondensation is sufficient to alter nuclear organisation in embryonic stem cells (Science 2014), while **Gilbert** delineated new mechanisms of chromatin structure and dynamics, supported by the Edinburgh Super-Resolution Imaging Consortium (Cell 2017).

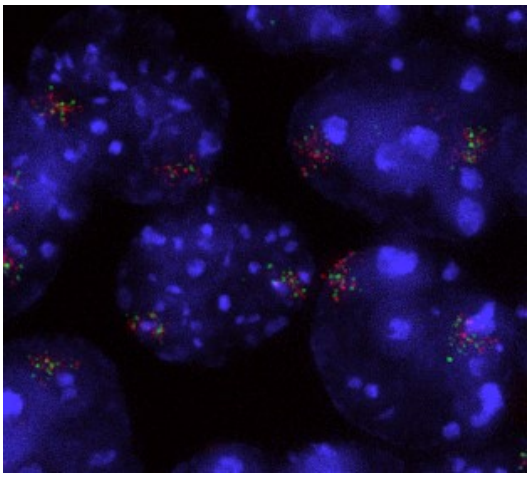

Figure 2: Understanding chromatin structure: Chromosome 2 polycomb positive (red) and negative (green) oligo paint on WT ES cells

Our *genome medicine* research focuses on the genetic analysis of complex traits and monogenic diseases, utilising state-of-the-art sequencing and computation analysis of whole genome and epigenome data to predict, diagnose and treat disease. **Lees** founded the PREdiCCt longitudinal follow-up study in IBD (Lancet 2016), and used capture-recapture methodology to determine a high IBD prevalence in Lothian (Gut 2019), and genetics to predict IBD treatment responses (Gastroenterology 2020). Our biomedical genomics research harnesses multidimensional genome-sized and population-scale data for biological learning. **Sproul**, **Marsh** and **A. Jackson** identified a reciprocal relationship between epigenetic marks and human embryonic growth (Nat Genet 2019). **Kudla** used synthetic biology at scale to understand genotype to phenotype links (Science 2016). **Tenesa** and **Canela-Xandri** developed new software to deal with data scale and kinship and produced the largest GWAS for quantitative traits in UK Biobank (Nat Genet 2018), and with **Haley** assessed the contribution of genetic and familial-shared environment to common disease using the UK Biobank (Nat Genet 2016). **Ponting** discovered the impact of non-coding RNA on mitochondrial function (eLife 2019) and **Taylor**, Reijns (UoA4) and **A. Jackson** showed how replication processes impact genome mutation rates (Nat 2015).

Our *medical genetics* research is based around single gene disorders, population genetics with a focus on 'complex' disorders of the brain, and novel gene therapies for Cystic Fibrosis. **A Jackson** has identified gene abnormalities of growth disorders, genome integrity and cell division (Genes & Dev 2016), inflammation (Nat 2017) and cancer (Nat 2018). **Marsh** has discovered how protein complex assembly can inform analysis of disease-related gene variants (Science 2015). **Porteous**, **Thomson**, **Nicodemus** and **Evans** have defined the genetic contributions to risk of schizophrenia and other major mental illness (Nat 2015, Mol Psych 2018, Mol Psych 2020). **Porteous** co-leads the UK Cystic Fibrosis (CF) Gene Therapy Consortium delivering pioneering translational and clinical CF gene therapy research (Lancet Respir Med 2015). **Marioni** researches the epigenetic changes of ageing and dementia (Mol Psych 2019).

Cancer: 33 UoA1 Staff Returned

Our Edinburgh Cancer Research Centre (ECRC) includes the core funded Cancer Research UK Edinburgh Centre (CRUK EC £7.7m; Director **Tomlinson**, Clinical Director **Gourley**) which brings together cancer scientists and clinicians from across the University of Edinburgh. CRUK EC is part of the network of CRUK Centres, and a partnership between UoE, CRUK and NHS Lothian. Clinical and translational emphasis is on colorectal cancer, women's cancers (breast, ovarian and endometrial) and brain cancer, for which Edinburgh is a CRUK Brain Tumour Centre of Excellence (Lead **Frame**). ECRC places significant value on clinical translational science with tissue collection/biobanking and trials activities fully integrated with IGMM research and NHS Lothian Cancer Services (Director **Hayward***). In addition to CRUK programme grant support to **Frame** (£1.9m) and **Tomlinson** (£2.2m), senior fellowships awarded within this research theme include **Wilkinson** who was awarded a CRUK Senior Cancer Research Fellowship (£2m).

Our *oncology discovery* research focuses on stem cells and the cancer niche, signalling and biological mechanisms. In cancer biology studies, **Frame** and **Brunton** (Figure 3) have shown how nuclear adhesion network hubs (FAK, Ambra1 and Kindlin) control intracellular trafficking and tumour T cell responses (Cell 2015, eLife 2017, Science Signalling 2017) leading to a clinical trial of FAK inhibition with immunotherapy. **Acosta** described the regulation of tumour cell senescence by innate immune sensing via Toll-like receptor 2 (Science Advances 2019, Genes Dev 2019 (with **Bickmore**, MRC-HGU), Nat Cell Biol 2015, J Exp Med 2017, Nat Commun 2018). **Wilkinson** uncovered a new non-canonical autophagy receptor required for pancreatic cancer proteostasis (Dev Cell 2018). **Unciti-Broceta** has pioneered the application of gold and palladium nanoparticles for controlled release of anticancer drugs (Nat Catalysis 2014), applying innovative chemistry to cancer biology. **Boulter** has described the role of Wnt signalling in biliary fibrosis and cholangiocarcinoma (Nat Commun 2020, JCI 2015).

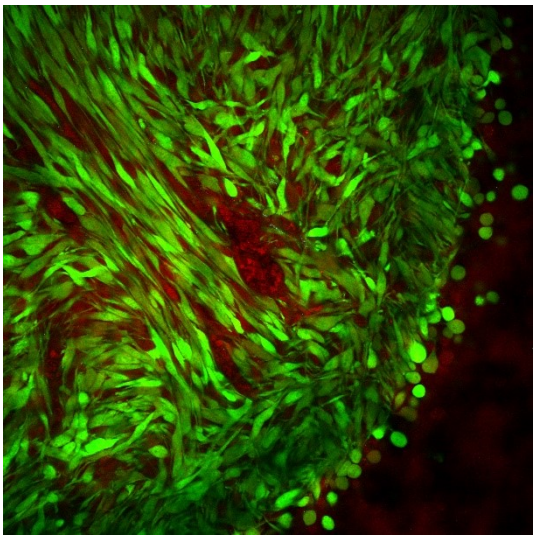

Figure 3: Watching tumour growth in real time: In vivo imaging of the tumour and its associated microenvironment using combined CARS / 2-photon microscopy (Serrels, Frame and Brunton)

Our *translational oncology* research focuses on cancer phenomics drug discovery, and stratification for prevention and therapy. In the area of colon cancer genetics, **Dunlop, Din**, **Farrington** and **Tomlinson** have advanced the fields of colorectal cancer risk (BMC Med 2018, J Clin Oncol 2015); the genetic determinants of colorectal cancer (Nat Commun 2016, 2019; Nat Genet 2016) and discovered a link between plasma vitamin D concentration and survival outcomes of colorectal cancer patients (Gut 2019). **Tomlinson**, a new senior recruit (incoming Edinburgh Cancer Research Centre and CRUK-Edinburgh Centre Director) has discovered genes that initiate tumorigenesis (Nat 2017, Nat Gen 2016, Nat Med 2015, Cancer Cell 2016). **Bankhead** who was recruited to enhance digital pathology, developed QuPath, a leading cross-platform open source software for quantitative pathology and bioimage analysis (Sci Reports 2017), that enabled key collaborative advances (Nat Neurosci 2017, eLife 2018). **Carragher** plays a key role in the 'Edinburgh Cancer Translational Pathway', by linking innovations in biomarker and drug development via protein micro-arrays, phenotypic-based drug screening and the development of small molecule inhibitor compounds (Cancer Cell 2015).

In our *clinical oncology* research, **Cameron** has made key contributions to global breast cancer trials including the Herceptin Adjuvant (HERA) trial (Lancet 2017) and UK TACT2 trial (Lancet Oncol 2017). **Gourley** has followed work defining risks associated with BRCA1 mutations in ovarian cancers (Lancet Oncol 2014) to be UK lead of the pivotal trial that helped Olaparib gain approval as maintenance treatment for patients with a newly-diagnosed BRCA-mutated advanced ovarian

cancer (N Engl J Med 2018). **Herrington** and **Gourley** have provided improved molecular taxonomy of endometrioid ovarian carcinoma (Nat Commun 2020). **Fallon** and **Laird** have led key clinical studies that influenced palliative and supportive care for advanced cancer patients, including testing oral ketamine in neuropathic pain (JAMA Oncol 2018). They also described the 'Edinburgh pain assessment and management tool' (J Clin Oncol 2018) and a novel mode of assessment of quality of life in patients with advanced cancer (J Clin Oncol 2016).

Data Sciences, Medical Informatics & Population Sciences: **62 UoA1 Staff Returned**

The core vision of this theme, based in the Usher Institute, is to take a multidisciplinary approach to information technology development and the increasing use of routine health data to improve practise and implement sustainable change in healthcare delivery. The Usher Institute is key in delivering Health & Social Care Data-Driven Innovation as part of the £237m awarded to UoE for research and development in data-driven innovation within the Edinburgh & South East Scotland City Region Deal.

Respiratory health is a strategic focus, including leadership of the Asthma UK Centre for Applied Research (**Sheikh** £2m) and the HDR-UK BREATHE Hub (Director **Sheikh** £6.9m). The aim is to support the use of respiratory data in high quality research and cutting-edge innovation, enabling the development of new treatments and better care to transform respiratory health for people across the UK. The NIHR Global Health Research Unit on Respiratory Health (RESPIRE, Director **Sheikh** £7.7m) was funded as part of the NIHR Global Health Research Programme in 2016/17. The RESPIRE collaboration spans Asia with organisations in Bangladesh, India, Malaysia and Pakistan working in partnership with the University of Edinburgh. **Pinnock** leads research on supported self-management of asthma through the IMP^{2}ART consortium (NIHR £1m). In addition to these strategic initiatives in respiratory medicine, **Harrison** is a Co-I in the £7m NIHR Global Surgery Research Unit (£1m to UoE), **Guthrie** is lead for the new (2020) Advanced Care Research Centre (Legal & General £20m) which, with **Mercer** and colleagues from Engineering, Art, Informatics and Social Sciences, will develop interdisciplinary solutions for care of the elderly, and **Sudlow** is leading a project to understand multi-morbidity using routine healthcare data (HDR-UK £1m).

Our *global health research* investigates the epidemiology of infectious disease. **Nair** and **Campbell's** work led to an expansion of the estimate of RSV-associated acute lower respiratory infection, finding that ~45% of hospital admissions and in-hospital deaths due to RSV-ALRI occur in children younger than 6 months, and that an effective maternal vaccine could therefore have a substantial effect (Lancet 2017). **Nair**, **Campbell** and **Rudan** analysed the decrease in child pneumonia and recommended further intersectoral action improving socioeconomic conditions and targetting risk factors to achieve the Sustainable Development Goals for health by 2030 (Lancet Glob Health 2018). **Atkins** investigates HIV-1 acquisition and prevention strategies and has developed models that describe epidemics, vaccine impact and the limitations of using population data to estimate fatality rates (Science 2020). **Rodger** leads work understanding the cost-benefit of prophylaxis and the risk factors in HIV transmission (Lancet Infectious Diseases 2018, JAMA 2016).

Our *primary care and multimorbidity research* exemplifies our data driven innovation strategy by using population health sciences data to improve care. **Colhoun** and **Morris** helped determine the heritability of the glycaemic response to metformin, a first-line treatment of type 2 diabetes, which informs mechanistic understanding and may improve predictions for stratified medicine (Lancet Diabetes & Endo 2014). **Pinnock**, **McKinstry** and **Wild** showed that supported telemonitoring improved clinically important measurement of glycaemic control in patients with type 2 diabetes (PLoS Medicine 2016). **McKinstry** (SHARE Director) led the HITS clinical trial, which demonstrated clinically significant improvements in ambulatory blood pressure using telemonitoring-assisted self-management despite fewer and shorter GP appointments (PLoS Medicine 2020), a system now being rolled out across all 14 NHS Scotland health boards (£2m, Scottish Government) and recognised by the Clinical Improvement Award at the UK General Practice Awards in November 2019. **Guthrie** researches organisational interventions to improve quality and safety, finding that blends of informatics, education and incentives can reduce risk and harm, which has influenced prescribing safety and pay-for-performance policy internationally (BMJ 2016, NEJM 2016, NEJM

2018); and with **Mercer** investigated management of patients with multimorbidity (BMJ 2015, BMC Medicine 2017, Lancet 2018), and is working with NICE and SIGN to improve consideration of applicability in live guideline development. **Shenkin** and Maclullich (returned UoA4) developed and validated a widely-used tool to diagnose delirium in older people in hospital, enabling rapid intervention to treat underlying cause (*UoA4 ICS/A*) (BMC Medicine 2019).

Our *interdisciplinary medical informatics research* focuses on using information technology solutions to measure the outcomes of healthcare. **Sheikh**, following an influential meta-analysis of the effect of smoke-free legislation on child health (Lancet 2014), contributed to an evaluation of the impact of London's low emission zone on air quality and children's respiratory health, finding no evidence for a reduction in the proportion of children with lung damage despite small improvements in air quality (Lancet Public Health 2019). **Sheikh** provided the first UK-wide estimates of the considerable morbidity, healthcare utilisation and financial cost of asthma (BMC Medicine 2016). **Harrison** and **Docherty** showed that patients from ethnic minorities hospitalised with COVID-19 were more frequently admitted to critical care and require ventilation than white patients with similar disease severity, despite being younger (BMJ 2020). **Price** leads the Cochrane Vascular review group contributing to advances in the management of type 2 diabetes, coronary heart disease and stroke, such as the effect of aspirin on risks of vascular events (Lancet 2018).

Usher hosts the *Edinburgh Clinical Trials Unit* (ECTU) leading research in novel trial design and methodology. **Lewis** developed world class trials guidance in data sharing and statistical analysis plans (JAMA 2017), and **Weir** and **Parker** reported the benefits of adaptive and model-based designs in trials (Stat. Methods Med. Res 2015, Clinical Trials 2020). More broadly, the expertise within ECTU in medical statistics and study design has been crucial for the success of many projects: **Norrie**, **Weir** and **Parker** are co-authors of several important studies highlighted in this UoA1 submission, such as AFFIRM fetal movement trial (Lancet 2018), and the role of troponin assays in the management of myocardial infarction (Circulation 2020, JACC 2019, Lancet 2018).

Regeneration and Repair: 105 UoA1 Staff Returned

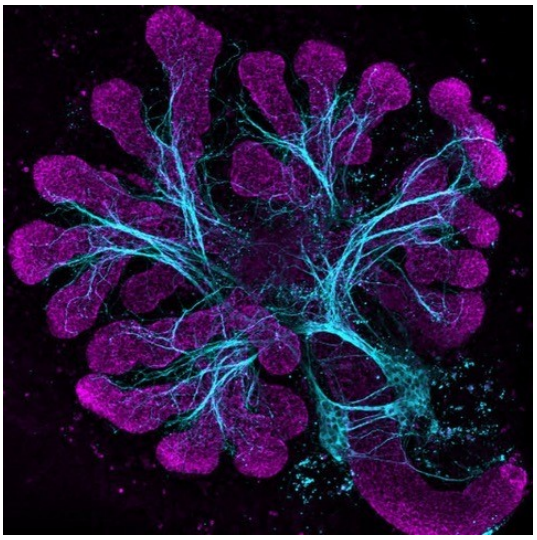

Figure 4: Model systems for studying regeneration: Mouse Salivary Gland

This research theme has been underpinned by MRC core funding in each of the key research areas being bought together in IRR and fundamental to our understanding of how to repair damaged tissues; regenerative medicine (MRC CRM £2.5m, Director **St. Forbes**), inflammation biology (MRC CIR £2m, Director **Gregory**), stem cell niche biology and computational biology (MRC Capital Award: Computational and Chemical Biology of the Stem Cell Niche, CCBN). Senior fellowships awarded within this research theme including MRC Senior Clinical Fellowship (**Mole**, £3.2m), NHS Research Scotland/Universities Senior Clinical Fellowship (**Fallowfield**, £0.4m), Wellcome Trust Intermediate Clinical Fellowships (**Baillie** (£1m), **Bird** (£0.9m), **Ferenbach** (£1.2m)), Wellcome Trust Senior Research Fellowships in Clinical Science (**Henderson** (£1.8m), **Walmsley** (£1.8m)), Wellcome Trust Senior Research Fellowships in Basic Biomedical Science (**Wood**, £1.8m).

Our *regenerative medicine research* investigates tissue formation, homeostasis and repair: **Illingworth** demonstrated the importance of 3D chromatin structure in stem cells (Science 2014, Genes & Dev 2020). **Kaji** identified genes and signalling pathways required for cell fate change in the development of pluripotency (Cell Stem Cell 2014, 2017). **Emmerson** (Figure 4) has defined the essential role of the neuronal niche in salivary gland development and regeneration (eLife 2017, EMBO Mol Med 2018, Development 2017). **Becker** has identified Wnt and Tnf signalling as potential

therapeutic targets for spinal cord regeneration in zebrafish (Development 2016, Nature Comms 2017, 2018).

Disease modelling and regenerative therapy development are a major focus: **A. Williams** utilises single cell genomics to elucidate the heterogeneity of oligodendroglia and mechanisms of remyelination in mouse and human brain (Nat Neurosci 2017, 2019, Sci Transl Med 2018, Nat Med 2018, Nat 2019). **Schumacher** uses computational biology to model and predict tissue regeneration at the cellular level. (Nat Cell Biol 2019). **Forrester** uses human pluripotent stem cell derived macrophages to model the human haematopoietic stem cell niche, identifying new strategies for red blood cell production (Nat Commun 2019, Blood 2020). **St. Forbes** elucidates mechanisms controlling regeneration in the damaged liver to identify therapeutic targets, (Nat Cell Biol 2015, 2019, Nat 2017, Sci Transl Med 2018) and has developed macrophage cell therapy from bench to Phase 1/2 clinical trials (Nat Med 2019).

Our *inflammation research* investigates the role of innate immune cells in tissue repair: **Dzierzak** defined cellular and molecular controls of the haemopoietic stem cell niche (Nat Commun. 2015, J Exp Med 2015, 2018, Immunity 2019). **Henderson** with **Ramachandran** studied human tissue injury using single-cell RNA sequencing and mouse in vivo genetic knockout approaches to explore the pathogenesis of fibrosis (Nat Commun 2016, Nature 2019, 2020). **W. Wood** used Drosophila to understand inflammatory cell migration and signal integration in tissue damage (Cell 2016, 2017, Dev Cell 2018, Current Biol 2014, 2020). **Saunders** has used the endometrium as a model of scarless tissue repair defining immune cell phenotypes in inflammation and regeneration (FASEB J 2016, 2019). **Anderton** has studied T, B and innate lymphoid cell controls, anti-tumour immunity and peptide immunotherapy (Nat 2014, Science 2016, Cell 2015, Immunity 2016). **Jenkins** and **Bain** have defined the biology of mucosal surface and cavity macrophages in health and disease (Nat Commun 2016, Sci Immunol 2020).

In work exploring the links between cellular and non-cellular mediators of inflammation, **Walmsley** and **Whyte** demonstrated the importance of oxygen and metabolite sensing pathways in regulating neutrophilic inflammation (Science Immunol 2017, Cell Metab 2020). **Walmsley** has defined how the metabolic response of neutrophils programs their behaviour in injured tissue (J Clin Invest 2017, 2020). **Rossi** and **Lucas** investigate how dying immune cells promote inflammation resolution, indicating potential therapeutic regenerative strategies (Am J Respir Crit Care Med 2015). **Cash** has developed models that identify inflammatory mechanisms influencing skin wound repair (EMBO J 2018, Current Biol 2014). **M. Gray** studies mitochondria and the pro-inflammatory effects of cell death upon macrophage activation in rheumatoid arthritis (Proc Natl Acad Sci USA 2016). **Yao** has described lipid regulators of inflammation, especially prostaglandins and their receptors, in immune and epithelial cell function (Science 2016).

We are developing *novel diagnostics and therapies for inflammatory diseases*. **Dhaliwal**, **Haslett** and **Akram** have developed *in situ* optical approaches to image lung infection and fibrosis (Sci Transl Med 2018). **Vendrell** developed novel fluorescent probes to identify apoptosis, infection and metabolites in situ (Nat Commun 2016, 2020). **Mole** described Kynurenine–3–monooxygenase as a mediator of multi-organ failure in acute pancreatitis and therapeutic target (Nat Med 2016). **Fallowfield** defined the role of relaxin in liver cirrhosis induced portal hypertension and renal disease and took drugs targeting this to Phase 2 trial (PLoS Med 2017).

Exploring the link between *regeneration and cancer*, **Serrels** elucidated the regulation of CD8 effector T-cell responses in pancreatic cancer, especially the role of focal adhesion kinase (FAK) (Cell 2015, Nat Cell Biol 2014). **Feng** has used zebrafish models to investigate the tumour initiating effects of inflammation (EMBO J 2015), while **Gregory's** work has revealed the oncogenic response of macrophages and extracellular vesicles to dying tumour cells (Current Biol 2015). **Hansen** has studied the Hippo pathway in tumours and tissue regeneration, describing links between the immune and mechanotransduction systems (Nat Cell Biol 2015 Current Biol 2019).

The role of stem cells in cancer development and therapy is investigated in collaboration with CRUK EC: **S. Pollard** has developed genome engineering tools to study the role of neural stem cells in glioblastoma development (Genes & Dev 2017, eLIFE 2016). **Ottersbach** has defined roles of

haematopoietic stem cell development and childhood leukaemia (Sci Rep 2019). **Guest** has identified a cell of origin and mechanistic drivers of cholangiocarcinoma (Cancer Res. 2014, Proc Natl Acad Sci USA 2016).

Cardiometabolic: 68 UoA1 Staff Returned

Our Centre for Cardiovascular Science (CCVS, Director: **Baker**), which had its BHF Centre for Research Excellence status renewed in 2019 (£3m) and was awarded the Queen's Anniversary Prize (2014-16), nucleates this research theme. BHF Centre funding for Vascular Regeneration was renewed 2017 (£2.5m). **Newby** (£1.8m) and **Baker** (£1.8m) have both renewed their BHF Chairs and **Dweck** was awarded a BHF Intermediate Clinical Fellowship (£0.9m). A Wellcome Trust Senior Research Fellowship in Clinical Science was awarded to **Semple** (£1.8m); **Denby** was awarded a KRUK Senior Fellowship (non-clinical, £0.5m).

Improved diagnosis and novel therapy development for cardiovascular disease is a major research focus. **Miller**, **Mills** and **Newby** demonstrated the adverse cardiovascular effects of air pollution (*UoA1 ICS/A*); their findings have driven policy change at local, national and international government level (Lancet 2013). In work on myocardial infarction, they also determined the optimal thresholds of cardiac troponin concentration for diagnosing infarction and defined early rule-out pathways resulting in faster and more accurate diagnosis, saving NHS resources (BMJ 2017, Lancet 2018, NEJM 2019). In parallel, **Newby** and **Mills** have developed novel cardiometabolic imaging techniques to improve diagnosis and aid development of future therapies and have published a large portfolio of work including multicentre randomised controlled trials (SCOT-HEART) in computed tomography positron emission tomography and magnetic resonance imaging (Lancet 2014, NEJM 2018, JACC 2019). **Baker** has developed RNA-, gene- and cell-based therapies for vascular disease including first-in-human approaches (JACC 2015, Circulation 2016, Circ Res 2019). **Brittan** (Figure 5) discovered novel targets modulating cardiac neovascularisation by resident endothelial cells following myocardial infarction and identified the vascular origin of endothelial progenitor cells (EHJ 2019, Circulation 2019).

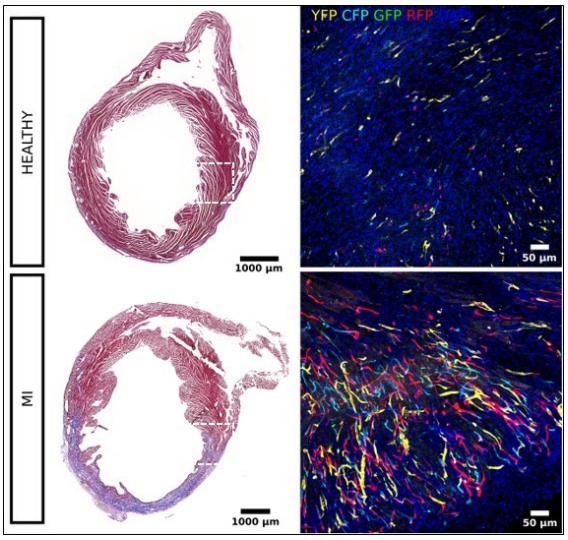

Figure 5: Cell lineage tracing during vascular injury and repair: A multispectral lineage-tracing 'Confetti' mouse model, which expresses 1 of 4 fluorescent proteins (GFP, RFP, YFP, CFP) specifically in vascular endothelial cells (Brittan)

Our *metabolism, obesity and diabetes* theme examines risk factors for cardiometabolic diseases. **Reynolds** has elucidated the effect of metformin on maternal and fetal outcomes in obese pregnant women (Lancet Diabetes & Endo 2015). **Stimson** has defined the regulation of metabolic activity of human brown adipose tissue (Cell Metabolism 2016, 2018). **Andrew** led a population-based cohort study in incidence of type 2 diabetes mellitus in men receiving steroid 5α-reductase inhibitors (BMJ 2019). **Benezech** has studied the role of iNKT cells and the lymphoid structures within visceral adipose tissue in the control of inflammation and obesity (Nat Commun 2016). **Cawthorn** analysed how bone marrow adiposity impacts human metabolism (Cell Metabolism 2014, Nat Commun 2015, 2020). **Morton** identified thiosulfate sulfurtransferase as an adipocyte-expressed antidiabetic target in mice selected for leanness (Nat Med 2016). **Minchin** has developed high-throughput in vivo profiling of candidate human obesity genes in zebrafish (Cell. 2019). **Sh. Forbes** is lead of the Scottish Islet Transplantation Service and is developing methods to optimise islet transplantation (Science Trans Med 2020). In work on renal disease, **Bailey** has defined the activation of the endothelin system in transition of acute kidney injury to chronic kidney disease (Circulation 2016). **Dhaun** identified a novel role for myeloid endothelin-B receptors in hypertension (EHJ 2019) and

Webb described the endocrine and haemodynamic changes in resistant hypertension, and determined its optimal therapy (Lancet 2016).

Addressing a major global need within metabolic medicine, **Dear**, **Eddleston** and **Webb** developed a *toxicology research programme* and, having validated a shorter treatment of acetylcysteine for paracetamol overdose patients which reduces adverse drug reactions and can save NHS resource (Lancet 2014, returned in REF2014) (*UoA1 ICS/I*), further stratified risk after paracetamol overdose using mechanistic biomarkers (Lancet Gastroenterology and Hepatology 2018). **Eddleston** is studying strategies to prevent pesticide self-poisoning in rural Asia using randomised trials (Lancet 2017) (*UoA1 ICS/K*) and has helped to determine risk factors for suicide and self-harm (Lancet Psychiatry 2019).

Reproductive Health: 28 UoA1 Staff Returned

Our MRC Centre for Reproductive Health (MRC CRH, Director: **J. Pollard**), which had its MRC core grant renewed for a second five-year term in 2016 (£2.3m), nucleates this research theme. The Edinburgh Tommy's Centre for Maternal and Fetal Health (£3.1m Director: **Denison**) is based within MRC CRH and works on the major clinical challenges of preterm birth, stillbirth, and the impacts of maternal obesity, depression and stress. A Wellcome Trust Intermediate Clinical Fellowship was awarded to **Stock** (£1.1m).

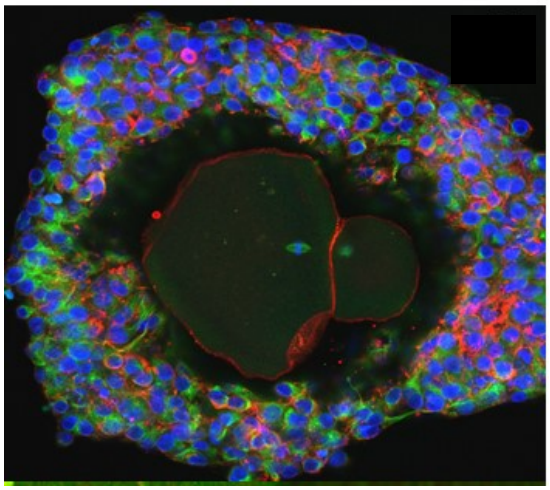

Figure 6: Understanding human germ cell development: A Human MII oocyte derived from in vitro culture (Anderson)

Reproductive resilience, repair and preservation is a key focus. In work on heavy menstrual bleeding (HMB), which is common and debilitating for women, **Critchley** and **Saunders** refined a mouse model of simulated menses (Sci Rep 2017), which models human menstrual bleeding and supports translational studies. **Maybin** and **Critchley** have described physiological endometrial hypoxia during menstrual bleeding and shown that women with HMB have decreased endometrial HI-1α during menstruation (Nat Commun 2018). **Horne** found that women with endometriosis have peritoneal mesothelial cells with an abnormal metabolic profile (JCEM 2014, PNAS 2019), leading to an ongoing phase II clinical trial (EPiC) and led a major trial of gabapentin for pelvic pain (Lancet 2020). In work on preservation after chemotherapy, **Mitchell** established a clinical and research programme for fertility preservation in pre-pubertal males (Cell Reports 2018), complementing the established ovarian cryopreservation programme run by **Anderson**, which achieved the first UK pregnancy after ovarian tissue transplantation and which has informed and led the European Society of Human Reproduction and Embryology guidelines (Figure 6).

In studies of *germ cell development and pregnancy*, **Anderson** identified novel targets of the RNA binding proteins DAZL and BOLL in human ovarian development and identified roles in primordial follicle formation (FASEBJ 2019). **N. Gray** has shown mechanistic roles for poly A binding proteins in germ cells (PNAS 2016, 2017). **Lin** has shown the mechanisms behind transcriptional activation in the early embryo (Cell 2018). **Mitchell** has developed xenograft models to show how commonly-used drugs affect testosterone production (Science Trans Med 2015). **Horne's** research into ectopic pregnancy has led to a Phase II study of gefitinib (epidermal growth factor receptor inhibitor) with methotrexate as a new strategy to treat ectopic pregnancies (Ebiomedicine 2018). Computational magnetic imaging studies by **Boardman** have shown how brain development is impacted by preterm birth, and identified genetic and environmental exposures that modify risk (eLife 2020, JAMA Network Open 2019, NeuroImage 2019). Miron (UoA4) and **J. Pollard** have shown that brain macrophages (microglia) are essential for brain remyelination after injury due to pre-term birth (Nat Neurosci 2019). **Stock** has demonstrated that the timing and mode of delivery have long-term

consequences for mother and baby, affecting neurocognitive, respiratory and metabolic outcomes (PLoS Med 2018)**. Norman** has shown in multicentre clinical trials that progesterone does not reduce risk in pre-term birth, also changing guidelines (NEJM 2019), and that awareness of foetal movement did not reduce risks of stillbirths (Lancet 2018).

In work linking with the Cancer and Regeneration themes above, work on *reproductive system cancers* by **J. Pollard** has pioneered studies of tumour associated macrophages and has described roles in metastasis (JEM 2015, Nat Cell Biol 2019) and inhibition of chemotherapeutic efficacy (Cancer Res 2015). Several of these studies have been translated into human endometrial and breast cancer therapeutic targets (Cancer Cell 2019).

Infection Medicine: 15 UoA1 Staff Returned

Prior to the COVID-19 pandemic, our research in infection medicine focused on host-pathogen interactions with the development of a core funded Centre being an important strategic goal. In work examining pathogens, **Schneiders** has described intrinsic mechanisms of antibiotic resistance, fitness and survival in Gram-negative bacteria (Nat Commun 2018), **Scortti** has identified molecular determinants of bacterial virulence (PLoS Genet 2018, Cell Rep 2019), **Bachmann** has developed strategies for rapid point-of care detection of anti-microbial resistance, bacteria and biomarkers to guide antimicrobial therapy and combat resistance (Biosens Bioelectron 2016) and **Welburn** (Figure 7) has identified the interactions between parasites and their vectors and hosts that lead to transmission of human sleeping sickness (PLoS Neglected Tropical Diseases 2016). Parallel work on host responses focuses on the role of immune cells in infection. **Dockrell** is working to recalibrate the alveolar macrophage antimicrobial responses he has described to combat anti-microbial resistance (Am J Respir Crit Care Med 2018, 2019), and **Bogaert** has described the roles of the microbiome, (epi)genetics and host immunity in the pathogenesis of paediatric respiratory infections (Lancet Respir Med 2019, 2020; Am J Respir Crit Care Med 2017).

Figure 7: Promoting Global Health: Cattle being sprayed to kill parasites to reduce human sleeping sickness (Welburn)

COVID-19 Research

These and other Edinburgh Medicine researchers reacted quickly to the COVID-19 pandemic and were able to rapidly pivot research, capturing research resources as a result of existing multi-disciplinary networks and close collaborations, and contributing crucial data in real-time as the pandemic has evolved.

Epidemiology. **Sheikh** and **Mills** are tracking the progress of the COVID-19 epidemic in near real time, using longitudinal healthcare records of 1.2 million people in Scotland to form a more complete picture of the effect COVID-19 is having upon people's health (HDR Breathe Hub). **Swann** and **Harrison** reported the clinical characteristics of children and young people admitted to hospital with COVID-19 in the UK (BMJ 2020). **Colhoun** is exploring the epidemiology of COVID-19 disease in diabetes. **Figueroa** is exploring the impact of COVID-19 on health services in rural Kenya. **Nair** is exploring the impact of COVID-19 on rural communities in South Africa by building on the existing population-clinic linkage in rural north-east South Africa (GCRF funded) with a focus on health

outcomes stratified by presence or absence of co-morbid chronic conditions such as HIV/AIDS, TB, cardiovascular and metabolic disease.

Genetics. **Baillie** is lead PI of GenOMICC, (£28m), the largest study in the world of its kind comprising of an open, collaborative, global community of clinicians and scientists trying to understand and treat critical illness. Partners have been recruiting patients since 2016 to study emerging infections (SARS/MERS/Flu) and adapted very quickly to respond to the COVID-19 pandemic leading to a milestone publication on genetic mechanisms of critical illness due to COVID-19 (Nature 2020). Coronagenes (**Wilson** and **Tenesa**) will recruit and follow the general population during the coronavirus pandemic through an existing online e-recruitment platform; the aim is to capture the self-reported longitudinal phenotypes of those who suffer a COVID-19 infection but that do not require medical intervention (complementing the GenOMICC study). **Schneiders** is investigating the role of bacterial co-infection in severe pneumonia-like disease in COVID-19 patients using a genomics approach in a multi-centre study in the UK and India. **Ponting** is analysing genetic and omic data, derived from COVID-19 patients in NHS intensive care units, to better understand host, virus and host-virus factors that alter outcomes from infection (medRXiv 2020).

Pathobiology. **Baillie** also leads, with **Docherty** and **Harrison**, the ISARIC-4C (£6m) Coronavirus Clinical Characterisation Consortium (BMJ 2020, Am J Respir Crit Care Med 2020). **Michlewski** has implicated TRIM25 as an essential RNA-binding protein in sensing and inhibiting the virus, pivoting a BBSRC funded project focused on influenza A. **Dockrell** is profiling the inflammatory cascade of COVID-19 to elucidate the peripheral blood signature mediators in four patient groups: community, at hospital admission, rapidly deteriorating, ventilated critically ill. **Dorward** has set up a rapid COVID-19 post-mortem study to describe the histological and molecular changes occurring in fatal COVID-19 infection (medRXiv 2020). **Ferenbach** is investigating the role of epithelial senescence on fibrosis and outcome after COVID-19 infection (£523k). **R. Gray** is studying the role of Neutrophil Extracellular Traps (NETs) in COVID-19 Pneumonia.

Diagnosis. IGMM scientists, laboratory space and equipment have supported NHS Lothian's testing efforts to combat the COVID-19 pandemic. A pool of 25 scientists (selected from >750 volunteers) delivered up to 1000 tests per day during the outbreak. Looking to next-generation testing, **Bachmann** is researching a molecular diagnostic of SARS-CoV-2 for community point of care infection testing with an industry partner, and **Gilbert** is developing a second-generation serology test for stratifying patients into groups corresponding to whether the patient has been infected with SARS-CoV-2, characteristics of immune response and prognosis for future resistance to disease (medRXiv 2020).

Clinical investigations. Our clinician scientists within CCVS are utilising advanced clinical imaging to detail the impact of COVID-19. **Newby** is examining the association between COVID-19 and thromboembolic disease using 18F-GP1 PET-CT and deploying the approved protocols of the iThrombus study. **Singh** and **Newby** are using gadolinium and manganese-enhanced MRI combined with CT coronary angiography to assess the mechanisms and direct impact of myocardial injury in patients who are recovering from COVID-19 infection. **Tavares** is using autoradiography techniques and microPET/CT techniques with 18F-GP1, a biomarker of blood clots, to study how COVID-19 triggers pulmonary thrombosis. **M. Williams** is using machine learning to classify features of COVID-19 on chest CT scans. **Dweck** is investigating COVID-19 effects on the heart and has found in a global study that almost half of Covid-19 patients who have been hospitalised had heart scan abnormalities resembling the early stages of heart failure (Eur Heart J Cardiovasc Imaging 2020).

Treatments. **Haas** and Tait-Burkard (returned UoA6) are testing a selected set of FDA-approved small molecule inhibitors and biologicals for antiviral activity against SARS-CoV2 and is also performing a genome-wide siRNA knockdown screen for host factors affecting SARS-CoV2 replication as part of the €77.7m IMI-2 CARE consortium. Drug inhibitors of the identified host factors will be tested for SARS-CoV2 inhibition. **Dhaliwal** is leading STOPCOVID-19 (£2m LifeArc): a team of 150 respiratory physicians and scientists testing existing and experimental drugs to find a treatment. **Sheikh** is investigating hypertonic saline nasal irrigation and gargling with hypertonic

saline for suspected or confirmed COVID-19 using a pragmatic web-based Bayesian adaptive randomised controlled trial (ELVIS COVID-19). **Ball** is determining if IFNA14 (a non-canonical subtype of IFNA) has therapeutic potential in COVID-19 patients.

1.4 Approach To Impact

Over the past decade, there has been a significant culture shift in the Edinburgh Medicine translational research environment. To address a paucity of translational activity, an Entrepreneur-in Residence was appointed (Dr Howard Marriage, 2009, MRC funded). As a result of an initial increase in translational activities, the infrastructure was further improved in 2011 by recruiting a wider team of industrialists with commercialisation experience and a proven track record in translating research outputs. This commercialisation team focused on increasing industrial collaborations as well as company creation by implementing targeted best practice translational business models. This strategic venture successfully increased translational and commercialisation activity within the Edinburgh Medicine Institutes: over 50% of academic staff are now engaged/interested in translational research. The Edinburgh Medicine commercialisation team are now embedded into Edinburgh Innovations (EI), the University of Edinburgh technology transfer office, to ensure that a streamlined professional service is offered to Edinburgh Medicine academics interested in translational activities.

A further transformational decision was to create a “CMVM Translation and Commercialisation Board" (TCB, led by **Carragher**) in 2018 to further increase the percentage of translationally active investigators and researchers and to facilitate translation of excellent clinical and veterinary research into impactful contributions to patients, animal welfare, food production and society. The TCB initially identified barriers to translation and commercialisation and are working on ways to overcome these through funding diversification, improving education and culture, continuing to develop partnerships, improving communications, promoting translational areas of excellence and exploiting our enterprise and facilities.

Our strategy to impact involves investment in support infrastructure, strategic funding schemes and the recruitment of dedicated research support officers, translators/entrepreneurs in residence and public engagement with research leads, alongside the embedding of impact into our research culture by its inclusion as a metric of success in the annual review process of Edinburgh Medicine investigators.

Infrastructure

Our philosophy of creating the physical infrastructure required to bring together the NHS and University on our two campuses promotes translational research, and we encourage this further by locating newly-formed spins-outs (e.g. Cellinta) within our Institutes or in dedicated bioIncubator space on the same campus. To catalyse this translation we have built up four supporting organisations, coordinated by the TCB, each described in Section 3; Edinburgh Innovations, driving commercial collaborations and the technology transfer office; Edinburgh Research Office (ERO), responsible for grant management; the Edinburgh Clinical Trials Unit and the joint UoE/NHS Lothian R&D support office (Academic and Clinical Central Office for Research and Development; ACCORD) enabling and overseeing clinical trial activity.

Strategic Funding

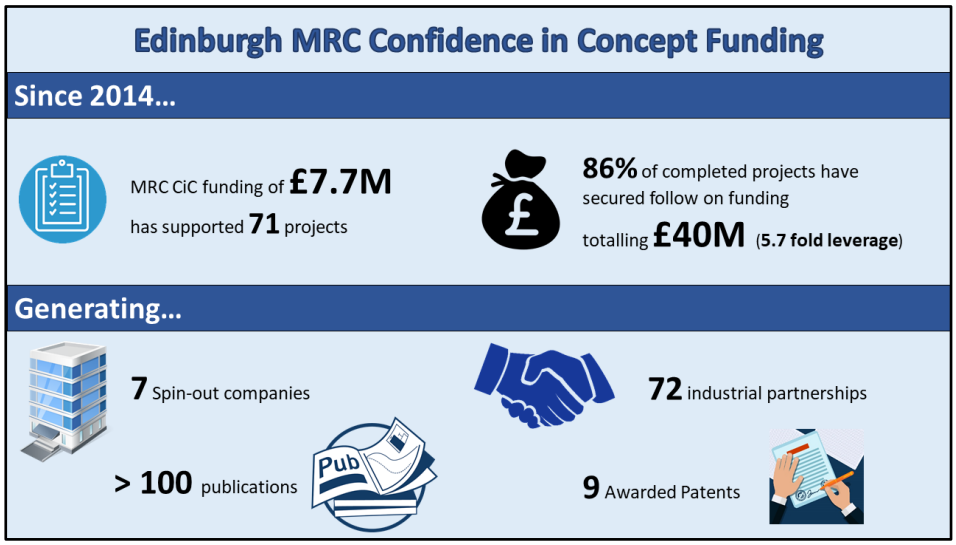

Figure 8: Outputs 2013-2020 from Edinburgh Medicine MRC CIC Awards

Four strategic funding schemes enable our investigators to develop impact. The £7.7m **MRC Confidence in Concept** (CiC) funding (the success of which is shown in Figure 8) has been awarded to Edinburgh Medicine each year since 2013. We have also secured **MRC Proximity to Discovery** funding each year since 2014 (£700k). This is used to promote academic and industry interactions and funds activities such as quarterly Drug Discovery Club symposia, 'Horizons' conferences, postdoctoral career support and staff exchanges with industry. The £12.75m **Wellcome Institutional Strategic Support Fund** (ISSF) (£2m WT, £2m UoE; 2014-2016; £3.75m WT, £5m UoE; 2016-2021) supports the strategic priorities of the University in biomedical sciences including commercial and translation and; public engagement.

A key innovation was the use of the fund to support a *Translator in Residence* role to project manage and support awardees towards commercial/translation outcomes. ISSF also funds a pilot programme to integrate an additional one year 'Engagement for Impact' training into a current PhD programme, so as to establish a culture shift and enable newly graduated PhDs to better engage with audiences beyond the academic world and become the next generation of commercial scientific leaders and policy makers. Evidencing success of the ISSF, awardees have leveraged £112m in additional funding, secured 106 external awards and 31 fellowships. It has led directly to impact: **Sh. Forbes** (CCVS) was awarded ISSF funding to develop a software tool to track the function of islet transplants in patients with type 1 diabetes – the BETA-2 score. The majority of islet transplant programmes globally now use this score (*UoA1 ICS/B*). The funding strategy is also nimble, in 2020 we earmarked £120k to support postdoctoral/research assistants on Covid-19 delayed projects and directed £300k to support COVID-19 research projects.

In 2018 UoE was awarded funding (£1.2m, renewed £2.4m 2020-23) for a **Wellcome Institutional Translation Partnership Award** (iTPA). The Wellcome iTPA team has enabled Edinburgh Innovations to better engage with Wellcome Trust funded researchers to identify and develop early stage translational opportunities. The team includes two Entrepreneurs in Residence embedded within our research structure (a model we have used since 2006 (as detailed in Section 1) and now widely adopted by others) with a successful commercial/translational background required to identify and then nurture projects towards translation through leveraging future funding, industry collaborations or commercialisation. This provides support to ~320 researchers during the funding period, increasing engagement with translation by 260%. The program has built an early stage funding pathway for 57 funded projects: 68% of the projects involve early career researchers new to translation; 54% of the projects are cross-disciplinary, and 49% involve collaborators including the NHS and industry. These projects have resulted in: 1 industry secondment; 16 invention disclosures; 5 patent applications; 3 licences (4 opportunities); and leveraged £24.6m further grant funding.

Support for Impact

Our *dedicated impact research support officers* include 2 CMVM Impact Officers (open-ended contracts, 1.9 FTE). Through proactive engagement with our academics, the Impact Officers facilitate and support research outputs that have the potential to impact national and global communities. A specific example is the Health and Ethnicity Linkage study (SHELS, **Bhopal** and **Sheikh**, Usher, 2003-2017) which demonstrated striking differences in health risk factors and outcomes between ethnic groups: this impacted on the Scottish Government's Racial Equality Action Plan (2017). Another is the worldwide uptake of the EQUitable Impact Sensitive Tool (EQUIST, **Rudan**, Usher) which was developed at UNICEF's request, for designing and delivering equitable healthcare improvement programmes in low-and-middle-income countries. The Impact Officers instigated a meeting between **Rudan** and key stakeholders from UNICEF and World Bank to map the global uptake of the EQUIST, reinforcing each stakeholder's commitment to EQUIST (*UoA1 ICS/ F*). Developing future impact is a key goal, for example the Officers are working closely with **Campbell** and NHS Consultant Clinical Scientist, (Cubie) on a preventative cervical cancer treatment in Malawi which has now screened 30,000 women (previously unscreened), treating 90% of those with early lesions on the same day and reducing cervical cancer cases by 6% in one clinic over 5 years (Int J Cancer 2016).

The Impact Officers also sit on the TCB to input to new initiatives, learn of emerging innovations and facilitate subsequent policy and practice impacts; this underlines our commitment to streamlined and joined-up processes for maximising impact from research and innovation successes.

Public Engagement with Research

Edinburgh Medicine uses *Public Engagement with Research* (PEwR) in many ways; to reveal knowledge, inspire interest, listen to new perspectives, consult people with lived experience, build trust in new technologies, collaborate and co-create research. Edinburgh Medicine employs a PEwR Manager (Lambert) to set strategic direction and enhance support for both engagement professionals and research staff. Lambert leads an active "engagement with research" forum with >70 members. She coordinates 15 other "engagement with research" posts (0.2 FTE to full time) across CMVM; this thriving PEwR community delivers and supports areas from outreach to involvement.

Figure 9: Edinburgh Medicine Public Engagement with Research strategy

In 2019, Lambert developed a strategy for PEwR in consultation with staff and students that can be adapted across research disciplines, funding and skill levels (Figure 9). Our approach aims to reveal, involve and embed underpinned by the principles of training, evaluation and partnership. It builds on the strength of outreach and community engagement work achieved since 2013.

Reveal: sharing our research.

Involve: asking the people we are trying to reach how we should shape our messages and activities.

Embed: making engagement a natural part of research activity.

An example of the impact of our public engagement with research is "Save a Life for Scotland" (2015–ongoing) which aims to increase survival of people undergoing "out of hospital cardiac arrest". **Clegg** (IRR) engaged policy makers, health practitioners and a range of public audiences from school pupils to shoppers. He researched barriers to cardiopulmonary resuscitation (CPR) and

delivered training to upskill whole communities. Over 200,000 people in Scotland are "CPR ready" as a result (*UoA1 ICS/J*).

Embedding Impact into our Research Culture

Finally, we have embedded impact into Edinburgh Medicine research culture by systematically reviewing metrics of activity during the annual review process in 5 categories: (1) practice and practitioners; (2) policy; (3) commercialisation and translation; (4) public, community and patient engagement; (5) education. Edinburgh Medicine staff can then be rewarded for achieving impact related to research outputs. An example of this is the SNAP clinical trial led by **Dear** (CCVS), which led to revisions of the national protocol for treating paracetamol overdose so as to produce fewer adverse side effects (*UoA1 ICS/I*). This impact was highlighted during the annual review meeting of **Dear** and was central to his promotion to Personal Chair of Clinical Pharmacology.

1.5 Integrity And Open Ethical Research

Research Integrity

The University of Edinburgh is committed to ensuring the highest level of research integrity and governance and this is firmly embedded in the University's ethos and culture. Institutional policies, and therefore those of Edinburgh Medicine, regarding research integrity and open research are covered in detail in the Ref5a submission.

A key step in enhancing research integrity was the appointment of MacLeod (UoA4) as Institutional Academic Lead for Research Improvement and Research Integrity with one day per week dedicated to this activity. Macleod and **Sena** have established CAMARADES, a collaborative group that has pioneered meta-analysis and systematic review for the analysis of reproducibility in experimental animal studies. This has expanded to six global national coordinating centres, with Australia, Canada, Germany, the Netherlands and USA. Macleod and **Sena's** work has influenced major publishers, including Nature Publishing Group, to implement strict criteria for reporting study methods, and funding bodies to examine experimental design.

MacLeod also co-leads the UK Reproducibility Network (UKRN), a peer-led consortium that investigates the factors contributing to robust research, providing training and disseminating best practice, and working with stakeholders to ensure coordination of efforts across the sector. Under his leadership, there are two specific Edinburgh Medicine Research Improvement Group projects:

- Induction training materials related to in vivo experimentation: access to animal facilities across the UoE are linked to training compliance and current employees also have to comply with this training.
- Improved process for trial reporting on EuDRACT: implemented in partnership with UoE/NHSL Academic and Clinical Central Office for Research and Development (ACCORD). All studies sponsored by University of Edinburgh are mandated to register and openly report.

Ethical Research

Edinburgh Medicine spans clinical and non-clinical research, student projects and research involving the use of animals and biobanks. To ensure this research is ethical, we use robust research ethics review processes and policies. Thus, Edinburgh Medicine research involving animals must be approved by the UoE Animal Welfare and Ethical Review Body. UoE is continually seeking to improve best practice regarding animal usage and reporting and monitors this (e.g. reporting of randomisation), in recognition of which UoE was awarded in 2019 a Public Engagement Activity prize at the Understanding Animal Research awards. The NHS Research Ethics Committee fulfils a similar function for research involving human participants or human tissue. The Edinburgh Medicine Research Ethics Committee (EMREC) covers all non-clinical work requiring ethical review. A new ethics review software system Infonetica is being implemented across the institution.

Data sciences pose particular ethical challenges, and in partnership with NHS National Services Scotland, we have also developed a national safe haven with high performance computing capability

which complies with the ISO/IEC27001 information security standard. This infrastructure is networked to four regional safe havens and supports analysis of population-wide data allowing researchers to process sensitive data with the highest standards of security. UoE provides a comprehensive Research Data Service, which provides guidance and advice to clinical researchers on issues around the management of data including sensitive data related to patient information.

Open Science

The University is a strong advocate for Open Science, contributing to and adopting LERU's Roadmap for Open Science. Progress against the 41 recommendations are regularly reviewed by the UoE Research Policy Group. The University was early in its adoption of open access for publications, launching its first institutional repository in 2003 and growing strong rates of open access research since then. Our open access repositories are well used; there were 1.6 million downloads from our repository systems during 2019-20, an increase of 33% from 2018. Krzak (CMVM Professional Services) and Tate (UoE Library) published a case study of large scale implementation of a REF2021 open access compliance programme (Journal of EAHIL 2016).

Specific metrics of Edinburgh Medicine success in open science and reproducibility include:

- The Edinburgh Open Science Initiative driven by Edinburgh Medicine staff (**Cawthorn**, CCVS) and PhD Students (Thomas, CCVS) to promote open research and research integrity (Biochem 2020).
- Increasing use of electronic lab books with 56 research groups within Edinburgh Medicine now actively using the RSpace service. Staff also utilise Research Electronic Data Capture (RedCap) which supports clinical trials. The University's Data Research Service continue to promote these services to increase user uptake.
- Pius' (Senior Data Manager, Usher Institute) work on HealthyR Notebooks: democratising open and reproducible data analysis in resource-poor environments funded by the Wellcome Open Research Fund in 2018. **Harrison** and Pius have published a book, HealthyR: R for health data analysis, which is available free electronically and HealthyR courses are available in the University.
- **Sena** is the inaugural editor of BMJ Open Science.
- The Human Phenome project led by **Sudlow**, HDR UK Scotland, and Hemingway, HDR UK London, is developing an online open-access, standards-driven library of complex health and disease characteristics (phenotypes) from diverse health data. This will significantly reduce duplication of effort and will be essential to the delivery of health research at scale.
- The IUPHAR database (Guide of Pharmacology) established in Edinburgh in 2009 and managed by Davies, provides a free and global, comprehensive, searchable online database of pharmacological information.

1.6 Future Aims

Edinburgh Medicine will execute major strategic developments during the period of the next REF cycle so as to bring all medical education, research and innovations to our two core campuses by 2024. In addition to the construction of a new biomedical and medical school we will:

(1) Create a new Institute, the Brain and Body Institute, bringing together our neuroscience community with researchers in the BHF Centre for Cardiovascular Sciences. It is increasingly clear that the diseases of metabolism and of vessel function play a major role in initiating or prolonging diseases of the brain. The traditional separation between brain research and the rest of the body is inappropriate and misses vital research opportunities. This move, which will be completed by 2024, will create major new collaborative opportunities and research programmes in diseases such as stroke, dementia, multiple sclerosis and brain tumours.

(2) Deliver the medicine and healthcare strands in the transformation of Edinburgh into the "data capital of Europe" as envisioned by the £661m DDI component of the Edinburgh regional city deal

(£237m from Governments to UoE, 2018). We will expand our world leading expertise in data sciences by providing the infrastructure for the curation, maintenance and interrogation of real-world health data records and by doubling the size of the Usher Institute with a £68m new building.

(3) Expand the new £90.7m IRR complex by the addition of interdisciplinary activities in chemistry and imaging to create the largest single institute for regeneration globally.

(4) Build on the investment and interaction within Infection Medicine across Edinburgh that has spearheaded our response to COVID-19 to develop a core-funded Centre as part of IRR where growing strategic links with inflammation research can be exploited.

Underpinning these strategic developments, and recognising that it is our people that drive our success, Edinburgh Medicine will continue to develop and nurture a research culture that mainstreams equality, diversity and inclusion practices into our activities.

Section 2. People

Edinburgh Medicine is a vibrant and diverse community of 377 researchers (early career to senior), 460 postdoctoral researchers, 673 research students, which is supported by 668 technicians/facilities manager and professional services staff. All University of Edinburgh employees have a mandatory personal development and review meeting each year which provides dedicated time for employee and line manager to reflect on achievements, training and career development aspirations.

Our vitality, diversity and inclusion are evident:

- 47% research staff growth (377 researchers returned in REF2021)
- 38% of returned researchers are female
- Appointed 73 new Chairs (22 new, 51 promotions) since REF2014
- 40% of new Chair appoints and promotions are female
- 29 nationalities are represented in our community
- 77.7% of our returned researchers are on open ended or full tenure contracts

2.1 Staffing strategy

Our staffing strategy focuses on attracting, retaining and nurturing talented researchers who align with our core strategies. Equally important, we strive to recruit talented technical and professional services staff who underpin our aims and provide crucial support to the research community. At the root of our recruitment standard and current community is diversity while exercising equality and inclusion. In return, we offer a healthy research and working culture, while ensuring our staff are provided with training and support to allow them to achieve their career and personal goals.

The University is a signatory of the 'Concordat to Support the Career Development of Researchers' and we follow the three clear principles: Environment and Culture, Employment and Professional and Career Development as described in this section below.

2.2 Recruitment, promotions and career development

Of the 377 researchers returned (360 FTE, 47% increase since REF2014), 143 represent new recruitments to the University of Edinburgh; 60% of these are new Early Career Researchers (ECR) and in total 32% are female. 139 researchers have transitioned from a fixed term to an open ended contract.

Overall 37% of our researchers are at professorial level with 22 new Chairs appointed. Some notable examples of strategic recruitment at senior level include:

- **Baker** (QMRI/CCVS) who led renewal of British Heart Foundation core funding and enhanced gene therapy expertise into CMVM;
- **Morris** (Usher) was instrumental in setting up the Usher Institute and is inaugural Director of Health Data Research UK;
- **Tomlinson** (IGMM/ECRC) who leads CRUK EC has integrated oncology research across a variety of biomedical areas, including human patient cohorts and clinics, animal models of disease and biomathematics;
- **Whyte** (IRR/CIR) was recruited to strengthen both inflammation research and College leadership and is currently Head of CMVM;
- **Carragher** (IGMM/ECRC) originally recruited from AstraZeneca, was promoted to Personal Chair of Drug Discovery and currently leads our Translation and Commercialisation Board.

We promoted 51 researchers to established Chairs. Key to these promotions has been our prior long-term investment in supporting careers and enabling young scientists to address key strategic problems. For example:

- **Williams** is a clinician scientist working in regenerative medicine who was an Edinburgh clinical trainee then PhD student with Brophy (UoA4) and who, after postdoctoral training in

Paris, was supported for Wellcome Trust intermediate and CSO clinical fellowships before being appointed to her chair enabling her work applying single cell sequencing technologies to neuropathology;
- **Dhaliwal** was an Edinburgh clinical trainee who, during PhD studies in lung inflammation in the MRC CIR, developed the idea of using optical molecular imaging via bronchoscopy to diagnose and treat pulmonary disease. He was supported in this by **Haslett**, then Head of Centre, to enable the development of an EPSRC funded strategic partnership with chemists. Appointed first as a Senior Lecturer and now Chair, he leads a large translational group discovering novel biosensing approaches to disease.

Early career researchers account for 34% of our REF staff return. Of the 23 Chancellor's Fellows returned in REF2014, 12 are now on open-ended contracts in UoE. Some notable examples of ECR recruitment include:

- **Vallejos** (IGMM/HGU), a Turing Fellow who was recruited from the Alan Turing Institute and University College London, for her expertise in biomedical data science;
- **Stagg** (UI/CPHS), holds an MRC Career Development Fellowship and was recruited from the London School of Hygiene and Tropical Medicine, for her expertise in infectious disease epidemiology;
- **Cash** (IRR/CIR) was recruited for her expertise and interest in wound healing and her specialised intravital microscopy techniques. She is a Chancellor's Fellow and secured a Sir Henry Dale Fellowship which allowed her to establish her own lab in 2016;
- **Gammoh** (IGMM/ECRC) was recruited for her technology expertise in RCAS glioma mouse models, in vitro lipidation and autophagy assays. She is a Chancellor's Fellow and has secured a CRUK Career Development Fellowship.

We also use similar recruitment strategies for our Professional Services staff:

- Elliott (CMVM Registrar) was recruited from the MRC to provide expertise in operational leadership, ethics and research policy and funding.

Supporting Principal Investigators

To provide the essential skills in team leadership and strategic planning we provide mandatory training on managing their research group for Investigators at the time of appointment. The focus is on skills often not learnt during post-doctoral training e.g. people management, equality, diversity and inclusion training, recruitment, challenging conversations etc. As part of this research leader training for new Investigators, we specifically offer training to support female researchers to develop their skills and advance their careers at the University and beyond. 40 female Edinburgh Medicine employees (26 academic and 14 professional services staff) have participated in the external AURORA programme during the current REF period.

Once established, we offer two types of career support for our Investigators. First, we offer different levels of leadership and management programmes to cater for aspiring to senior leaders: the Edinburgh Manager and the Edinburgh Leader programmes. Given our focus on strategic gain in senior appointments we also provide a new 6-month Strategic Leadership in Research programme (UoE investment £400K, 2019-20) which has skilled 48 exceptional mid-career colleagues from across the University (16 from Edinburgh Medicine) to excel in challenge-led research environments and to equip them with the leadership skills, knowledge and behaviours required to win large-scale strategic funding.

Second, we provide bespoke support most commonly around grant applications and fellowships. The Institute of Academic Development, Edinburgh Research Office and Edinburgh Innovations together work closely with individual investigators to identify funding, partnership and engagement opportunities, bringing together any necessary teams to address these and provide expert support in completing those parts of an application requiring input outside the skill set of the investigator. Together with the Dean of Research and the CMVM College Research Office, this team provides a

powerful mechanism for career development by ensuring that opportunity, expertise and resource are matched in preparing high quality applications.

Expanding Skills and Personal Development

A one-stop-shop for staff and student skills training and career development is provided by the Institute of Academic Development (IAD, >30 FTEs). A comprehensive portfolio of free courses and workshops, napped against the UK's Researcher Development Framework, allows staff to evaluate their current skillset and plan their personal development. Workshops include 'Careers in academia', 'Academic progression: becoming a Professor', 'Research grant finance management', 'Mentoring', 'How to run a viva' as a career coaching with external STEM career instructors for researchers at key career transition stages. We are running a pilot career development scheme for clinical academics: activities include work shadowing and local mentorship from senior colleagues. In addition, IAD offers staff one-to-one consultations with a professional career advisor.

We have addressed the need for training in early translational engagement and project development, consultancy activities, industry engagement and collaboration, management of intellectual property and commercialisation support through licensing and company formation. We were awarded MRC Proximity to Discovery funding (£700k since 2014) to specifically support industrial engagement, knowledge transfer and translational training activities.

Since 2015, all staff are required to complete online 'Overcoming unconscious bias' and 'Equality and diversity' training: recruitment panels have an appropriate gender balance. Training is available to all staff with regards to: recruitment and interviewing; performance and development reviews; career development for early career researchers; managing parental/carer leave of staff; flexible working rights; study leave and opportunities; how to apply for promotions; and family friendly policies.

2.3 Early Career Researchers

The University of Edinburgh's Strategy 2030, commits us to being the UK's leading institution supporting the development of early career academic staff. Our investment in early career researcher excellence is demonstrated by the continuation of both our existing Edinburgh Medicine career development track programmes:

Edinburgh Clinical Academic Track (ECAT, Directors Whyte, Walmsley, Henderson, Gilbert, Jackson) The ECAT programme was established to support and mentor future clinician scientists with an emphasis on making our medically qualified and veterinary clinical academics competitive for next-level fellowships. Underpinned by continuous Wellcome Trust investment since 2007 (£5.5m 2007, £6.2m 2013 and £10.2m following 2017 renewal and supplements), ECAT allows the most promising clinicians to study for a PhD, embedded within UoE/NHS Education Scotland-funded Clinical Lectureships to provide a bespoke, comprehensive run-through clinical academic training programme. This is an interruption of clinical career e.g. a temporary step aside to allow full-time immersion in discovery research. We are able to facilitate this by the unique flexibility to allocate Clinical Lectureships to trainees in any clinical discipline. The ECAT programme has also led benefits for women who took the opportunity of a break from clinical work to be able to start or add to their family, without impacting clinical progression.

A total of 70 trainees have been appointed to the programme to date, and funding is in place for a further 7 in 2021. This "junior to consultant" research training has matched clinicians with excellent supervisors, including those outside a standard clinical pool, and attracted excellent applicants from a wide range of so-called "orphan" academic disciplines. The early cohorts of ECAT lecturers (23 individuals) have exited the programme and 14 now have intermediate fellowships or senior lectureship posts at UoE or elsewhere. This cohort includes **Baillie**, Anaesthetist (Member of SAGE COVID-19 Clinical Information Network, PI of GenOMMIC).

Our ECAT scheme has become an exemplar for clinical academic training in the UK devolved administrations, reflected in investment from the Welsh Assembly and Welsh Universities to establish a similar scheme (WCAT) and, in Ireland, the Wellcome – Health Research Board Irish Clinical

Academic Training (ICAT) Programme. Australia are also implementing the model as their MACH-Track programme.

The ECAT model also underpins our recent award, jointly with Glasgow, of a CRUK Clinical Academic Programme (3 CRTF and 4 MB PhD students annually). Furthermore, clinical PhD studentships aligned to ECAT have been leveraged from MRC (4 studentships) and CRUK (9 studentships). The award of *ad hoc* externally funded clinical PhD fellowships has been enhanced by ECAT. By July 2020, we had 59 non-ECAT clinicians in doctoral studies. The success of our structured approach to clinician scientist training is evidenced by the 30 Clinical Training Fellowships awarded during the current REF period.

We have further invested into training our clinical academics through strategic use of CMVM endowment funds and WT ISSF Funding, linking PhD programmes and *ad hoc* fellowship appointments. We provide career advice and mentorship from early days at medical school through academic foundation years, and core and specialist training (the ECAT website receives >1500 hits/month). Support is provided by a team of senior clinical academics and coordinated by a dedicated UoE-funded administrator.

Edinburgh Scientific Academic Track (ESAT, Directors: Bickmore and Dzierzak) is a sector-leading, carefully structured development programme of tenure track positions for early career scientific researchers, targeted to areas of strategic research priority. Selection onto ESAT is based on potential success; hence, there is the expectation of permanent appointment after a review at year four. Fellows join ESAT through their appointment either as Chancellor's Fellows (see REF5a) or by gaining nationally competitive career development fellowships (e.g. MRC Career Development Award, Royal Society/Wellcome Trust Sir Henry Dale Fellowship, CRUK Career Development Award, Kennedy Trust Senior Fellowship).

Since REF2014, we have appointed 60 Edinburgh Medicine early career scientific researchers into ESAT, 20 of whom have secured career development fellowships including: CRUK Career Development Fellowships; MRC Career Development Awards; Royal Society/Wellcome Trust Sir Henry Dale Fellowship; UKRI/Rutherford Innovation Fellowship.

We have invested £25.8m, an average commitment of £430k per appointee, representing salary support and start-up costs. Annual symposia and workshops are held to equip ESAT fellows with the skills to be the next generation of research leaders and include events dedicated to academic teaching, research integrity, media training and grant funding; these sessions are led by representatives from UKRI, Wellcome Trust, CRUK and ERC grant funding panels. ESAT fellows are also encouraged to network with their peers from across the University to stimulate collaborative interactions.

ESAT 'alumni' have already demonstrated exceptional research leadership qualities and include: **Marsh** (MRC CDA; RSE Patrick Neill Medal 2019/20, Lister Prize 2018; Science 2015; Cell 2016), **A. Wood** (SHDF; Genetics Society Balfour Lecturer 2018; Genes & Dev 2016; PLoS Biol 2018). ESAT fellows who have been promoted to permanent academic posts include **Mill** (Reader, MRC Programme grant, BSCB Women in Cell Biology Medal; eLife 2018), **Joshi** (Reader, Nat Commun 2017), **Theodoratou** (Chair of Cancer Epidemiology and Global Health, Gut 2109: Nat Commun 2019), **Nair** (Chair of Paediatric Infectious Diseases and Global Health, Lancet Global Health 2019).

2.4 Postdoctoral Researchers

Postdoctoral researchers (PDRAs) are at the heart of Edinburgh Medicine research. We are home to more than 460 PDRAs from 29 nations around the world, and are committed to providing them with an environment that enables them to thrive in Edinburgh as well as make the best-informed choices about the next stages of their career, whether in or beyond academia.

UoE is a signatory of the Concordat to support the Career Development of Researchers and IAD are working with the research community to embed our Concordat actions in core practices integrating career and skills development into the PDRA community. Specific training courses provided include: attracting research funding; public engagement; and writing research proposals. Edinburgh

Innovations also provides training in commercialisation for University staff engaged in translational activities. We also support PDRA career development by encouraging them to become Researcher Co-Investigators on projects, which allows them to provide significant intellectual input to grant writing and design. This is beneficial when applying for Fellowships and aids their transition to independence. Edinburgh Medicine also offer mock fellowship interviews for PDRAs who are pursuing an academic career path.

Support and development of this group is co-ordinated through the @EdMedECR initiative, which was established in 2017 and is led by **G. Gray**, Head of Medical School ECR Experience, who is seconded to IAD 1 day per week to develop this aspect. **Hadoke**, Director of Post-Graduate Student and Early Career Research Experience for CMVM has specific responsibility for developing support for our PDRAs and post-graduate experience. New arrivals are introduced to established PDRA-led societies to embed them in the wider local community: these societies offer social interactions, peer support networks, training opportunities and a forum to provide views and feedback on their research environment. Training in careers in and beyond academia with experiential presentations from alumni is provided: there is also an MRC Proximity to Discovery funded PDRA careers seminar series with a focus on career progression into industry/commercial organisations.

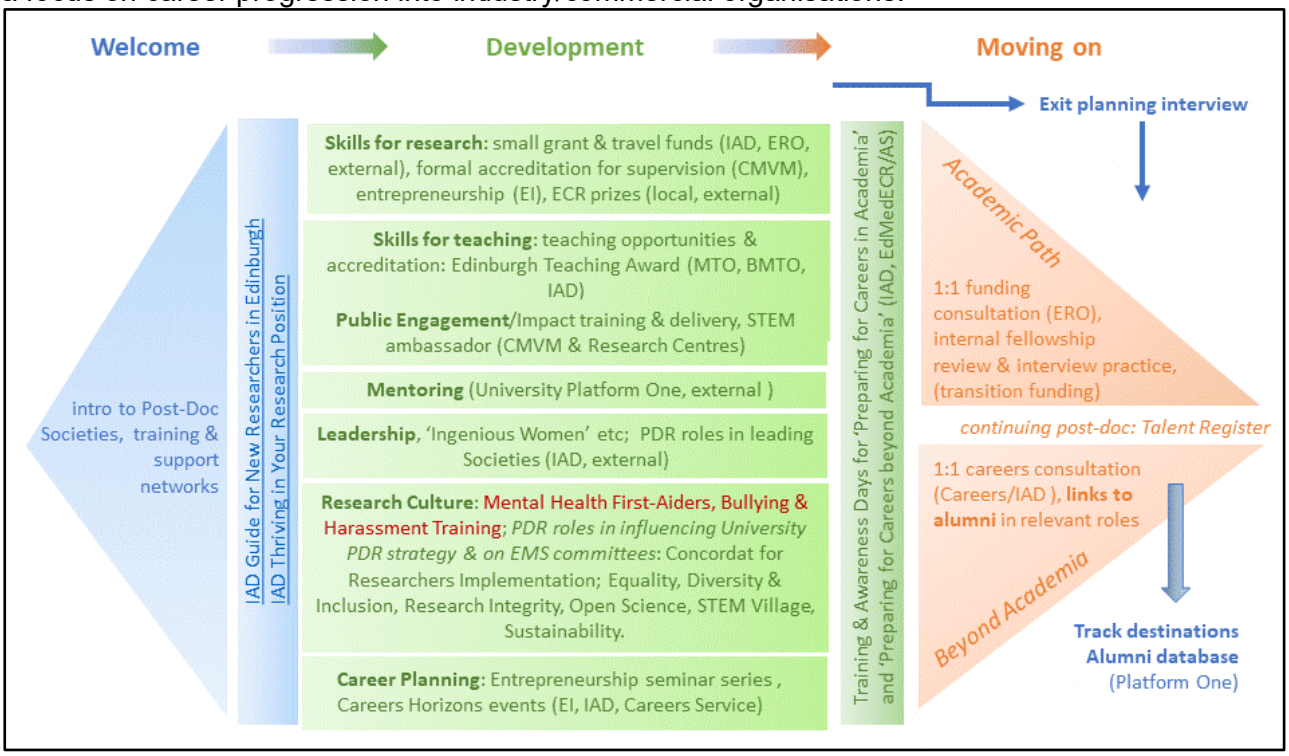

Figure 10: Edinburgh Medicine PDRA Development Strategy

The Edinburgh Medicine PDRA development strategy (Figure 10) is designed to ensure PDRAs are aware of the extensive Researcher Development programme offered by the University and beyond and to encourage early and continued engagement. PDRAs are embedded into well-established networks within the Centres/Institutes: Edinburgh Medicine also has several internal funding schemes (detailed in Section 3) that are particularly supportive for PDRAs and early career researchers including the Wellcome Trust iTPA and MRC Proximity to Discovery.

PDRA contribution is celebrated during international PostDoc Appreciation Week in September each year. The future plan is to recruit local PDRA champions and create a PDRA academy at the University of Edinburgh.

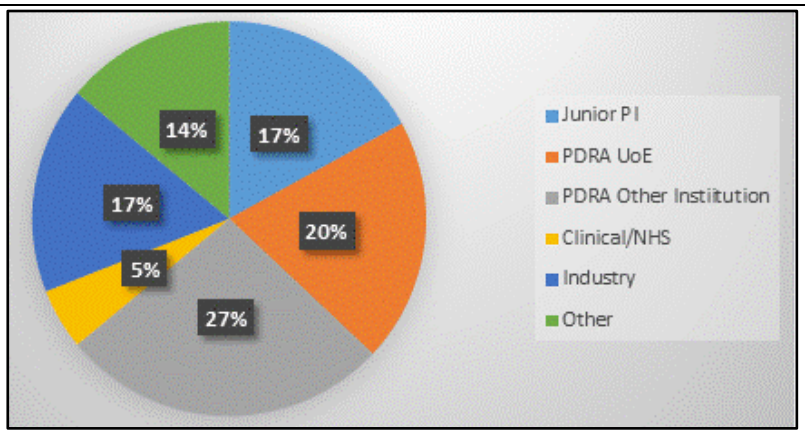

Figure 11: Edinburgh Medicine PDRA Destinations

Edinburgh Medicine PDRA success is evidenced by the award of independent fellowships and career progression to independent ECR positions (**Gwyer Findlay**, Royal Society Dorothy Hodgkin Fellowship; **Bain, Gibson**, SHDF; **Illingworth**, MRC CDA); and being named as inventors on patents (**Cassetta**; **Starkey-Lewis**). The career destinations of our PDRAs (Figure 11) stand in testament to the career development experienced here: the majority continue in scientific research, becoming the next generation of research leaders, while others opt to branch out to positions within the NHS, industry or other fields, reflecting the wide-ranging exposure to opportunities.

2.5 Technical Staff

Our technicians are key partners in the research enterprise and drive many innovations in Edinburgh Medicine. Our research excellence is underpinned by access to cutting-edge core technologies and facilities including imaging; genomics; proteomics; tissue culture; histology. The maintenance and use of these facilities, and the development of innovative strategies to address previously inaccessible research problems, is the responsibility of a highly skilled group of technical staff into our Institutes and Centres. It is essential that these staff know they are valued and feel appropriately rewarded and incentivised, and have in place a career structure that encourages ambition.

Edinburgh Medicine implemented a Fair Publication policy in 2020, which ensures that contributions from technical staff are acknowledged in publications.

UoE has also launched of a programme of Career Development Support for technicians. The University is a signatory to the Technician Commitment, recognising the role technicians play in research as well as teaching and supporting students. This is implemented through the IAD and includes funding to support the first year of professional registration; we also hold "Writing Retreats" to facilitate the application process for professional registration. Professional registration has been awarded to 16 Edinburgh Medicine Technical staff; 12 of these registrations are a result of the support fund created in 2019. A quarterly Technicians newsletter is produced to provide an update on events and opportunities across the University for technicians along with information on career development support and advice.

Edinburgh Medicine also funds a “Business Excellence for Facilities Management” certificated programme to support 10 core facility staff managers. The objective is to build business management skills and an opportunity for knowledge exchange across facilities and enable facilities managers to innovate in their role in order to enhance and develop services.

2.6 Professional Services Staff

Our research is also underpinned by a large and talented team of Professional Services (PS) staff embedded across the research institutes to provide specialist operational and strategic support for research activities. PS staff are vital for research development, data management, HR, project management, public engagement and communication, finance, governance, impact, translation/commercialisation, procurement as well as operations and logistics. PS staff are encouraged to participate in learning and career development opportunities including taught workshops (Aspiring Manager Development Programme) and online programmes (LinkedIn Learning). PS staff involved in research management and administration are provided with membership and encouraged to engage with the training and CPD offers of professional

organisations such as the Association of Research Manager and Administrators (ARMA) or Praxis Auril.

2.7 Research Students

Edinburgh Medicine attracts the highest calibre of scientific and clinical postgraduate (PG) students from a wide variety of backgrounds, and offers broad-based external programmatic support including the UK's third largest MRC Doctoral Training Programme (DTP), and two Wellcome Trust (WT)-funded programmes with contributions to several other Centres for Doctoral Training (CDT) including one of the UKRI Artificial Intelligence CDTs.

CMVM research training strategy has, since REF2014, strategically pivoted towards cross-centre, cross-college and cross-institution cohort-based training, in step with strategic objectives of the University and major PG research funders to promote broad cross disciplinary training.

Major cohort-based training programmes include:

- MRC Precision Medicine DTP (26 students pa, joint with the College of Science and Engineering, the University of Glasgow, and the Karolinska Institute)
- WT programmes:
    - Translational Neuroscience (7 students pa, 2014-)
    - Tissue Repair (7 students pa, 2014-19)
    - One Health Models of Disease (7 students pa, 2020-)

Increasing cross disciplinarity is also reflected in growing numbers of students within CMVM supported by cohort-based programmes based in the College of Science and Engineering, prominently including

- EastBio (BBSRC, 54 CMVM studentships since 2014
- PhD with Integrated Study in Advanced Care, a recently launched joint venture between Legal and General and the UoE
- OPTIMA (EPSRC & MRC; 23 CMVM studentships since 2014)
- CDT in Biomedical Artificial Intelligence (UKRI)

Our PhD programmes equip graduates with diverse skills applicable to careers in research, industry or allied sectors through bespoke generic training, industrial placements, integrated taught modules, and/or "real world" interactions with entrepreneurship and/or healthcare. We are committed to innovation in doctoral training, with a flexible PhD portfolio that includes several 4 year degree formats, including those with an initial rotational year; those with a "1+3" profile, the first year yielding an MSc; and, those in a novel 4 year format with a customised integrated taught component. This integrated approach was pioneered in Edinburgh Medicine in the Precision Medicine MRC DTP, and is now adopted by many other DTPs including WT Translational Neuroscience and One Health programmes. Another key area of innovation is the development of two new PhD programmes addressing societal needs not matched by conventional programmes: PhD programmes with Integrated Studies in Engagement for Impact or Advanced Care.

Our PG research student numbers have increased by 16% since REF2014. This growth has been driven by a combination of the new WT and MRC DTP awards as above and the success of our research themes in attracting notable new programmes including; Human Genetics and Genomics (MRC HGU; 8 students pa), Cardiovascular Biology (Centre for Cardiovascular Science; BHF; 6 students pa), Cancer Biology (Cancer Research Centre; CRUK; 2 students pa) and Biomedical AI (Usher Institute et al, UKRI; 12 students pa).

As mentioned previously, doctoral training for clinician scientists is delivered through the highly successful WT ECAT programme (5 medical and 2 veterinary studentships pa) as well as numerous personal UKRI and charity fellowships. The portfolio has been diversified with recent funding of the joint Edinburgh/Glasgow Train and Retain Academic Cancer Clinicians (TRACC) programme, which includes 4 MBPhD studentships as well as 2 clinical training fellowships per year, and Kennedy Trust MB PhD programme (TRAM, 4 MBPhD studentships pa).

Together with the MRC Precision Medicine DTP and the Edinburgh-Glasgow One Health PhD programme, the TRACC and TRAM programmes are the most recent example of successful joint working in doctoral training with the University of Glasgow. This is part of a wider strategy to use PhD programmes to develop collaborative training and research with international partners. Further examples include new university-wide funding of One Health (Leiden), Vascular Biology (Leuven) and Human Genetics (Helsinki) collaborative PhDs, adding to an existing joint PhD programme in neuroscience with the University of Aarhus and PhDs by integrated study which are part of the Zhejiang University-University of Edinburgh Institute.

Finally, strategic funding has been used to back the investment in Chancellor's Fellows by funding of doctoral studentships for each fellow, who are supported as first time supervisors by an experienced co-supervisor as part of a supervisory team.

Great care has been taken to ensure continuous improvement of training quality and student experience while student numbers increase. All PhD students receive induction, pastoral support and close monitoring by supervisory teams and Centre-based thesis committees, fostering a culture of two-way dialogue. Rates of PhD thesis submission within 48 months are consistently above 80%, significantly higher than those reported across all UKRI funding councils (52-63%). Commitment to student welfare within CMVM is illustrated by the creation of the new senior role of Director of Postgraduate Student and Early Career Researcher Experience, separating the experience portfolio from the financial and strategic focus of the Dean of Postgraduate Research, while the creation of the UoE Doctoral College (operational since March 2020) has critically enhanced coherence and coordination of PGR support and generic training across the university. The Doctoral College includes the Institute for Academic Development (IAD), offering a wide variety of curated transferrable skills and career management training, and the Information Service (IS), which provides PhD students with support including research data service, computing, and publication management (e.g. support for Open Access publishing). Students are encouraged to participate in the UoE '3-minute thesis' competitions, scientific meetings and to take advantage of training opportunities with international partners. PhD supervisors complete mandatory supervisory training every 5 years, to ensure an evenly high standard of supervision and ensures supervisors are up to date with changes in process ensuring best practice is in place. Within Edinburgh Medicine, Principal Investigators are encouraged to undertake mentorship and mental health first aid training. During the COVID-19 pandemic, a major effort has been invested in adapting face to face induction and briefing events in online formats for both students and supervisors and PhD students had priority access into our buildings during the gradual reopening process.

Destination data from 2017/18 CMVM pool of research student graduates (including Edinburgh Neuroscience UoA4 and Roslin UoA6) shows that 98.58% secured employment or went onto further study (*51% response rate*).

2.8 Equality, Diversity And Inclusion

Both the University of Edinburgh and Edinburgh Medicine are committed to mainstreaming equality, diversity and inclusivity and supporting all staff and student groups from our diverse community. Our commitment to EDI is evidenced by the many initiatives that benefit all Edinburgh Medicine staff groups as well as targeted initiatives for staff (as referenced in Ref5a) e.g. the Disabled Staff Network and the Staff Pride Network.

Over the past three years we have focussed on scaling up efforts to embed gender equality. In Edinburgh Medicine, 38% of the returned researchers are female, compared to 30% submitted for REF2014: The progression of junior female researchers is actively monitored to ensure this group are nurtured, retained and, when appropriate, promoted leading to improved gender parity in senior positions. The introduction of mandatory gender representation on PhD selection and supervision teams has raised general awareness of the importance of the visibility of female academics in senior/leadership roles.

The current Chancellors Fellows recruitment round indicates our commitment to a culture of openness and diversity. Our aim is that at least 50% of the new Chancellor's Fellows appointments will be women and 20% will be from black and minority ethnic groups. The University is a member of the UK Race Equality Charter and a proud holder of the prestigious Athena SWAN Silver Institution Award for our work in advancing gender equality. Edinburgh Medicine also has a Silver Athena SWAN award. Our Edinburgh Medicine Athena Swan team is currently led by **Mercer** and **Wigmore**.

In line with the UoE REF2021 Code of Practice, we have adopted an inclusive approach to defining 'independent researcher', and have embraced the decision to return 100% of eligible academic staff, which builds on our inclusive submission to REF2014 (85% of eligible staff). We adopted a rigorous, fair and transparent approach to selecting outputs, fully accounting for staff special circumstances which have affected their research activity. The process took full account of E&D considerations, building in unconscious bias and E&D training. We also set up an independent E&D group to review the distribution of outputs across staff by gender and career stage (noting that we were unable to access accurate data on other protected characteristics because of the voluntary nature of the information and constraints to updating personal details). The result of this review demonstrated a balanced spread of outputs across gender and career stage: 32% of outputs submitted are authored/co-authored by female staff (who comprise 38% of our returned staff); 37% by ECRs and Grade 8 colleagues (49% of our staff). This is testament to how our inclusive approach to research support has enabled staff to flourish, across gender and career stages.

EDI Policies & Initiatives

Since REF2014, the University of Edinburgh has implemented a suite of 'Family Friendly' policies (full information provided in Ref5a) providing all employees with access to a wide range of leave and support entitlements including but not limited to: flexible working policy, parental leave policy, time off in an emergency to care for dependents, adoption/surrogacy leave policy. Any employee applying for promotion is encouraged to identify periods of significant absence e.g. ill health or maternity leave, that may have had an impact on productivity and this will be taken into account. This policy will also come into play with the COVID-19 pandemic having an effect on researchers with caring responsibilities including but not limited to childcare.

All Edinburgh Medicine employees are eligible to apply for flexible working including part-time roles, condensed hours or agreed arrangement for working from home: all 153 Edinburgh Medicine applications (120F/33M) were approved from 2013-2018. Our Flexible Working/Return to Work Initiatives including a Research Leadership Course prioritising researchers with caring responsibilities who may forego leadership opportunities due to courses being held out with the University. We offer a returners programme for staff who have taken leave greater than four months to help transition back into the workplace and minimise disruption to staff career trajectories. Flexible Caring for Carers grants are also offered to enable those with caring responsibilities to attend conferences or workshops (also available for invited speakers). We recently held a workshop as part of the Athena SWAN action plan to explore the challenges of part-time researchers: this also included full time employees who due to teaching commitments or technical/facility responsibilities have limited research time. A recent output of the workshop was the 'Part Time Research; Full Time Challenge' one day conference to explore this topic further.

Since 2016 the live-streaming of seminars within Edinburgh Medicine has increased which has had multiple benefits for our research community as it allows researchers based at different campuses to easily access presentations from internal and visiting speakers. The seminars are recorded and made available after initial broadcast allowing part time workers, or those away at scientific conferences or with family commitments to access these talks. There is also a regular Technicians EDI newsletter.

To oversee the effectiveness for Edinburgh Medicine of these initiatives, and develop more targeted approaches to enhance EDI, There is an overarching CMVM EDI Committee (EDIC) (also encompasses UoA4 and UoA6) that meets quarterly led by **Chapman** and Boyd (UoA6). Within

Edinburgh Medicine, there are three local EDI groups: the BioQuarter Local EDI Group, the Central Campus Local EDI Group and the Western General Campus Local Group who act as local ambassadors and champions for EDI within their geographical area. The objective is to organise a programme of local events and to influence strategy, inform policy development, generate and interrogate EDI evidence, develop and cascade best practice across CMVM as well as acting as the first point of contact and source of local advice.

Achievements to date are:

- WREN programme (Work Shadowing for Women): a pilot programme, initially for female clinical academics, to understand why women are often under-represented in senior leadership roles and solutions. This received very positive feedback and is being further developed to extend to other groups.
- Part-time researcher events – to identify challenges faced and look for solutions as mentioned above.
- Career Coaching Programme – following a competitive application process, 12 female participants have completed this programme with excellent feedback, round 2 is now in process.
- Careers Beyond Academia – an event for ECRs, exploring motivations and requirements, identifying opportunities and options and how to market skills and experience to a non-academic employer. Feedback included 'one of the best events I have ever attended'. Further virtual events are being explored for 2021.
- Inspiring People annual symposium to celebrate diversity and offer role models from different genders, ethnicity, sexual orientation, ability/disability with a focus on career progress and insights.
- ECAT SUSTAIN events – an innovative annual programme of training and support which develops leadership and career potential of participants.
- Lunchtime Forums run by the Edinburgh Medicine Athena SWAN team cover a wide range of topics including academic promotions, how to run a viva, flexible working, meet the professor and career progression for professional services staff.

M. Gray (CIR) leads on BAME in the CMVM EDIC and is a member of the UoE BAME equality sub-committee; she is representing Edinburgh Medicine, working to tackle structural racism in the University and address the BAME student attainment gap. She was awarded a Principal's Teaching award to undertake qualitative research for the latter; her work is in conjunction with the University's Race Equality Charter commitment, which aims to eliminate institutional, structural and individual racism. Work on "decolonising' the curriculum is underway as part of a project to develop a more inclusive curriculum. There is also work underway to update our curricula to address how inequalities impact health which is particularly relevant as evidence builds showing the disproportionate effects the COVID-19 pandemic is having on BAME groups: **Harrison** from the Usher Institute is keeping these issues on the national agenda (BMJ 2020). We are hosting a UK wide event for medical schools to discuss issues of equality, diversity and inclusivity in medical training and academic clinical careers, leading an initiative to provide role models and mentors for Black, Asian and Minority (BAME) students across the University.

Research Culture

In July 2020 the University carried out a survey of academic staff employed to carry out research; participants were asked their views on the University's research culture and the support they received. The survey was intended to identify barriers to and opportunities for improving practice and equality with particular regard to those with protected characteristics. The design of the survey drew on the results from the Wellcome Reimagining Research survey on research culture carried out in 2019 which had identified the necessity to embed EDI principles into policies on research grant applications, participation in research events, research collaborations and output authorship. The objective is to

deliver a responsive and supportive research culture and ensure that all involved in research are given equality of opportunity.

Edinburgh Medicine has a zero-tolerance stance towards any form of bullying. The Respect at Edinburgh web hub was created as a resource for staff and students providing information on Institutional policy, processes for raising and addressing concerns as well as support and training information. Staff are encouraged to become Respect Champions for their work area. The recent "Don't Cross the Line" campaign raised awareness to reduce all forms of bullying and harassment and the related training covers all protected characteristics.

Health & Wellbeing

UoE has a health and wellbeing dedicated website providing information and resources for use by both staff and students. Training courses are available for staff with regards to time management and managing workload. The University Counselling Service and Occupational Therapy team provide confidential support. There are also a number of Institutional and Edinburgh Medicine projects and activities in place to promote health and wellbeing and encourage community spirit including but not limited to:

- University Chaplaincy provides mindfulness drop in sessions which transferred to an online format during the COVID-19 pandemic;
- JogScotland offer running groups and there are organised walking groups on multiple Edinburgh Medicine campuses;
- CRM has a team of Mental Health First Aiders who are trained to support colleagues;
- SolidariTEA is a postgraduate student initiative providing advice and support from peers and encouraging discussion across the Edinburgh Medicine community;
- BioRhythms Choir is for all staff, students, patients, carers and community members based at the BioQuarter.

Section 3. Income, infrastructure and facilities

3.1 Income

Our research income has grown by an average annual growth rate of 16% since REF2014 and is derived from a wide range of national and international funding bodies totalling >£540m (Figure 12) as well as >£12m in philanthropic donations. The sponsor table (Table 1) demonstrates the diversity of our research and impact activities and our 'mixed economy' of research funding.

Sponsor Area		Sponsor Type	
UK	88%	Government and Research Councils	51%
EU	8%	Charities	49%
Overseas	4%	Industry	6%
		Other	3%

Table 1: Funding Sponsor Information

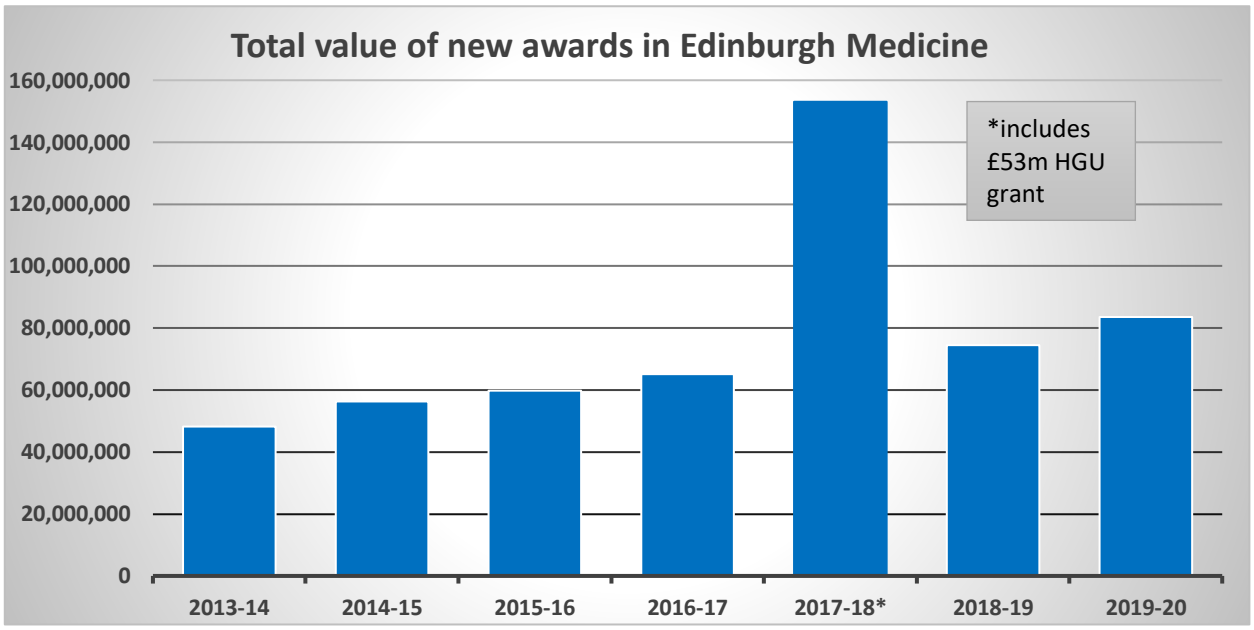

Figure 12: Edinburgh Medicine annual Research Income 2014-2020

Edinburgh Medicine's research funding success has been built on a strategy incorporating five components.

(1) A focus on *securing core funding* from MRC, CRUK, BHF and other relevant funders to support our Research Centres. Table 2 details the £127m core funding that has supported each of the established Centres that together form our four Institutes.

Edinburgh Medicine

Queen's Medical Research Institute	Institute of Genetics and Molecular Medicine	Usher Institute *New since REF2014	Institute for Regeneration and Repair *New since REF2014
Director: Haslett	*Director: Frame*	*Director: Sheikh*	Director: Forbes
			
Centre for Cardiovascular Sciences *Director: Baker* BHF Excellence Centre 2017-21 £5.5m BHF Centre for Vac Regen 2017-21 £2.5m	Edinburgh Cancer Research Centre *Directors: Cameron and Frame* CRUK Centre 2017-22 £7.7m	Centre for Medical Informatics *Director: Harrison* Farr Institute 2013-18 £7m HDR UK 2018-23 £5.2m	Centre for Regenerative Medicine *Director: Forbes* MRC Centre 2013-20 £2.5m
Centre for Reproductive Health *Director: Pollard* MRC Centre 2016-21 £2.3m Tommy's Centre 2016-21 £3.1m	Human Genetics Unit *Director: Bickmore* MRC Unit 2018-23 £53m	Centre for Global Health Research *Directors: Campbell and Rudan* NIHR GHR Unit RESPIRE 2016-21 £7.7m Asthma UK Centre for Applied Research 2019-2024 £2m	MRC Centre for Inflammation Research *Director: Gregory* MRC Centre 2011-18 £2m
Infection Medicine *Director: Dockrell* Centre-in-Development	Centre for Genomic and Experimental Medicine *Director: Aitman* Scottish Genome Partnership 2015-20 £7m	Centre for Population Health Sciences *Directors: Weller and Norrie* Advanced Care Research Centre (ACRC) 2020-2025 £20m	

Table 2: Edinburgh Medicine Core Funding

(2) We seek *funding for research projects across institutional, international and disciplinary boundaries*. We have adapted to funding environment changes by winning large collaborative interdisciplinary awards that are major drivers of innovation and led large cross-institutional consortia with a focus on impact driven research.

- The PROTEUS Hub (**Dhaliwal,** £11.3m) aims to develop revolutionary technologies that will provide quick bedside diagnosis and management of lung diseases in the clinical critical care environment;
- The UK Regenerative Medicine Platform Engineered Cell Environment Hub (**St Forbes,** £9.5m) aims to understand how stem cell behaviour is influenced in tissue environments and use this knowledge to develop future therapies for serious untreatable diseases;
- The HDR Core and Breathe Hub (**Morris**, **Sheikh**, £12.1m) uses health data to develop a better understanding of these diseases and ways to prevent, treat and cure them;

(3) We seek *seed and strategic support funding*. We have been consistently successful in securing money to be used for internal strategic purposes (detailed in Section 1). We enable these funds to work together to maximise success and have a proven track record of using these internal

funding schemes to leverage further funding from external sources, most commonly by providing support towards data required for a fellowship application or seed funding promising collaborative and/or innovative ideas to make them competitive for a larger external application.

- **MRC Confidence in Concept** funding has been awarded to Edinburgh Medicine each year since 2013, totalling £7.7m and supporting over 70 translational projects.
- **MRC Proximity to Discovery** funding each year since 2014 (total £700k) with a remit of promoting academic/industry interactions.
- **The Wellcome Institutional Strategic Support Fund** (ISSF) brought in £4m (£2m WT, £2m UoE; 2014-2016) and £8.75m (£3.75m WT, £5m UoE; 2016-2021). This cross-College fund supports the strategic priorities of the University in biomedical sciences. ISSF awardees have leveraged £112m in additional funding; this includes 106 external awards funding and 31 fellowships. 20% of supported competitive applications included an EDI element.
- UoE was awarded funding (£1.2m, 2018) for a **Wellcome Institutional Translation Partnership Award** (iTPA). This provided support to ~320 researchers during the funding period, increasing engagement with translation by 260%. The program has built an early stage funding pathway for 57 funded projects, with significant over-representation of Early Career Researchers (ECRs) new to translation led projects (68.4%), cross-disciplinary (54.4%), and involving collaborations between NHS and industry (49.1%). These projects have resulted in: 1 industry secondment; 16 invention disclosures; 5 patent applications; 3 licences (4 opportunities); and leveraged £24.6m further grant funding.

(4) Edinburgh Medicine *Personal/Project Funding*: this represents the core of our funding and is supported through peer feedback of outline applications and mentorship of our ECRs. Please see below for a *selection* of notable personal funding successes. Clinician scientists are in italics.

Programme	**BHF:** Baker (£1.3m), *Mills* (£1.2m)*, Newby* (£1.8m) **CRUK:** *Dunlop* (£3.5m), Ottersbach (£0.7m), J. Pollard (£1.1m), S. Pollard (£1.6m) **MRC:** Benezech (£1m), Eddleston (£2.7m), Minchin (£0.6m), Rossi (£2m), Saunders (£1.4m), Smith (£2.1m), Kaji (£4m) **WT:** J Pollard (£4.3m), *Newby* (£2.3m) **Other:** Gregory (Bloodwise, £1.2m), Anderson (BBSRC, £0.5m), Sudlow (HDR-UK £1m)
Translational	**BHF:** *Mills* (£1.2m, £1.1m), *Newby* (£0.6m, £0.9m) **Innovate UK:** *Fallowfield* (£1.7m), Forrester (£0.5m) **MRC:** Dockrell (£3.5m), Hay (£1.5m), *Laird* (£1m) **NERC:** *Mills* (£1.6m) **NIHR:** *Horne* (£1.1m)*, Newby* (£1m)*, Ralston*, Hill (£1.5m) **WT:** Boyd (£0.7m), *Newby* (£2.3m) **ESRC/Newton**: Bachmann (£2m)
EU Funding	**ERC Consolidator:** Patton (£1.4m) **Advanced:** *A. Jackson* (£1.9m), Dzierzak (£1.9m), *Ralston* (£1.8m)*,* Crow (£1.8m) **FP7/H2020:** Baker (£1.5m), Mill (£1.5m), Vendrell (£1.5m)

Table 3: Selection of Edinburgh Medicine Personal/Project Funding

5. Our strategy to enhance impact (Section 1) has increased our *commercial and translational income* from £11m in 2016 to £22m in 2020. Notable successes include:

- **St. Forbes** (IRR) was awarded funding for three MRC Developmental Pathway Funding Scheme projects (£3m, £1.9m, £3.3m) to develop cell therapies to treat liver disease. One of these projects (Autologous Macrophage Therapy for liver cirrhosis) in now in a Phase II trial.

- **Critchley** (QMRI) carried out an NIHR funded randomised controlled clinical trial (£1.9m) investigating ulipristal acetate versus conventional management of heavy menstrual bleeding (including uterine fibroids).
- **Pollard** (IRR) and **Carragher** (IGMM) were awarded funding from CRUK and the Brain Cancer Charity (£12m) to support research working towards new treatments for glioblastoma

3.2 Organisational Infrastructure

Institutes and Centres

As described in Section 1 and illustrated in Table 2 above, our core organisational strategy is the creation of Institutes comprising a number of core-funded Centres. The Director of each Institute is supported by the Heads of each Centre and an administrative team, with research seminars, research in progress meetings, journal clubs, interview and grant feedback, annual appraisals and postdoctoral/student mentorship organised at a Centre level.

Research Support

Edinburgh Research Office (ERO) centrally coordinates the University's research grant applications and awards facilitating cross-College collaborations for large, complex bids. Comprehensive ERO support enables academics to concentrate on the scientific aspects of their applications. ERO aids researchers by co-developing funding applications pre-award following up with contracts support and post-award grant management.

The CMVM College Research Office creates the environment to nurture research excellence by supporting research ethics, integrity and governance, open science compliance and impact. The team (5.4 FTE) includes the Head of the CMVM College Research Office, two dedicated impact officers, two translational project managers and a research information officer with a remit including overseeing and supporting specific activities in targeted priority areas of the Edinburgh Medicine research portfolio including international and global health research; translational and innovation; and delivery of our clinical research portfolio. The team play a major role in horizon scanning as well as developing and optimising strategic submissions.

Each Edinburgh Medicine research Institute has a dedicated Edinburgh Innovations team with business development, enterprise formation, consultancy and intellectual property expertise, embedding a translation and commercialisation culture aligned with each Institute's research strategy and providing support for translational and industrial funding applications.

Sponsorship and governance of clinical research is coordinated through a joint office with NHS Lothian (ACCORD, Section 4), which works closely with the UK-CRC registered Edinburgh Clinical Trials Unit (ECTU). ECTU provides an infrastructure to design, plan and deliver clinical research studies across a varied portfolio of clinical specialties and methodologies. The Edinburgh Medicine Research Ethics Committee (EMREC) covers all non-NHS and global health research studies requiring ethical review.

3.3 Operational Infrastructure: Buildings & Estates

Edinburgh Medicine currently spans two campuses: the Western General Hospital and Edinburgh BioQuarter (EBQ). Since REF2014, significant continuous investment has enhanced cross disciplinary research at each site and the University has an ambitious programme for medical research colocation at EBQ.

Shared access to key facilities promotes economy of scale, collaborative research and skills training. These include Flow Cytometry and Cell Sorting, Confocal and Advanced Light Microscopy, Histology and specialist assay development, Biomolecular Core, Mass Spectrometry, HTPU microarray services and Healthcare Technology Accelerator Facilities. Shared facilities operate on a cost recovery basis ensuring sustainability, retention of expert technical managers and potential to upgrade technology.

Western General Campus:

The MRC Institute of Genetics and Molecular Sciences (IGMM) is located at the Western General Campus and is integrated with the NHS Lothian regional cancer hospital (Western General Hospital) and clinical genetics service. A £27.2m expansion of the research space was completed in 2016, funded by the MRC, Wellcome-Wolfson Capital Awards and UoE. This five level building created a new connection across three centres (MRC Human Genetics Unit, Edinburgh Cancer Research Centre and the Centre for Genomic and Experimental Medicine), improved the flow of staff and students to support research connections, and provided collaborative space and a 180-seat lecture theatre. This enabled mathematical and computational capacity to expand (an area of strategic focus) allowing the integration and interrogation of large clinical, genomic and biological datasets. The new building hosts 100 data scientists, as part of the 500 strong Institute. This has supported new cross-disciplinary collaborative research and facilitated training schemes including the Biomedical AI CDT (led by the School of Informatics, UoA11) and the £2.2m (MRC/UoE) cross-disciplinary fellowships (XDF) programme: a postdoctoral level programme for physicists, chemists, mathematicians, statisticians, engineers, computer scientists and other experts seeking training to become leaders in Quantitative Biomedicine.

ECRC laboratories have undergone a £2.5m upgrade. Further investment at this campus will provide an integrated undergraduate and postgraduate education centre, with computer labs, meeting and wellbeing space. They will be joined by the Division of Pathology (Director, **Arends**) and the Experimental Cancer Medicine Centre (ECMC), together forming a Host and Tumour Profiling Unit for state-of-the-art genomic, proteomic or metabolomic analyses of patient-derived samples for translational studies. These will be united in a single building with excellent connectivity, social and lecture space. The value of the new building in bringing together IGMM scientists, encouraging collegiate working and stimulating new scientific collaborations is significant. CGEM has brought in £23m of grant income including funding of an Illumina HiSeq platform (£7.5m), the funding of the MRC Node for Molecular Pathology (£2m, Edinburgh and St Andrews) and the Scottish Genome Partnership), together providing new impetus in Edinburgh to deliver medical genomics and molecular pathology to the NHS.

Edinburgh BioQuarter (EBQ) Campus (Figure 13):

EBQ is a partnership between UoE, NHS Lothian, the regional development agency Scottish Enterprise and City of Edinburgh Council. This partnership supported the co-location of academic health science, clinical care and commercialisation across multiple shared function buildings, and 3 of our institutes (Usher, IRR and QMRI) are located on the 160-acre site alongside the 1000 bed teaching hospital Edinburgh Royal Infirmary, Edinburgh Medical School, the Anne Rowling Regenerative Neurology Clinic (a clinical research facility for UoA4) and 8,500sqm commercial/incubation space providing an incubator building with specialist and flexible accommodation for (25 at present) rapidly growing life science companies. Since 2014, the EBQ infrastructure has been expanded by the UoE Centre for Dementia Prevention (UoA4), the Centre for Tissue Repair (enabling IRR to realise the added value of bringing together stem cell biology, tissue regeneration and inflammation research - £90.7m), the Royal Hospital for Sick Children (£150m) and Clinical Neurosciences. Further expansion is underway for the Centre for Tissue Repair expansion (to promote interdisciplinarity by co-locating the PROTEUS collaboration of chemists, optical physicists and clinician scientists, reproductive health and infection medicine with IRR) and agreed for the Usher Institute (£68m) and the Regenerative Neurology Clinic (£15.3m), along with the refurbishment costs (£7m) to create the Brain and Body Institute within QMRI in 2025.

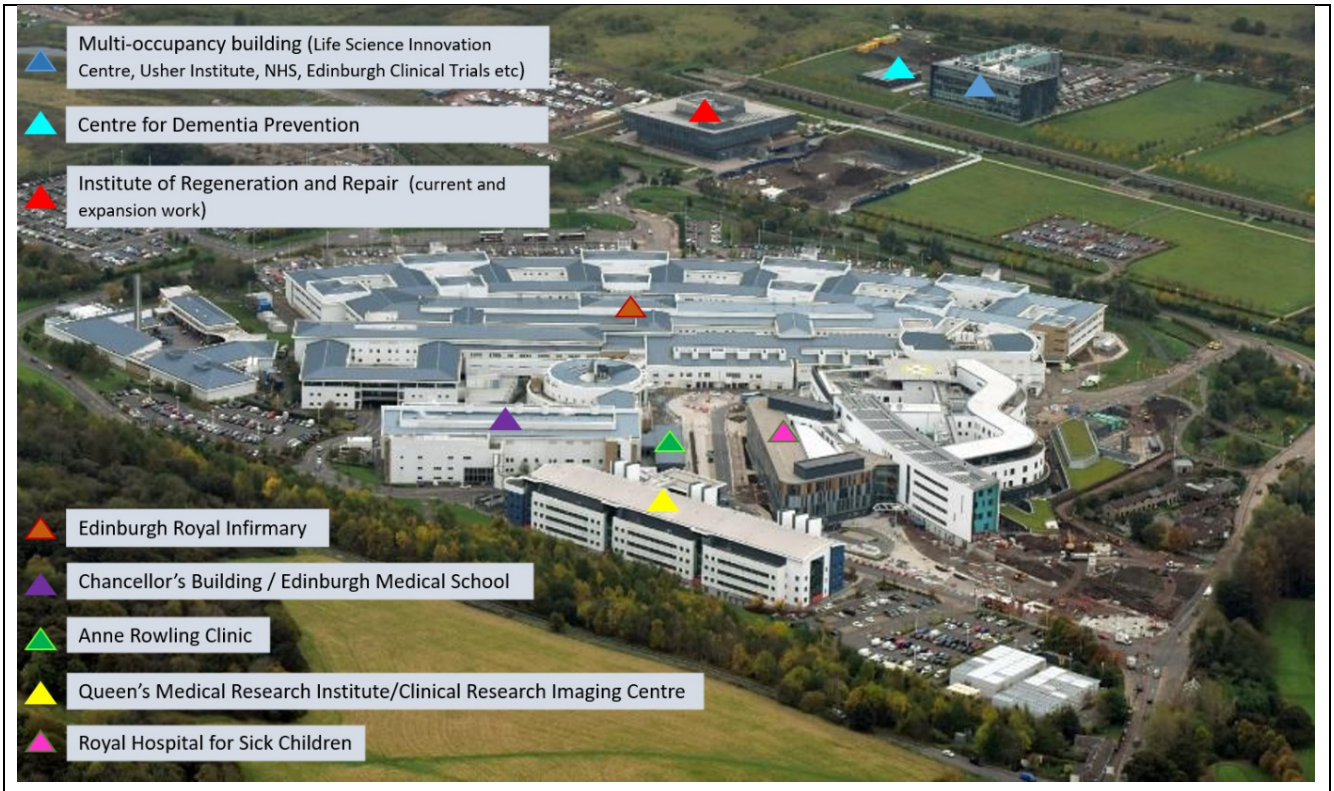

Figure 13: Aerial picture of the Edinburgh BioQuarter campus, showing the Usher Institute, IRR, and QMRI clustered around Edinburgh Royal Infirmary and the new Royal Hospital for Sick Children

Future EBQ partnership plans also include relocation of Edinburgh Eye Hospital to EBQ, further commercial and life science incubator facilities and residential and social development creating an integrated academic health science park and community development.

3.4 Scholarly Infrastructure

Tissue Biobank: NHS Lothian hosts an NHS Tissue Biobank, the NRS BioResource and the Tissue Governance Unit; which is part of a Scottish network overseen by the Chief Scientists' Office and local NHS R&D departments. The Biobank works closely with UoE researchers to provide access to research materials, with governance managed through the ACCORD office (See Section 4).

Data Safe Haven: In partnership with NHS National Services Scotland, we have developed a national safe haven with high performance computing capability, networked to four regional safe havens and supporting secure analysis of population-wide data. Edinburgh Medicine academics hold leadership roles in the MRC Farr Institute, UK Biobank, NHS Digital Academy, Scottish Government's Digital Health and Care Review, the Edinburgh Parallel Computing Centre national supercomputing facilities, ESRC Administrative Data Research Centre and EPSRC Alan Turing Institute. Investments from UKRI, Scottish Government, charities and industry have catalysed excellence in large-scale imaging research (Scottish Universities' Imaging Network, SINAPSE); capacity for high throughput whole genome sequencing (Scottish Genomes Partnership); a network of high quality NHS-embedded tissue biorepositories; expertise in digital molecular pathology (MRC/EPSRC Molecular Pathology Nodes); and outstanding precision medicine research through our Scottish Precision Medicine Ecosystem partnership between academia, NHS and industry. Crucially, we will leverage substantial investment from the £1.1b Edinburgh City Deal, which aims to make Edinburgh the data science capital of Europe and brings £237m to the University for data-driven innovation. UoE/NHSL have also agreed a joint strategy to build a 'Data Loch' as part of the DDI component of Edinburgh's City Deal to make health data accessible for research and innovation with a single streamlined approval and access process. The Data Loch went live in April 2020, well ahead of the scheduled June 2021 launch, to collate Covid-19 datasets and is led on behalf of Edinburgh Medicine by **Mills**.

Generation Scotland: GS is an ethically sound resource of human biological samples and data which are available for medical research with a focus on identifying the genetic basis of common complex diseases. Led by **Porteous**, as a joint venture between the Scottish Medical Schools and NHS (£15m funding from SFC, CSO, MRC and Wellcome), GS has created a unique partnership between the Scottish Medical Schools, NHS Scotland and the people of Scotland towards the common goal of developing more effective treatments based on genetic knowledge of complex disease. There are currently 3 GS Research Tissue Banks: the Scottish Family Health Study; Genetic Health in the 21st Century; and the Donor DNA Databank. GS supports the £5.2m HDR-UK award (2018-2023, Sudlow/Porteous) and a £1.3m MRC Pathfinder on Mental Health award (McIntosh/Porteous).

3.5 Edinburgh Medicine Facilities

Edinburgh Imaging constitutes a key part of Edinburgh Medicine, UoE and national academic research infrastructure. It also forms a crucial part of the overall NHS Scotland clinical imaging delivery network. Since REF2014 two standalone facilities have been integrated, the Brain Research Imaging Centre (BRIC) and the Clinical Research Imaging Centre (CRIC), into a single Edinburgh Imaging entity supporting medical imaging research across Edinburgh Medicine, and Edinburgh Neuroscience, strengthening interdisciplinary links. Edinburgh Imaging is world class in terms of size, scope, co-location and integration of academic research scanning facilities and equipment: supporting laboratories and activities, academic, clinical, technical, image analysis, data management and professional services expertise. The facilities are also integrated with NHS Lothian clinical diagnostic services, data archives and embedded online and campus teaching activities. Recent investments from UoE, MRC, BHF, Wellcome Trust and NHS have upgraded the clinical research imaging facilities to incorporate two PET/CT scanners, a 3T brain-optimised MR scanner adjacent to the RIE Emergency Department, a BHF-funded upgrade of the existing 3T MR system; and a combined PET and 3T MR scanner. The latter was installed as part of an £8m project co-funded by MRC Dementia Platform UK and UoE. This expansion of activity is now being enhanced further by a major £2m upgrade to double the capacity and upscale the capability of the radiochemistry suite which includes a cyclotron with Good Manufacturing Practice (GMP) and Medicine and Healthcare products Regulatory Agency (MHRA) licenced production facilities. There are extensive image analysis facilities plus growing activity in retinal and optical imaging. All activity is underpinned by an integrated data management platform. This represents circa £40m capital investment in imaging equipment over the last 10 years, and an annual turnover of nearly £4m. This world class equipment infrastructure is underpinned by 11 senior academics in radiology, medical physics, image analysis plus ~100 imaging scientists and technical support staff.

Edinburgh Preclinical Imaging at EBQ is a state-of-the-art facility with 4 imaging modalities: high-field magnetic resonance imaging (MRI), ultrasound, optical imaging and micro PET/CT. The facility has an integrated strategy to develop novel in vivo imaging technology to understand disease mechanisms and develop therapies.

Edinburgh Clinical Trials Unit (ECTU), a UK-CRC registered trials unit, provides the expertise and infrastructure to design, plan and deliver clinical research studies across a varied portfolio of clinical specialties and methodologies. ECTU employs 63 staff and contributed to over 70 studies during the REF period; trials are supported by a team of trial managers, data managers and programmers. ECTU is core to our ability to deliver clinical insights that transform clinical guidelines, practice and patient outcomes. Indeed, 6 of the 13 impact case studies in this Edinburgh Medicine submission involve a clinical trial as a key component.

Clinical Research Facilities (CRFs): There are four CRFs managed as a single UoE/NHS Lothian collaboration, comprising adult CRFs at the two major adult hospital sites, the paediatric CRF and the Dementia CRF. Both adult and paediatric CRFs have full accreditation to undertake Phase 1 (first in human) studies, managed through a Phase 1 committee. In 2018 Edinburgh CRF opened 99 new clinical research studies and supported the delivery of 212 active trials. The clinical trials supported by the CRFs have seen a consistent 20% increase in clinical trials year on year- most notably in

phase 1 and 2 trials. Over 8100 participant visits were conducted in the CRF, or by the community outreach team.

A state of the art 1000 m^2 GMP **cellular therapy facility** is based within the CRM. The facility was designed in consultation with the MHRA to meet the evolving regulatory expectations for cell therapy manufacturing within UK and Europe. The facility is licenced by the Human Embryology Fertilisation Authority (HFEA), Human Tissue Authority (HTA) and MHRA and is jointly operated by Roslin Cell Therapies Ltd. and the Scottish National Blood transfusion Service (SNBTS). The facility has 7 high quality clean rooms (4x Grade B, 2x Grade C and 1x Grade D) including support areas and dedicated GMP quality control laboratories for stem cell characterisation and safety testing. SNBTS have a research, development and manufacturing team within CRM that collaborate with UoE academics to deliver phase 1/2 cell therapy trials.

Other Edinburgh Medicine facilities of note include:

Edinburgh Super-Resolution Imaging Consortium (ESRIC) joint with Heriot Watt University: This national facility has a focus on interdisciplinary collaboration and training providing an openly accessible resource with the tools to address fundamental questions in human biology and disease. ESRIC houses state-of-the-art imaging technologies alongside molecular biology and cell culturing facilities, which are open to researchers from any field anywhere in the world with equal priority to all. ESRIC won the Times Higher Education Award for STEM Research Project of the Year 2018.

UK Zebrafish Screening Facility: This facility has an automated zebrafish embryo handling system (VAST, Union Biometrica), combined with a high speed spinning disk confocal microscope (Zeiss/Yokogawa) for rapid zebrafish screening. The facility also has a Zeiss LSM880 microscope with Airyscan for super resolution in vivo imaging. This combination allows high-throughput in vivo chemical screening, with follow up at the sub-cellular level in living embryos, to identify potential drug targets and understand their mechanism of action.

Edinburgh Genomics (EdGe): provides advanced genomics services for researchers. Based in the School of Biological Sciences (UoA5), EdGe deliver next-generation sequencing and bioinformatics support. EdGe provide training in bioinformatics (e.g. RNA-seq data analysis, metagenomics) and has supported >800 publications.

National Phenotypic Screening Centre: the University of Edinburgh is part of the collaborative National Phenotypic Screening Centre network which also involves the Universities of Dundee and Oxford. Edinburgh Phenotypic Assay Centre (EPAC, led by **Carragher**, **Frame** and D. Gray (UoA5)) aims to develop state-of-the-art cell based assays suitable for medium to high-throughput screening. EPAC links research groups with cutting-edge automated imaging, image-informatics, biological modelling and assay screening.

Section 4. Collaboration and contribution to the research base, economy and society

Edinburgh Medicine has an exceptionally strong collaborative ethos, developing international and national partnerships to promote research and teaching (top-down) and also encouraging individual investigator-led collaborations to drive specific research projects (bottom-up). This is made possible by the colocation of NHS, commercial and academic research; our translational infrastructure (Section 1); and availability of responsive internal funding that catalyses the development of collaborative interdisciplinary projects (Section 1). Our research strengths also allow us to respond to national and international priorities as evidenced by a series of key international collaborations; see specific examples throughout Section 4.

4.1 National Partnerships

NHS Lothian (NHSL): Our key partnership between UoE and NHSL (and other National NHS bodies) remains strong. Of the 377 researchers returned, 131 hold NHS honorary appointments. Over 700 NHSL employees currently hold honorary UoE contracts. Joint appointments at the highest level ensure that collaboration continues to thrive; notably, the NHSL R&D Director (**Walsh**) is a joint UoE/NHSL appointment, providing overall leadership and strategic oversight for clinical research. Seamless delivery of world-class clinical research is facilitated/delivered by a fully integrated UoE/NHSL research office, the Academic and Clinical Central Office for Research And Development (ACCORD) with a framework agreement that defines shared responsibilities for all aspects of research development and governance. In 2018/19, ACCORD managed 700 non-commercial clinical studies, many led by UoE academics or research active NHS clinicians with honorary UoE status, recruiting >12,000 patients. ACCORD also manages an active commercial portfolio (>1200 recruits in 2018/19); many of these are complex phase II/III trials involving collaboration between UoE and NHSL clinicians. The embedded joined-up approach to clinical research enabled emerging COVID-19 research studies to be swiftly triaged and supported. NHSL is the leading Scottish health board for COVID-19 recruitment with more than 4000 patients enrolled.

UoE/NHSL collaborate to create a world class research environment by actively reflecting National Institute for Healthcare Research (NIHR) structures through disease specific Network and Specialty Groups. Eight of the Scottish network/specialty leads are based in UoE/NHSL: **Shenkin** (Aging, UoE); **Cameron** (Cancer, UoE); **Gillies** (Anaesthesia and Critical Care, NHSL); **Weller** (Dermatology, UoE); **Lees** (Gastrointestinal, UoE); **Ralston** (Musculoskeletal Disease, UoE); **Schwarze** (Paediatrics, UoE); **Hill** (Respiratory, NHSL). In addition, NHSL funds over 50 NHS Research Scotland (NRS) Research Clinicians, mostly consultants, through protected time to undertake research, often with UoE collaborators.

The Edinburgh Clinical Research Facilities are managed as a single UoE/NHSL collaboration and NHSL also hosts an NHS Tissue Biobank (Section 3: Facilities). NHSL funds a successful Patient/Public Involvement (PPI) programme for research, including regular training programmes for researchers/academics. This provided advice to >90 research projects, including support for grant submission. NHSL hosts >25 PPI panels and 8 PPI champions actively support a wide range of research areas.

NHSL also leads the recently established East of Scotland NHS Innovation Test Bed to develop health and social care innovations, health technologies, DDI and NHS priorities - maximising NHS, academic, and industry collaboration.

Examples of joint academic/health service research and resulting impact include:

- UoE/NHSL collaboration integrating genomics into clinical care (**Fitzpatrick** and **Meynert,** IGMM). Outputs include: (a) implementation of trio exome sequencing workflow in NHS Lothian (2019); (b) creation of new accredited role for clinical scientists using genome analysis aided approaches to diagnose and treatment of human disease; and (c) co-developing new tests and clinical applications utilising novel technologies.
- The Edinburgh Resuscitation Research Group (RRG) works with the NHS and Scottish Ambulance Service optimising delivery of care after out-of-hospital cardiac arrest (OHCA)

and optimising the "chain of survival" (*UoA1 ICS/J*). **Clegg** is the Chair of the OHCA Strategy Delivery Group, a collaboration involving all of Scotland's emergency services, Scottish Government, Third Sector, NHS and academic partners.

- **Simpson** and **Sheikh** (Usher) collaborated with Health Protection Scotland (NHS Division) to establish robust systems to demonstrate the effectiveness of the seasonal influenza vaccine. These studies have informed the Joint Committee for Vaccination and Immunisation who advise the UK Department of Health and the Devolved Administrations on amendment to vaccination policy, and contribute evidence for WHO recommendations on annual influenza vaccine strain selection.
- **Reynolds** and **Denison** (QMRI) have demonstrated the negative impact of maternal obesity on pregnancy outcomes. With funding from the charity Tommy's, they found that obese mothers attending a multidisciplinary clinic were 8 times less likely to suffer a still birth, compared to matched controls. Tommy's Metabolic Antenatal Clinic was opened at the Edinburgh Royal Infirmary in 2011, renewed in 2016 and is an integral part of MRC Centre for Reproductive Health's research.
- **Gourley** (IGMM) has been named as an 'NHS hero' for his contributions to investigating gynaecological cancers. He was pivotal in pushing for genetic sequencing in ovarian cancer patients after observing in clinical trials that women with BRCA1 and BRCA2 gene mutations responded particularly well to an experimental new drug, Olaparib, now available on the NHS.

Other national collaborations of note include:

Health Data Research UK (HDR UK): This funding (£5.2m, 2018-2023) creates a substantive site in Scotland capitalising on world-leading health and informatics research capabilities and exceptional data assets from Scotland's population of 5.4 million people. The Universities of Edinburgh (co-ordinating), Glasgow, Dundee, Aberdeen, St Andrews and Strathclyde bring multidisciplinary expertise in epidemiology; learning health systems; clinical phenotyping; precision medicine and therapeutics; clinical trials; public health; genomics; molecular pathology; informatics; supercomputing; data systems; software architecture; and advanced, scalable analysis methods including machine learning, artificial intelligence and natural language processing.

Cancer Research UK (CRUK): The CRUK-Edinburgh Centre (CRUK-EC) is a physical hub and cancer banking activities at ECRC/IGMM with considerable CRUK-funded research existing as 'spokes' across UoE. CRUK-EC is part of a network of CRUK Centres underpinned by a core and training CRUK Centre Award, £7.7m (renewed 2017). CRUK-EC benefits from UoE infrastructure and collaborations across Edinburgh Medicine including IGMM, Usher Institute, IRR and MRC CRH demonstrating the interdisciplinary nature of CRUK-EC themes. Strong links exist between the CRUK-EC and the CRUK-Glasgow Centre/CRUK Beatson Institute and recent joint CRUK funding was obtained to Train and Retain Academic Cancer Clinicians (TRACC; led by **Whyte** and MacInnes (University of Glasgow) £6m). The partnership between UoE, CRUK and NHS Lothian brings together cancer scientists and clinicians, delivering outstanding cancer research and patient care. The CRUK/CSO-funded Experimental Cancer Medicine Centre (ECMC, £0.9m) was renewed in 2017. ECRC is a CRUK Brain Cancer Centre of Excellence (Lead **Frame**). CRUK-EC is working with Scottish Government to streamline and optimise clinical cancer research across Scotland in line with the Innovative Healthcare Delivery Programme (IHDP).

MRC Molecular Pathology Node: The Edinburgh-St Andrews Molecular Pathology Node (£2m, MRC) led by **Aitman** (IGMM) integrates state-of-the-art genomic and epigenomic methods with image analysis of complex phenotypes and bioinformatics to develop molecular diagnostics for use in mainstream medicine. Rapid translation to the clinic will be achieved by engaging closely with the NHS, industry and academia. An MRes Programme in Molecular Pathology has been created to train a new generation of molecular pathologists with modern genome-analysis capability to provide a skilled workforce for this area.

Scottish Genomes Partnership: The Scottish Genomes Partnership (£15m 2015-2020) was a major Scotland-wide research programme between the Universities of Edinburgh, Glasgow, Aberdeen and Dundee, with NHS Scotland, NHS Lothian, NHS Greater Glasgow & Clyde, NHS

Grampian and NHS Tayside. The programme, led by **Aitman** (IGMM) and Biankin (University of Glasgow), explored causes of central nervous system disorders, developmental disorders, and cancer, as well as examining genes which influence risk factors for common, complex diseases in a Scottish population.

UK Regenerative Medicine Platform (UKRMP): UKRMP brings together leaders in regenerative medicine from across 16 UK universities, creating a critical mass of expertise and knowledge. UKRMP funding supports translational research generating scientific knowledge to help deliver the great promise of regenerative medicine. Edinburgh (**St. Forbes**, IRR) led the initial UKRMP Niche Hub (£4.5m, 2014-2018) which was renewed as the UKRMP Engineered Cell Environment Hub (£5.1m, 2018-2023) involving multiple Edinburgh Medicine academics.

PROTEUS/OPTIMA: PROTEUS is an interdisciplinary research collaboration, with major investment from EPSRC (£11.3m) and 3 consortium Universities (£3m). This team of internationally recognised researchers and academics from UoE (**Dhaliwal**, **Haslett** and Bradley (UoA8)), Bath and Heriot Watt, are working to revolutionising how lung diseases are diagnosed and managed within the Intensive Care environment, where respiratory failure is common and bedside care is critical. PROTEUS' leading fibre optic research, sensing and imaging, signal processing, and clinical care has resulted in the design of a fully integrated system for rapid and accurate diagnosis of bacterial infections.

Healthcare Technology Accelerator Facility (HTAF): This is a collaborative facility involving UoE (lead) and several UK Universities (Bath, Durham, Heriot-Watt and Strathclyde) and the NHS. Funded by the MRC, EPSRC, Wellcome Trust and Carb-X, (£1.2m) HTAF aims to expedite the development and commercialisation of healthcare technologies, provides a sterile GMP environment for primary manufacturing, packaging and assembling of medicines for use in clinical trials and investigations.

Northern Alliance Advanced Therapies Centre: Funded by Innovate UK (£7m), NAATC is a consortium of twenty organisations (industry, NHS and academic including UoE) led by Newcastle Hospitals and the Scottish National Blood Transfusion Service (SNBTS) to develop the systems and infrastructure required to support the delivery and increase patient access to advanced therapy medicinal products (ATMPs). Edinburgh Medicine's involvement is led by **Baker** (QMRI) and **St. Forbes** (IRR) who have track records developing advanced therapies.

4.2 International Partnerships

Our strategy is to develop deep and sustainable partnerships with key institutions across regions, increasing opportunities for research and knowledge development, especially in emergent disciplines. International collaborations account for 54% of all papers published in the assessment period.

To help mitigate against Brexit, we have established strong partnerships with key European Institutions through our European Global Scholarships Programme that has cemented commitments between institutes. UoE is one of eight leading European research universities in the UNA Europa alliance with Data Science, Artificial Intelligence and One Health highlighted as key research strands. We are also a founding member of the *League of European Research Universities (LERU),* which is a prominent advocate for the promotion of basic research at European research universities: we have implemented LERU Open Science recommendations (Section 1).

International collaborations/activities in our portfolio include:

Zhejiang University-University of Edinburgh Joint Institute (ZJE): ZJE is the largest UoE transnational research-led educational activity established in 2016 at the new 200 acre International Campus of Zhejiang University in Haining, China. Occupying a new 10,000 m^2 research facility, at full capacity ZJE will host ~40 research groups, 550 post-graduate researchers, and 630 under/postgraduate students. ZJE was awarded the Education Institutional Partnership of the Year 2018 at the China-Britain Business Awards and currently hosts the British Council Joint Institute Alliance, convened by **Welburn**, ZJE Executive Dean. We continue to develop the UoE-ZJU partnership across mutual research areas and funding opportunities, including new PhD and Masters programmes. **Bachmann**, Director of UoE Postgraduate programmes at ZJE, is leading the existing and developing new PG programmes as part of the Biomedical Talent & Translation Pathway at ZJE.

NIHR funded Global Health Units and Groups: The **RESPIRE** collaboration (Director **Sheikh**) includes organisations in Bangladesh, India, Malaysia and Pakistan working in partnership with the UoE to reduce respiratory disease deaths in Asia. **DIPLOMATIC** (Director **Reynolds**) is a Global Health Research Group aiming to reduce preterm birth and stillbirth and to optimise outcomes for babies born preterm in Malawi and Zambia.

Euro Marie Sklodowska-Curie Innovative Training Network (NOVA-MRI): This €4m network coordinated by Leiden University Medical Centre in the Netherlands involves 16 organisations, including the University of Edinburgh as well as 7 industrial partners. The Edinburgh team is led by **Vendrell** (IRR), and creates multiple avenues for cross-collaboration and translational research across different institutions in Europe.

THERACAT: An international and multidisciplinary consortium (MSCA-ITN European Training Network) developing novel bio-orthogonal catalysis-based tools for cancer therapy. The network comprises 6 academic partners (**Unciti-Broceta** IGMM), 3 industrial partners and 3 partners with a focus on science communication (CRUK), EDI (UAB-Observatory for Equality), management and entrepreneurship (ESADE business school).

International Centre for Cancer Vaccine Science: (€11.5m; 2017-2023) a research collaboration between the University of Edinburgh (**Hupp**) and the University of Gdansk with a focus on innovative, interdisciplinary programmes and industrial collaborations driving translational clinical developments and commercialisation in infectious diseases and cancer.

Innovative Medicines Initiative: VALUE-Dx this project involving 20 academic partners (Edinburgh lead **Bachmann**) plus BioMérieux, Janssen Pharmaceutica, Bio-Rad, Accelerate Diagnostics, Becton Dickinson and Wellcome Trust will define and understand value indicators and barriers to adoption of diagnostics of Community-Acquired Acute Respiratory Tract Infections (CA-ARTI) in order to develop and improve health economic models to generate insight in the whole value of diagnostics and develop policy and regulatory recommendations. **RESCEU Respiratory Syncytial Virus Consortium in Europe** (€3.6m (UoE) 2017-2021) brings together clinicians, epidemiologists, scientists, health economists, statisticians, public health professionals, patient organisations, regulatory agencies and industry to address key gaps in knowledge of RSV. **Nair** and **Campbell** lead from Edinburgh.

Project DOSA: Diagnostics for One Health and User Driven Solutions for AMR: This programme (£2m, MRC), led by **Bachmann** brings together five Indian (Indian Institute of Technology, Delhi; Centre for Cellular and Molecular Platforms, Bangalore; ICAR-Central Institute of Fisheries Technology, Cochin, Kerala; ICAR-National Dairy Research Institute, Karnal, Haryana; Silchar Medical College and Assam University, Silchar) and four UK academic institutions (the Universities of Edinburgh, Bradford, Southampton, and University of the Arts London). Medical researchers, diagnostic innovators, economists and social scientists will create rapid diagnostic solutions to fight AMR in diverse settings such as community healthcare, dairy farms and aquaculture.

Human Cell Atlas Programme: This international consortium aims to create comprehensive reference maps of all human cells as a basis for understanding human health and disease. **Ponting** (IGMM) is a member of the Organising Committee, **Fitzpatrick** and **Vallejos** are on the funding panel.

4.3 Translation & Development of Impact

The University of Edinburgh was a finalist in the Outstanding Entrepreneurial University category of the Times Higher Education Awards 2019. Figures from Research England's Higher Education Business and Community Interaction (HE-BCI) Survey showed the University of Edinburgh rose from 15th place in 2014 to 4th in 2020.

Company Creation: Edinburgh Medicine has been involved in the creation of 6 spin out companies during the REF reporting period. UoE has developed a number of strategic partnerships with venture capital investment firms with interests that align with Edinburgh Medicine research outputs including Epidarex Capital, Mercia Technologies plc and Advent Life Sciences. We have also highlighted some

key value inflection points that are relevant to companies reported during the last REF reporting period.

Name of Company	Year	Comments
Aquila Biomedical Ltd	2011	Innovative contract research solutions for drug discovery. Currently employs >30 members of staff and is situated on Edinburgh Bioquarter campus. Acquired by Concept Life Sciences in **2017**; Spectris plc (FTSE250) has since acquired Concept Life Sciences.
NeurocentrX	2013	Development of therapeutics for neurological conditions through reformulation, clinical development and product in-licencing. Investment was provided by Equity Gap Ltd, Scottish Enterprise, and Carbon Life Ltd
Corticrine	2014	Small molecule inhibitor UE2343 (Xanamem): company acquired by Actinogen Ltd (2014). Phase II Clinical Trial in early dementia patients nearing completion (2019).
Edinburgh Molecular Imaging	2014	Optical Molecular Imaging technology. Multiple clinical trials ongoing. Situated on the Edinburgh Bioquarter campus; £5M investment secured from Epidarex Capital, Scottish Enterprise and private investors.
Triscribe Ltd	2015	Building world-class health analytics as a service - helping NHS clinicians with better information about medicines usage in hospitals. Private Seed funding 2018
PhenoTherapeutics	2019	Development of remyelination therapeutics for multiple sclerosis £2m investment secured from Advent Life Sciences, the Scottish Investment Bank and Life Arc
Macomics	2020	Immuno-oncology company developing first-in-class cancer therapies targeting cancer immune evasion pathways. CiC funding in 2018 (£97k), £1.3m seed financing led by Epidarex Capital and Scottish Investment Bank (SIB).

		Scientific co-founder Cassetta has a 50% FTE position as a UoE Chancellors Fellow to continue to develop his academic career.
Cellinta	2020	Gene Therapy company targeting cancer. £1.3m investment by SV Health and CRUK Seed Fund.

Table 4: Edinburgh Medicine Spin Out Companies

In addition, Edinburgh Medicine academics lead several companies:

- **Stemnovate Ltd**: **Hay** (IRR) is a Director and Co-founder of an SME providing compliant organ-on-chip platforms integrating stem cell research and tissue engineering as physiological alternatives for precision drug discovery and screening.
- **MyWay Digital Health: Wake** (Usher) is CEO and Clinical Lead of the company providing a diabetes self-management app to NHS Scotland.

Industrial Collaborations: Our academics have a proven track record of collaborating with the pharmaceutical and biotechnology sector. Collaborations can occur using a variety of different models including: co-sponsored PhD studentships; research collaborations; technology beta testing and development; tools development; and clinical research. Specific examples of translational collaborative activities with industry include (with more examples listed in Figure 14 below):

- **Webster** (QMRI) and **Mole** (IRR) discovered a clinical development candidate (GSK3335065), arising from research on the role of KMO in acute pancreatitis which entered Phase 1 trials in partnership GSK (Nat Med 2016, Nat Commun 2017). This was a GSK Discovery Partnership with Academia project.
- **Vendrell** (IRR) has developed novel fluorescent probes for the identification of apoptosis, infection and metabolites *in situ.* This technology is patented and the associated IP has been licenced by Merck, Biolegend and Cambridge Research Biochemicals.
- **Boulter** (IGMM) identified key factors in the development and progression of cholangiocarcinoma (JCI 2015) and is probing whether these could be amenable to intervention in partnership with Leap Therapeutics.
- **Boyd** (IGMM) is involved in the UK Cystic Fibrosis Gene Therapy Consortium, joining **Boehringer Ingelheim** and Oxford Biomedica to develop a new viral vector-based therapy.

The partnership builds on pioneering research carried out by the consortium including clinical trials, which have shown encouraging results.

Figure14: Edinburgh Medicine Industry Collaborations (please note only collaborations that are in the public domain are included)

4.4 Edinburgh Medicine Engagement with Communities and the Public

From 2013 to 2020, our colleagues have won funding for engagement activities from the MRC, Wellcome Trust, the European Commission, learned societies and charities.

Annual returns to the Higher Education Business and Community Interaction Survey reveal growth in participation numbers in estimated external 'engagements' between 2013 and 2019, from an estimated 170,000 'engagements' in 2013 to an estimated 260,000 in 2019. This reflects growth in support from professional engagement and communications staff to researchers and development of engagement approaches that better consider the needs of participants and that focus on quality of interaction.

An excellent example of community engagement was the Castlebrae Science Development Project. The aim was to enrich science education and STEM engagement within Castlebrae Community High School and its cluster primary schools (Castleview, Newcraighall & Niddrie Mill) through a partnership with CRM by developing science capital in young people whose backgrounds meant they may not traditionally have viewed science positively or as an opportunity for them. Schools, pupils, engaged parents and scientists/STEM providers welcomed the opportunities and particular activities offered and rated their experiences positively. All partner schools initiated some enhancements to science delivery during the timescale of the Project. A particularly successful mentoring scheme was introduced which consisted of fortnightly sessions involving interactions between CRM volunteer mentors (typically PhD students) and pupil mentees.

In 2019, Edinburgh Medicine received three major national public engagement awards including the 2019 Understanding Animal Research Public Engagement Award for openness about the use of animals in research (all participants in Edinburgh Medicine). CRM in collaboration with Castleview Primary School won the 2019 Rolls Royce Science Prize and the Eden Award for community science engagement.

Figure 15: Edinburgh Medicine public engagement: the IRR team receiving their award of the 2019 Rolls-Royce Science Prize for their work with Castleview Primary School

In January 2020 we launched the Academic Leads for Public Engagement leadership programme and recruitment to the first PhD programme to combine medical science research with credited teaching in communication, engagement, patient involvement, data design and informatics. Both the academic lead programme and the Medical Sciences and Translational Research PhD with integrated studies in Engagement for Impact programme are part of long-term culture change initiatives led by the College to work towards an environment where researchers are best equipped to solve real-world problems through excellent research.

Edinburgh Medicine Response to COVID-19 Pandemic

Public Engagement

Our scientists have included public engagement in their research response to the Covid-19 pandemic. The *Coronagenes* study has made extensive use of social media to recruit and inform, but also to engage by hosting Q&A on Instagram Live to encourage people all over the world to join the study. *RuralCovidLife* builds on the original CovidLife study to address experiences in Scotland's more remote communities. In the city of Edinburgh itself we contributed to the Curiosity Box initiative led by Edinburgh BioQuarter: a STEM education pack was delivered to every pupil who attends primary school in our neighbouring communities.

Public Health Policy

Researchers from the Usher Institute are advising government on public health policy including activities such as social distancing, tracing and tracking the spread of infection and testing. Four Usher researchers are members of the Scottish Government's COVID-19 Advisory group: **Morris** (chair), **Sheikh**, Sridhar (returned UoA20) and Woolhouse (returned UoA6). This group supplements the work of the UK Government Scientific Advisory Group on Emergencies (SAGE), which has been advising ministers north and south of the border: **Morris** is also a member of SAGE; **Baillie**, **Docherty** and **Harrison** are members of the COVID-19 Clinical Information Network. **Rudan** is a key advisor to the Croatian Government, providing support with COVID-19 strategy and communications.

Training & Education

UoE's MSc in Critical Care team, with colleagues from the Royal College of Physicians of Edinburgh, created an online educational resource to respond to the pandemic: the free to access "COVID-19 Critical Care: Understanding and Application" programme teaches clinicians how to effectively care for critically ill patients. To date 45,000 learners from 197 countries have engaged with this resource.

Wider activities and contribution to the research base, economy and society

The University of Edinburgh Chancellor's Awards recognise innovation, relevance, creativity, personal dedication and impact in teaching and research. Since REF2014, Edinburgh Medicine researchers have received the following Chancellor's Awards: **Fitzpatrick** (Impact 2018), **Walker** (Research 2015), **Frame** (Research 2014), **Mills** (Rising Star 2014).

Table 5 illustrates examples of our contribution to the research base, economy and society:

Contributions to Governmental and International Advisory Bodies	
International Advisory Committees	A*STaR Health and Biomedical Sciences International Advisory Council (Savill); A*STaR Clinical Sciences Unit Scientific Advisory Board (Seckl); Breast International Group (Cameron, Chair 2019); Gates Foundation Scientific Advisory Group (Nair, 2014); Singapore Academic Research Council (Savill, 2020); WHO Experts in Digital Health (Pagliari); WHO Steering Group for Impact Working Group (Welburn); SAB Centre for Regenerative Therapies Dresden (Becker, Chair), International Society for Pneumococcal Disease (Bogaert); European Academy of Allergy and Clinical Immunology (Schwarze); Consulting Group Contraception Discovery and Development Branch, NICDH USA (Anderson); International Federation of Gynaecology and Obstetrics Committee for Menstrual Disorders (Critchley), Vice Chair of JPIAMR Scientific Advisory Board (Bachmann, 2018-20), Member of CARB-X Advisory Board (Bachmann, 2020).
Leadership in UK Science	MRC Chief Executive Officer (Savill 2010-18); AMS Council Member (Critchley); BHF Data Science Centre Director (Sudlow); Longitude Prize Advisory Panel/Judge (Bachmann, 2017-); NHS Research Scotland Clinical Cancer Research Champion (Cameron); NHS Research Scotland Primary Care Research Champion (Guthrie); NICE Multi-morbidity Guideline Development Group (Guthrie, Chair 2014-16); Royal College of Obstetricians and Gynaecologists Stillbirth Clinical Study Group (Stock, Chair 2017); Scottish Clinical Virology Consultants Group (Haas); Chief Scientist at the Scottish Government Health Directorate (Morris); Scottish School of Primary Care Executive Management Group (Guthrie); Scottish Universities Life Science Alliance AMR Steering Group (Bachmann, Member); UK BioBank Chief Scientist (Sudlow 2011-2020); UK Clinical Academic Training Forum (Whyte Chair); UK Government Cabinet Office Better Use of Data in Government: QA Group (Pagliari, 2016); UKRI Digital Health Research and Innovation Project Expert Group (Sudlow, 2019); University of Cambridge Centre for Trophoblast Research SAB (Critchley); WT Population Health Expert Advisory Board (Sudlow, 2015); WT Science Review Advisory Group (Sudlow, 2019); Zika Virus UK Government Advisory Committee (Jackson, 2016)
Contributions to Science Funding	
Funding Committees and Organisations	Current chairs of major UK panels: Innovate UK Biomedical Catalyst Major Awards (Seckl); MRC Asset Sharing Initiative (Seckl); MRC Confidence In Concept (Seckl); MRC DPFS (Seckl); MRC Methodology Research Panel (Sudlow); MRC/NIHR Efficacy and Mechanisms Evaluation Board (Norrie); MRC Molecular & Cellular Medicine Board (Jackson, Deputy Chair); MRC Proximity to Discovery (Seckl); MRC Training and Careers Board (Whyte); MCSA Individual Fellowship Programme (Becker, Vice Chair Life Sciences), NIHR HTA General Committee (Norrie, Deputy-Chair); Wellcome Trust: Molecular Basis of Cell Function ERG (Bickmore), UKRI Future Leaders (Dockrell), MRF National Doctoral Programme in AMR (Dockrell), Fellowships and Awards Working Group, European Respiratory Group (Bogaert), AMS INSPIRE grants panel (Seckl)

Other Measures of Distinction	
Elections to Learned Societies	26 fellows of the Academy of Medical Sciences including new Baker (2015), Dzierzak (2015), Sheikh (2015), St. Forbes (2016), J. Pollard (2016), Fitzpatrick (2017) and Campbell (2020) 4 fellows of the Royal Society including new Bickmore (2017), Jackson (2020) 34 fellows of the Royal Society of Edinburgh including new J. Pollard (2015), Sheikh (2015), Welburn (2015), St. Forbes (2016), Rudan (2016), Aitman (2017), Dzierzak (2018), Ponting (2018), Sudlow (2018), Whyte (2018), Fitzpatrick (2019), Saunders (2019), Wigmore (2019); Guthrie (2020), Murray (2020)
Contribution to Societies and Organisations	British Society of Immunology (Davidson, Public Engagement Secretary 2018); Genetics Society (Bickmore, President 2015-20); MRC Harwell (Bickmore, Chair 2015); British Association of Cancer Research (Frame, President 2015-19); MRC Unit for Lifelong Health and Ageing (Bickmore, Member 2018); Lister Institute of Preventive Medicine Governing Body (Bickmore, Chair 2014); Marie Curie Research Strategy Board (Norrie 2016); Royal Society of Edinburgh (Welburn, Chair Sector A Selection Panel); Sanger Institute (Bickmore, Chair 2017); UCL Scientific Advisory Board (Fitzpatrick 2016); Weatherall Institute for Molecular Medicine University of Oxford (Bickmore, Chair 2014-17); Scientific committee of European Cystic Fibrosis Society (Bogaert); Programme committee European Society Clinical Microbiology and Infectious Disease (Bogaert)
Notable Awards/Prizes	UK Civil Honours System: British Empire Medal (Hannah, 2016); CBE (Hastie, Haslett (2017), Morris (2018); OBE (Frame, Seckl (2018), Porteous (2019)). James Black Medal, Royal Society of Edinburgh (Haslett 2014); Donald Metcalf Award, International Society of Experimental Haematology (Dzierzak 2015); George Abercrombie Award, RCGP (Murray 2015); Wellcome Trust Beit Prize (Feng 2014, Christophorou 2015 and Gibson 2020); Royal Society of Edinburgh Patrick Neill Medal (Unciti-Broceta 2016, Marsh 2019, Boulter 2020); Teamwork in Innovation Award; Royal Society of Chemistry (Mole, Webster 2016); Chinese University of Hong Kong Distinguished Scholar (Guthrie 2017); BMJ Imaging Team of the Year (Scot-Heart trial 2017); Pfizer SRI President's Presenter Award (Gibson, CCVS 2017); British Association for Cancer Research AstraZeneca Young Scientist Frank Rose Award (Serrels 2017); Rosetrees Trust Prize for Interdisciplinary Research (Bachmann/Dear 2017); American Thoracic Society International Trainee Scholarship Award (Marsh 2018); Society for Endocrinology Early Career Prize Lecture (Gibson 2018); Lister Institute for Preventative Medicine Lister Prize (Marsh 2018); Africa Palliative Care Association Award (Murray, 2019); Sir William Gilliat Congress medal (Stock 2019) and Academic Award (Critchley 2020), RCOG; BHF Research Fellow of the Year Award (Mills 2019); Women in Cell Biology Prize from the British Society of Cell Biology (Mill 2019); British Pharmacological Society's Lilly Prize (Eddleston 2019); Hind Rattan (Jewel of India) award (Nair 2019); Hooke Medal (Chambers 2020); Royal Society of Edinburgh Patrick Neill Medal Marsh (2019), Boulter (2020)

Table 5: Wider activities and contribution to the research base, economy and society