THE AUSTRALIAN
E●HEALTH
RESEARCH CENTRE

LEADING THE WAY IN HEALTH IT RESEARCH

ANNUAL REPORT

2016 / 2017

RESEARCH · DISCOVERY · INNOVATION
POWERS HEALTH IN THE DIGITAL AGE

CSIRO

Queensland Government

Contents

The Australian e-Health Research Centre

A Partnership between CSIRO and the Queensland Government, The Australian e-Health Research Centre (AEHRC) is the leading national research facility applying information and communication technology to improve health service delivery for Australians. The Centre is an unincorporated joint venture between CSIRO and the Queensland Government.

Established in 2003 with initial funding from the Department of State Development and CSIRO, the partnership was extended in 2007 for a further 5 years with funding from CSIRO, Queensland Health and the Department of Employment, Economic Development and Innovation. The partnership was extended again in 2012 for a further 5 years with an additional contribution of $15 million from CSIRO and Queensland Health, supplemented by in-kind contributions from the partners, as well as funding from grants, research consulting and commercialisation.

The partnership was extended again in 2017 for a further five years.

As CSIRO's e-Health Research Program – part of CSIRO Health and Biosecurity – the Australian e-Health Research Centre has grown to a national research centre. In 2009, the AEHRC established the Australian Tele-health Research and Development Group(ATRDG) in Perth in conjunction with the Western Australia Department of Health. While the initial focus of this activity was on telemedicine and ocular imaging technologies the group has grown to include tele-medicine delivery for a wide range of conditions. Through further CSIRO in-kind contributions and other external funding the AEHRC now has scientists and engineers in Sydney and Melbourne.

Through its research program, the AEHRC develops and deploys leading edge information and communication technology innovations in healthcare to:

* improve service delivery in the Queensland and Australian health systems
* generate commercialisation revenue, and
* increase the pool of world-class e-health expertise in Australia

The AEHRC's multi-disciplinary team includes internationally prominent researchers, software engineers and doctoral students, dedicated to serving the needs of patients, clinicians and health service providers.

The Australian e-Health Research Centre is CSIRO's e-Health Research Program, conducting research across Health Informatics, Biomedical Informatics and Health Services.

Forward by Chairman

I have thoroughly enjoyed my first year as the Chair of the Board of the Australian e-Health Research Centre. Over the past 12 months I have seen in much more detail the depth of science that an organisation such as CSIRO can bring to Australia's digital health agenda and have been impressed by both the quality of the science and the impact that it is having on healthcare in Australia.

Digital health is at an exciting point in Australia and worldwide as healthcare increasingly embraces digital technologies. The new Australian Digital Health Strategy provides a roadmap for the increasing use of digital health technologies. The National Clinical Terminology Service, a joint project from the AEHRC and the Agency – will continue to be one of the foundation services of Australia's Digital Health infrastructure. But much of the science from the AEHRC will be part of the future of digital health in Australia from mobile health solutions for integrated care to imaging and genomics for personalized medicine.

I am also pleased to report that the Joint Venture partners, CSIRO and Queensland Health, have extended their joint venture relationship in the Australian e-Health Research Centre for a further five years. This is a testament to the value that the AEHRC delivers to both organisations.

Queensland Health continues to reap the benefits of a world recognized digital health research centre with headquarters in Brisbane, with many deep collaborations between clinicians and health services and the AEHRC. The AEHRC is also a core part of CSIRO's health business and CSIRO continues to grow the AEHRC around Australia.

I would also like to acknowledge the great work accomplished by my predecessor, Professor Bruce Barraclough. Bruce has done a tremendous job in providing guidance for the management of the AEHRC as the Centre has grown over the past few years – with an increase in both staff numbers and the impact from our research. I am excited by the opportunities for the AEHRC and look forward to working with CSIRO, Queensland Health and the staff of the AEHRC over the coming years.

Richard Royle
Chairman, the Australian e-Health Research Centre

Foreword by the CEO

I would like to thank our Joint Venture partners, Queensland Health and CSIRO, for their continuing support for the work of the Australian e-Health Research Centre. The extension of the joint venture for a further five years is certainly recognition of the great work the team has been doing and we look forward to the opportunity for continuing our research.

The past 12 months has been another year of growth for the Australian e-Health Research Centre with our staff numbers growing to 80 scientists and engineers as we have been successful in developing new business opportunities and research collaborations.

Our collaborations in Queensland have continued to grow, with many new opportunities as well as continuing collaborations. The AEHRC has recently partnered with the QIMR Berghofer, the Queensland Cyber Infrastructure Foundation, the University of Queensland and the Queensland University of Technology to lead the Genomic Information Management workstream of the Queensland Genomics Health Alliance. With the AEHRC also involved in the Australian and Melbourne Genomics Health Alliance the centre is an important health and bioinformatics partner for Australia's genomics and health projects.

We have also recently had four new mobile health clinical trials begin. These initiatives with Metro North and Metro South Health and Hospital Services will trial the use of mobile health to support patients with Gestational Diabetes, Peritoneal Dialysis, newly diagnosed type 2 diabetes and COPD. Cardihab has recently commenced a first capital raising and two of our staff have joined the new company.
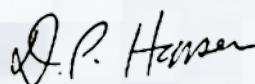
The AEHRC maintains a considerable shareholding in the new company and we hope for a bright future for Cardihab.

Our node in Perth, The Australian Tele-health Research and Development Group is our partnership with the Western Australian Department of Health. The team has recently completed two trials with a trial of diabetic retinopathy screening in GP offices and a mobile phone wound care program.

Our imaging researchers have had their software for MRI based radiotherapy planning used for patients as part of a trial the first step in the adoption of a new, less risk and automated planning software platform. We have also had two of our PhD students receive an Advance Queensland fellowship providing funding for three years for a Postdoctoral Fellowship. This will enable them to put into trial the imaging software for understanding Cerebral Palsy with our collaborators at Lady Cilento Children's Hospital.

The AEHRC continues to contribute to national programs. Our data analytics team have recently partnered with the Department of Health to provide the Risk Stratification algorithm for the Healthcare Home project.

The outcomes from the AEHRC over the past five years put us in a fantastic position at the start of the next five year journey. I am confident that the Centre will continue to grow its impact on Australia's healthcare system over the next five years.

Dr David Hansen
Chief Executive Officer

Research Investment Advisory Committee

Reporting to the Board of the Australian e-Health Research Centre, the Research and Investment Advisory Committee performs an advisory function for the Centre's research activities, and assists the Board to carry out the functions of the Australian e-Health Research Centre.

RIAC Chair: Dr Michael Steyn

The following persons were members of the Research and Investment Advisory Committee throughout 2016-2017:

Chair

- **Dr Michael Steyn**, Director Department of Anaesthesia & Perioperative Medicine, Royal Brisbane & Women's Hospital

Members

- **Dr Andrew Staib**, Metro South HHS and e-Health Queensland
- **Ms Cathy Ford**, Chief Digital Officer, e-Health Queensland, Queensland Health
- **Mr Michael Drahiem**, CCIO, Metro South Health and Hospital Service
- **Mr David Bunker**, Executive Director, Queensland Genomics Health Alliance
- **Dr David Hansen**, CEO, the Australian e-Health Research Centre
- **Dr James Lind**, Director, Emergency Medicine Training, Gold Coast Hospital Emergency Department
- **Dr Cathy Robinson**, CSIRO Land and Water

The following AEHRC staff members attended Research and Investment Advisory Committee meetings during 2016-2017 as guest presenters:

22 August 2016

- NEAT and NEST Research outcomes – **Justin Boyle**
- Overview of Health Informatics at AEHRC – **Michael Lawley**
- Overview of Biomedical Informatics Research at AEHRC – **Olivier Salvado**
- Overview of Health Services Research at AEHRC – **Mohan Karunanithi**

8 February 2017

- The Emerging FHIR Standard – **Michael Lawley**
- Cloud based imaging services – **Jurgen Fripp**
- Mobile Health for Diabetes Patients – **Hang Ding** and **Mohan Karunanithi**

RESEARCH INVESTMENT ADVISORY COMMITTEE

Board of Directors
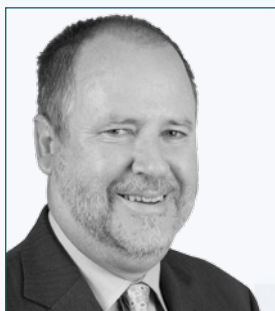
Richard Royle

Chair, the Australian e-Health Research Centre

Richard has 35 years experience in the healthcare industry and has spent the past 10 years as Executive Director of UnitingCare Health in Queensland, incorporating 4 private not-for-profit hospitals totalling over 1,000 beds, and employing approximately 4,000 staff.

He is immediate past President of the Australian Private Hospitals Association and an Adjunct Professor at the University of Queensland and Queensland University of Technology in Health Management.

Richard has overseen the successful development and opening of Australia's first fully integrated digital hospital in Hervey Bay in 2014, and in 2013 undertook the role of chairing an independent review into the Personally Controlled Electronic Health Record on behalf of the Federal Government. He is now actively involved in establishing the new governing body for digital health in Australia.

Dr Richard Ashby AM

Dr Ashby is the Chief Executive of eHealth Queensland responsible for advancing healthcare through digital innovation.

In 2016 Dr Ashby oversaw the successful delivery of Australia's first large-scale digital hospital, the Princess Alexandra Hospital, as the Chief Executive of Metro South Hospital and Health Service. Dr Ashby believes that digital healthcare is one of the most important revolutions in healthcare – providing highly connected and interactive models of care that support personalised, precise and well informed treatment of patients across care settings and care teams.

Dr Ashby is regarded as one of the state's most experienced clinicians and health administrators. In 2010, Dr Ashby was awarded a Member of the General Division of the Order of Australia for service to emergency medicine, medical administration, and a range of professional associations. He is active across a broad range of areas, including teaching, research and consultancy.

Dr Ashby contributes to a significant number of organisations/committees. His roles include:

- Director, Translational Research Institute
- Board Member, Australian e-Health Research Centre
- Board Member Australian Prostate Cancer Research Centre
- Chair, Queensland Policy and Advisory Committee on Health Technology
- Project Lead, Queensland Digital Hospital Program

Cathy Ford

Cathy has more than 25 years experience in the industry supporting organisations, executives and their teams through transformation activities that delivered sustained change.

As a management and ICT professional Cathy works with organisations to transform their business by developing strategies to make better use of people, information, systems and technology. Cathy delivers business value by acting as a change agent for organisations seeking to optimise their business whether that be through customer engagement, service improvement, organisational productivity and efficiency strategies or technology innovation.

Cathy has been the Chief Digital Officer for eHealth Queensland for more than a year. In this role she is responsible for leading the state towards a fully integrated healthcare system, supporting the ICT needs of the state's 16 Hospital and Health Services and the Department of Health.

Rob Grenfell

Dr Rob Grenfell joined CSIRO in June 2016 as the Health Director of the Health and Biosecurity Business Unit.

Rob was previously the National Medical Director of Bupa Australia and New Zealand. He has also held roles as the National Director of Cardiovascular Health at the Heart Foundation and as the Strategic Health Advisor to Parks Victoria and previously a Senior Medical Advisor at the Department of Health Victoria.

Adrian Turner

Adrian Turner is the CEO of Data61 at CSIRO. Data61 is creating our data-driven future. Adrian is a successful and influential Australian technology entrepreneur who has spent 18 years in Silicon Valley. Most recently he was Managing Director and Co-Founder of Borondi Group, a holding company focused on the intersection of pervasive computing, platform economics and traditionally conservative industries. Prior to this, Adrian was co-founder and CEO of smart phone and Internet of Things security company Mocana Corporation, had profit and loss responsibility for Philips Electronics connected devices infrastructure, and was Chairman of the Board for Australia's expat network, Advance. org. He was recently named co-Chair of the Cybersecurity Growth Centre, is a member of the Board of the Australian eHealth Research Centre and is also a member of the UTS: Business School Advisory Board.

He is regarded as a thought leader on entrepreneurialism, Internet of Things and the impact of network connectivity on business economics. He authored the eBook BlueSky Mining Building Australia's Next Billion Dollar Industries. Adrian is a UTS graduate and has completed the Executive Program for Managing Growth Companies at Stanford University.

Richard Symonds
Minutes Secretary

Kelly Tighe
Finance Manager, CSIRO

MEETINGS - Board Meetings for 2016/2017 were held as follows:
29th August 2016 | 31st October 2016 | 6th March 2017 | 5th June 2017

Management and Leadership

DR DAVID HANSEN

MICHAEL LAWLEY

OLIVIER SALVADO

David Hansen is CEO of the Australian e-Health Research Centre, a Research Program in the CSIRO Health and Biosecurity business. David leads an e-Health research portfolio developing information and communication technologies for the healthcare system. These projects across health informatics, biomedical informatics and health services research will underpin the e-health architecture in Australia.

Prior to joining CSIRO, David worked for LION bioscience Ltd in the UK, developing genomic data and tool integration software that was used to publish the first human genome and used at over 200 pharmaceutical and biotechnology companies and research institutes worldwide.

Group Leader, Health Informatics

Dr Michael Lawley is a Senior Principal Research Scientist and Group Leader with the CSIRO Australian e-Health Research Centre, part of the Health & Biosecurity Flagship. Michael leads the Health Informatics Group with teams working on Health Data Semantics, Health Statistics, as well as a Software Engineering team.

He has deep expertise in Clinical Terminology and specifically large scale ontologies such as SNOMED CT. Technology developed by Michael and his team have produced technologies that have been licensed nationally and internationally by standards bodies, government organisations and SMEs.

Group Leader, Biomedical Informatics

Dr Salvado is the group leader for the Biomedical Informatics group at the AEHRC. He is adjunct Professor at the University of Canberra, adjunct Associate Professor at the University of Queensland, and Honorary Research Fellow at the Florey Neuroscience Institute. His research interests include developing bio-informatics methods for large multi-scale clinical studies, Neuroimaging technologies, and investigating novel multi-modal clinical imaging biomarkers. Since 2009, he has been co-supervisor or assessor of 10 PhD students (2 current co-supervisions).

Dr Salvado has published over 70 original research papers cited more than 2700 times in highly-regarded journals including Lancet Neurology, JAMIA, Journal of Neuroscience, NeuroImage, PLoS One, Annals of Neurology, and Brain. Dr Salvado is the co-chair of the ISBI conference that took place in Melbourne, Australia in 2017.

MOHAN KARUNANITHI

PROF. YOGESAN KANAGASINGAM

Group Leader: Health Services

Mohanraj Karunanithi leads the Health Services group at the AEHRC. Mohan has a doctorate in Biomedical Engineering, University of New South Wales. He has over 10 years of experience in cardiac research and 5 years of medical industries experience. At AEHRC, Mohan manages and coordinates research in ICT application in healthcare management and delivery of chronic diseases and aged care.

Director, Australian Tele-health Research and Development Group

Prof Yogesan has developed medical technologies from bench to bed and one of his inventions is used by NASA in the International Space Station. He was the Australian of the Year finalist from WA (2015) and also WA Business Leader of the Year finalist in 2014 for his contribution to Medical Sciences and prevention of blindness. He is a Visiting Scholar to Harvard University and Professor at the School of Medicine at the University of Notre Dame. He was a Fulbright scholar to Stanford University School of Medicine and a NHMRC Research Fellow.

MANAGEMENT AND LEADERSHIP

2017 Annual Colloquium

Over 350 people attended this year's 13th Annual e-Health Research Colloquium held at the RBWH Education Centre in Brisbane on 28 March 2017 and hosted by the Australian e-Health Research Centre.

Professor Keith McNeil, Chief Clinical Informatics Officer of the UK NHS, was our international key note speaker this year, providing an overview of digital health activity in the NHS as well as providing some challenging ideas around digital disruption of the health system.

Attendees also heard about Queensland and Australian initiatives. Dr Richard Ashby, CEO of e-Health Queensland, started the talk by providing an update on the Queensland iEMR and other digital health programs. Particularly pleasing for the AEHRC was Dr Ashby's announcement of a five-year extension to the Joint Venture between CSIRO and Queensland Health. Tim Kelsey, CEO of the Australian Digital Health Agency, then gave an update on the National Digital Health Strategy – and the features of Australia's MyHealth Record system that were international best practice in sharing information with patients and their care givers.

The program then heard talks from our collaborators about the work which our scientists and engineers are enabling across the health system. Talks this year were:

- **Prof Roslyn Boyd**, Scientific Director – Queensland Cerebral Palsy and Rehabilitation Research Centre speaking on advances in Cerebral Palsy research – including the work our imaging scientists are doing to help diagnose the condition earlier and our mobile health researchers are doing in developing rehabilitation technologies.
- **David Bunker**, Executive Director – Queensland Genomics Health Alliance – providing an update as the projects are getting underway to trial the use of genomics in clinical care.
- **Emily Brindal**, from CSIRO's Health and Nutrition group spoke how the personalisation of diet type using psychological theory can help with weight loss.
- **A/Prof Paul Thomas**, Director of the Herston Imaging Research Facility, gave an overview of how the AEHRC biomedical imaging research was helping to advance clinical care across a number of areas by providing quantitative markers from different imaging modalities.
- **Tabs Basit**, Health Psychologist at the Institute for Urban Indigenous Health & our own Dana Bradford gave an overview of the mobile phone enabled Work It Out program for chronic care for our Indigenous population.
- **Dr Anthony Bell** from Metro North Health and Hospital Service provided an overview of the evidence for differential and out of hours outcomes that our health data analytics researchers are undertaking with him.
- **Michael Draheim**, CIO – Metro South Health and Hospital Service, then gave an overview of the iEMR program at PA Hospital, with Michael Lawley from the AEHRC, providing a view of some of our activities in adding additional tools and analytics to the program.
- **Yogi Kanagasingam**, from the Perth office of the AEHRC, then gave an overview of a trial underway in Perth of diabetic eye screening in GP offices with the support of the CSIRO Remote-I store and forward tele-ophthalmology system.

The morning tea and lunch breaks gave all attendees the opportunity to discuss our projects and technology with our scientists through viewing posters and technology demonstrations. The technology demonstrations spanned mobile health – for Indigenous health, cardiac and chronic diseases and orthopaedics; biomedical imaging – for Cerebral Palsy to Alzheimer's disease; genomics – with our big data analytics tools; and our health data tools – from our clinical terminology tools to our health data analytics tools.

Feedback from the day was again excellent and it was great to see so many of our partners and stakeholders together.

News and Awards

News and Communications

AEHRC Research was highlighted many times in the mainstream media during the year.

- The final report of the National Tele-health Trial were released with considerable press interest. Rajiv Jayasena was interviewed by Channel 7 News, the Financial Review and on ABC Radio while David Hansen was interviewed for Channel 10 news.

- Research results from the Mental Health CRC were also highlighted – with Olivier Salvado interviewed on ABC Radio and our collaborator interviewed on Channel 10's The Project.

- David Hansen was on a panel on the ABC Radio National program Big Ideas. The panel was from the Melbourne Genomics Health Alliance (MGHA) and discussed the outcomes from the first stage of the MGHA program.

- David Hansen was interviewed on ABC News 24 about tele-health.

- Farhad Fatehi from AEHRC, Tony Russell and Len Grey were featured on Channel 10 Brisbane with a story about the mobile health diabetes trial AEHRC are running with Metro South Brisbane and University of Queensland.

The AERHC contributed a number of articles to The Conversation:

- David Ireland and Dana Bradford had two articles in The Conversation – "Research in autism-friendly technology needs to improve to make a real difference for people" and "Your smartphone knows a lot about you, but what about your mental health?"

- Olivier Salvado had an article published "Why artificial intelligence has not revolutionised healthcare... yet"

Awards

The AEHRC was again successful at the Annual Australian Information Industry Association (AIIA) iAwards

- In August 2016 SnoMAP won a National Merit Award at the iAwards – a project between AEHRC and Metro South HHS

- In June 2017 the Transformational Bioinformatics team won 2 New South Wales iAwards event for the GT_Scan2 technology for gene-editing – winning the awards for "Big Data and Machine Learning" and another for Primary Industries.

- Also in June 2017 the AEHRC Clinical Terminology team won 2 Queensland iAwards for the National Clinical Terminology Service, our project with the Digital Health Agency in the categories of "Infrastructure and Platforms Innovation of the Year" and "Public Sector and Government Markets"

- Cardihab was selected as one of the Tech23 for 2016 and participated in the Tech23 Showcase in Sydney in October 2016. Cardihab was awarded 3 prizes at Tech23: the "Austrade Best Startup award", the "AMP Amplify award for best technology Tech23 2016 start-up founded by a woman", the "Amazon web services award".

- PD-BUDDy (Peritoneal Dialysis platform) was presented at Renal Society of Australasia (RSA) conference and won the "People's Choice" Award.

Research Program

Over the past five years the AEHRC has developed into a full Health and Biomedical Informatics research program. The span of a health and biomedical informatics research program is across health informatics, covering data about patients, services and populations; biomedical informatics, using patient genomic and imaging data to personalise diagnosis and treatment; and health services – the use of technology in delivering services to patients.

The AEHRC Strategy for the next five years aims to use the research capability of our three research groups – health informatics, biomedical informatics and health services research – to continue to tackle challenges of Australia's healthcare system and expand the impact of our research.

The challenges set out in this strategy for the next five years are to:

- increase our science outcomes to be recognised in the top three e-Health research centres in the world;
- increase our impact through increased adoption of our technologies;
- develop new areas of impact in Indigenous Health, Precision Medicine, Big Data Medical Research, Healthy Ageing and a Learning Healthcare System;
- increase our commercial outcomes; and
- continue the growth of the AEHRC around Australia.

The AEHRC research program is informed through strong partnering with the health industry – including clinicians, researchers, health service executives and the Health IT vendor community. With more than half our staff based on the Royal Brisbane Women's Hospital campus in Brisbane, AEHRC scientists and engineers have strong relationships with Qld health administrators, clinicians and researchers. As CSIRO's e-Health Research Program, AEHRC can also access expertise from across CSIRO.

HEALTH INFORMATICS

The introduction of electronic health and medical records, including the Federal My Health Record, is increasing the demand for clinical information to be shared between health practitioners and with patients.

Our Health Informatics research develops and applies innovative tools and techniques for evidence-based solutions and strategies to support improved health outcomes. Our goal is to unleash the value in health data, including both electronic health records and administrative data sets, to improve patient outcomes and health system performance and productivity.

Our scientists and engineers apply machine learning, natural language processing, formal logic, statistical and simulation approaches to the collection, processing, analysis and sharing of health information for decision support, systems modelling and reporting.

BIOMEDICAL INFORMATICS

New medical technologies – especially genomic and imaging technologies – are leading a revolution in the personalisation of diagnosis and treatment.

Our Biomedical Informatics research develops innovative technologies for the discovery and communication of meaningful patterns from the new medical technologies. The aim is to develop techniques to report and visualize complex biomedical information for clinical diagnosis and screening. This information can ensure that the diagnosis is precise and the treatment appropriate to reduce unnecessary treatment and improve outcomes.

Our scientists and engineers use the simultaneous application of statistics, computer programming, and applied mathematics to develop solutions that communicate insights to clinicians and clinical researchers.

HEALTH SERVICES

The increase in mobile technologies and high bandwidth broadband is changing the way that services are provided in all walks of life – including health services.

Our Health Services researchers work with health service providers to develop internet enabled models of care to overcome the burden being placed by chronic disease and aged care. Our teams are currently trialling technologies to deliver health services through mobile health and tele-health technologies for diseases from eye diseases, cardiac diseases and diabetes to stroke and hip replacement patients.

Our scientists and engineers use our expertise in mobile technology, home monitoring, telemedicine, wellbeing and behavioural change to improve health services to urban, rural and remote Australians.

Health Informatics

2016/17 Science and Impact Highlights

- The Health Data Analytics team continued to be recognised by CSIRO with winning the 2016 Health & Biosecurity Impactful Publication Award for their seminal work on hospital performance targets published in the MJA.

- Analysis conducted by the team in 2016 quantified the impact of winter on state-wide hospital bed planning to form the basis of winter bed plans for all of Queensland Hospital and Health Services. The results were directly incorporated into the 'Winter Beds Strategy 2016' published by the State of Queensland via their Healthcare Improvement Unit.

- The SnoMAP tool, developed with Metro South HHS, is now being used by all Qld Hospitals deploying the Cerner iEMR to meet statutory reporting requirements with a resulting measurable increase in data quality.

- The Australian Digital Health Agency launched the National Clinical Terminology Service – a joint project with the Australian e-health Research Centre. Through the NCTS over 20 companies and organisations have licensed the AERHC terminology server, Ontoserver, for implementation of state-of-the-art support for clinical terminology in their e-Health products.

- The Medtex, medical text analytics tool, was deployed within Queensland Health to process and analyse both the historical and live pathology feeds for cancer notifications reporting from public and private pathology laboratories across the State of Queensland.

- The AEHRC clinical terminology team is contributing to the Australian, Queensland and Melbourne Genomics Health Alliances to capture accurate clinical phenotypes – a vital part of ensuring that Australia will get full value from investments in genomics medicine.

HEALTH INFORMATICS

Health Informatics Group Leader: Michael Lawley

Australia's health care system faces many challenges. One is the increasing demand for clinical information to be shared between individual health practitioners, health care provider organisations and state/territory health departments.

Our Health Informatics research develops and applies innovative tools and techniques for evidence-based solutions and strategies to support improved health outcomes. Our goal is to improve the quality of, and unleash the value in, health data, including both electronic health records and administrative data sets, to improve patient outcomes and health system performance and productivity.

We apply machine learning, natural language processing, formal logic, and statistical and simulation approaches to problems involving decision support, systems modelling and reporting.

Health Data Semantics Team Leader: Anthony Nguyen

Data is captured about patients in a number of different formats, electronic repositories and using many different terminologies. Our technologies are targeted at understanding the information in data, whether the data is captured in an electronic health record, coded in a clinical database, captured from sensors, described in medical free text reports or even captured using imaging technology.

The Health Data Semantics team is focused on deriving value from electronic health data in terms of improving patient outcomes, and health system performance and productivity. The group does this by developing and applying machine learning, natural language processing, information retrieval and formal logic approaches to deliver and support meaningful data interoperability and analysis for decision support, analytics, modeling and reporting.

Health Data Analytics Team Leader: Rajiv Jayasena

Our work in this area supports acute hospitals by applying evidence-driven strategies to support improved health outcomes. For example, hospital overcrowding and timing of discharge are commonly linked to sub-optimal patient flow, poor quality of care, and unnecessary mortality. Consequently hospital services subscribe to theoretical targets for occupancy levels and discharge times. A better understanding of how occupancy levels and discharge times influence patient flow parameters, and more precise targets based on these, derived through modelling and simulation, would improve capacity management strategies and care outcomes.

Health Data Engineering Team Leader: Derek Ireland

Our world class Health Data Engineering team are a dedicated team of software engineers who work with our scientists across the AEHRC in delivering solutions to our customers and partners.

Projects

Clinical Terminology

Successful adoption of standard terminologies such as SNOMED CT and the Australian Medicines Terminology (AMT) is vital for the success of enabling patient data to move between clinical systems, including the My Health Record system, in a safe way. Many systems across health organisations such as Queensland Health will be required to migrate from other code sets to SNOMED CT. Our tools help with this migration and deal with complexities such as the level of detail in each code and gaps in the codes while still ensuring that high-quality data is captured.

We have developed significant national and international impact through our tools: the free SNOMED CT and AMT browser, Shrimp; the terminology mapping and subsetting tool, Snapper; the cloud-based terminology server, Ontoserver; and the reasoning engine, Snorocket.

A National Clinical Terminology Service

The AEHRC has worked with the Australian Digital Health Agency to deliver the National Clinical Terminology Service (NCTS). Following success with the phase 1 project, the AEHRC's Ontoserver was selected to deliver this service via a nationally hosted service. Technology providers can also license Ontoserver free of charge for integration into their own health record solutions, with a syndication service keeping the standardised terminology content up to date. This is a pioneering approach to making standard clinical terminology readily available – going well beyond the traditional mechanism of providing files for download along with documentation.

Advantages to this approach include:

- Providing terminology server software ensures consistent interpretation of specifications and that state-of-the-art search algorithms are available to all implementers.

- Local terminology server instances allow for local autonomy; local code systems and value sets can be supported using the same system supporting standard clinical terminology like SNOMED CT-AU.

- Syndication of content ensures that every terminology server instance can easily remain up-to-date with monthly SNOMED CT-AU releases without complex and manual update processes.

- Use of the simple and easily adopted HL7 FHIR API not only means there's no lock-in to one proprietary terminology server implementation, but it is both cloud and mobile friendly, and paves the way to broader adoption of what is promising to be a truly revolutionary standard for Health IT.

Through 2016/17 the team finalised the implementation so that Ontoserver was enterprise ready and then commenced a major upgrade to the next version of FHIR (STU3), closely engaged with the FHIR community to clarify, refine and improve details of the Terminology Services subsystem of the HL7 FHIR Specification, and engaged closely with State jurisdictions and the vendor community through a series of very successful Connectathons and workshops to ensure that the resulting service delivers what is needed.

The service was soft-launched in October 2016 with several Health IT providers and State health departments ready to go from day one. There are now nearly 400 licensees accessing SNOMED CT-AU through the NCTS portal, and more than 20 organisations with Ontoserver sub-licences, and at least four production deployments. There has also been considerable interest in the service from international jurisdictions with New Zealand investigating how they might participate in an expansion of the NCTS and Canada initiating a similar service.

The NCTS was the winner of two state AIIA iAwards: *Infrastructure & Platforms Innovation of the Year and Public Sector & Government*. NCTS also won the AIIA Pitchfest in the Public Sector & Government category.
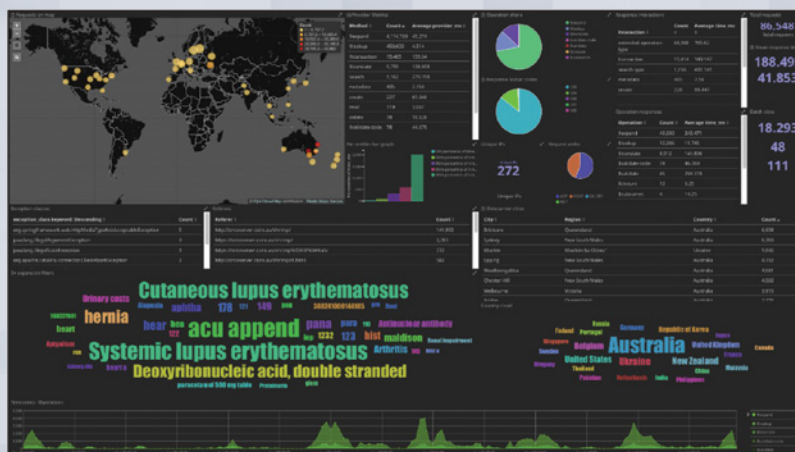

Figure 1. A typical seven days of Shrimp usage

HEALTH INFORMATICS

Clinical Terminology *(continued)*

SNOMED CT in the Qld Digital Hospital Project

The Queensland Digital Hospital Project is introducing the SNOMED CT terminology as part of the implementation of an integrated Electronic Medical Record. As part of this project the AEHRC has worked with the Princess Alexandra Hospital's (PAH) Digital Hospital program on several collaborative projects. An early outcome was to work with the PAH and the Australian Digital Health Agency to release an extension to SNOMED CT-AU containing more than 100 new procedure codes required to support the pioneering use of SNOMED CT in the deployment of the Cerner Surginet product. Further work continues to expand the SNOMED CT reference set for SurgiNet as the Cerner product is deployed in other Queensland hospitals.

SNOMED CT encoded data for secondary reporting purposes

One part of broader project dealt with the problem of continued reporting of ED non-admitted patients after the switch from use of ICD 10 AM to SNOMED CT. The result of this was a tool, snoMAP. The snoMAP tool extends coverage of SNOMED CT from a relatively small subset of Clinical Findings to all relevant codes clinicians will need to use to document patient records in the Emergency Department setting. The goal was to re-purpose the original SNOMED CT-encoded patient data and maintain its truth value for clinical care delivery, and to ensure it complies with, and qualifies, for Activity Based Funding. As the Digital Hospital program has been rolled out across Queensland, additional hospitals have begun to use snoMAP. snoMAP content, both SNOMED concepts and ICD-10-AM codes, are updated twice per month allowing PAH and other QH Digital Hospitals to submit data for ABF in near real time.
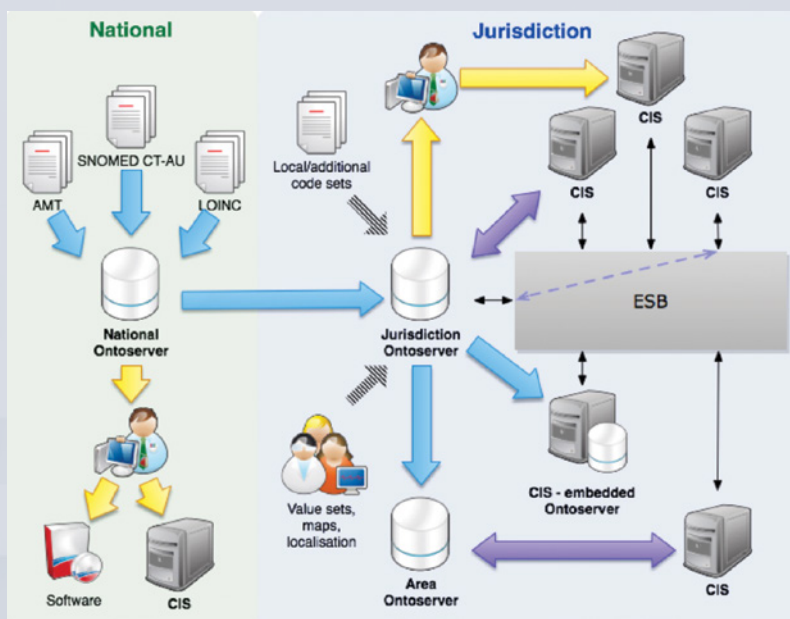

Figure 2. High-level architecture of the National Clinical Terminology Service (NCTS)

Injury surveillance and reporting

This approach to using SNOMED CT encoded data, and snoMAP, has now been extended to include specific subsets suited to Injury Surveillance and Reporting.

Clinical cohorts

Work continues on developing particular subsets or SNOMED CT for analysing data based on patient cohorts. Early work has investigated the use of snoMAP to produce routine reports for particular patient cohorts, such as patients presenting with Diabetes or Mental Health issues. This work will help preserve the routine and ad hoc reporting – at a local hospital level – in the same way that data analysts previously produced 'dash-board' reports using ICD-10-AM encoded data.

Data validity

Another project was to evaluate SNOMED CT data quality as affected by specific user interface elements. Escargot provides a visualisation of refinements to the display text of SNOMED CT diagnosis codes in the patient record. By performing some simple analysis, these changes can be categorised to indicate whether a significant change in meaning is indicated and thus can be used to highlight potential data quality problems. Preliminary results show that most changes are refinements to the code's meaning.

Allied Health

Further terminology work has been undertaken to support the development of state-wide data collections for the Allied Health Sector. Various Allied Health disciplines are unifying their approach to data capture and reporting, and are standardising using SNOMED CT in the Cerner product. At present the legacy termsets have been mapped to SNOMED CT (n=2000 terms). Approximately 200 new concept requests have been generated by the Allied Health discipline groups, and these will be added to SNOMED CT AU in due course. The plan is to expand this initial mapset of 2,000 concepts and increase the expressivity of data capture in Allied Health records. A much richer and descriptive data collection will enable expanded measures of the effectiveness and clinical outcomes achieved by the Allied Health profession, rather than only service event based metrics.

RACS MALT goes SNOMED CT-native

During 2016 the AEHRC continued our collaboration with the Royal Australasian College of Surgeons (RACS) to successfully transition their Morbidity Audit Logbook Tool (MALT) from ad-hoc terminology to using SNOMED CT-AU procedure codes natively. This includes the development and maintenance of aggregation maps to support ongoing reporting processes from the MALT data. During 2016/17 RACS has migrated to an NCTS-based deployment of Ontoserver using FHIR-based valueset and map artefacts, and we are now working toward expanding their initial SNOMED CT valueset (from 14,000 concepts, to 30,000 procedure concepts). RACS are also considering broadening the use of SNOMED CT, so that MALT will allow their users to also capture data relevant to disgnoses and outcomes.

NPS-Medicine Insight

AEHRC have worked with the National Prescribing Service (NPS) on their Medicine Insight program during 2016-17. The NPS Medicine Insight program colects data from participating General Practitioners, and provides reprots (insight) about their prescribing behaviour, their patients and casemix, and related metrics. Much of the patient data collected by NPS is non standard, chararcterised by the impacts of different GP desktop systems and different (non comparable) native termsets. The vast majority of data received by NPS is uncoded, free text and is not amenable to straightforward data analysis.

The project focussed on data transformations from native termsets used in GP systems to SNOMED CT using Snapper, and the conversion of uncoded free text to SNOMED CT encoded data using first line NLP methods. Data transformations to SNOMED CT will give the Medicine Insight program an increased ability to unify and analyse data received based on a single national standard terminology, regardless of its origin system.

Over 180,000 data instances were transformed, providing a SNOMED CT valueset of 15,000 unique concepts which represented 98.8% of the routine data collection.

AEHRC also provided assistance in establishing the NCTS-Onotserver instance for NPS use across their data warehouse and data store, providing the opportunity to adopt SNOMED CT for other NPS programs and products.

Key Collaborators:

- Australian Digital Health Agency/National eHealth Transition Authority
- Royal Australasian College of Surgeons
- Princess Alexandra Hospital, Metro South HHS
- Australian Genomics Health Alliance
- National Prescribing Service

Project Highlights for 2016/17:

- Development of Ontoserver V5 for the NCTS with the latest STU3 version of HL7's FHIR APIs and syndication support
- Contribution to the refinement of the HL7 FHIR Terminology Services API standard STU3
- First full implementation of the IHTSDO's Expression Constraint Language and Logical Model (DL)
- Complete rewrite of Snapper to work with FHIR and run in a web browser as a cloud-based app
- Impact and expansion of the snoMAP tool as it has been taken up at additional sites throughout Queensland

Project Aims for 2017/18:

- Expand and improve terminology-enabled data analytics
- Investigate models to support reasoning across modular and multi-versioned ontologies
- Develop enhanced algorithms for automated analysis of terminology quality metrics to improve data quality
- Develop more sophisticated auto-mapping strategies in Ontoserver to be utilised via Snapper
- Develop assistive technologies that will support the clincian community to capture accurate, codeable, data for documentation of patient records.
- Enhanced support for OWL-based ontologies to support genomics projects
- Extend our automated techniques for developing aggregation-based maps for reporting and data analytics
- Build on the successful rollout of Ontoserver as the NCTS terminology server platform-of-choice through international adoption and licensing

HEALTH INFORMATICS

Health Text Analytics

Electronic Health Records (EHR) are expected to enable better health outcomes and improved efficiencies in our health services. The majority of EHR data is recorded in unstructured free-text; clinical progress reports, imaging and laboratory reports, discharge summaries, death certificates are just some examples. This data contains information that is valuable for clinical decision support and secondary use such as for population health monitoring and reporting. However, the extraction of clinical information from large volumes of free-text data hinders manual interpretation.

The medical text analytics team is developing and applying advanced natural language processing, information retrieval, and machine learning techniques, along with standard clinical terminology (e.g. SNOMED CT) semantics and reasoning, to provide meaningful and accurate computational interpretation of clinical free-text.

Our solutions have been developed in partnership with healthcare practitioners from Cancer Registries, hospital radiology and emergency medicine departments. Working with health industry stakeholders allows our medical text analytics solutions to leverage the wealth of clinical free-text reports and aid in decision support and reporting.
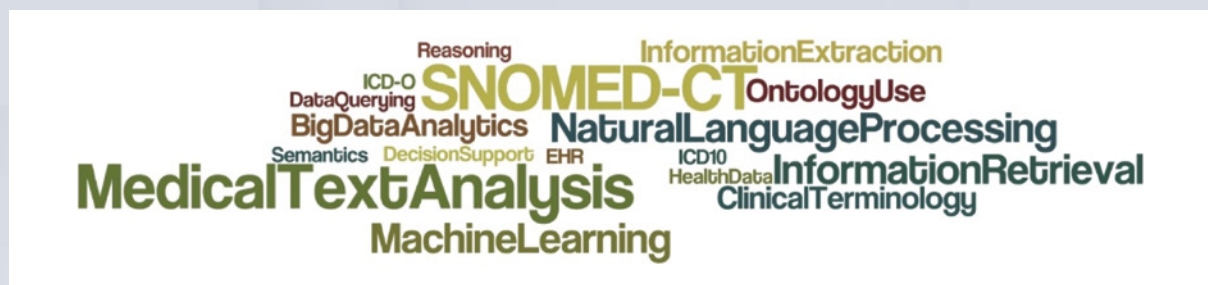

Figure 1. Artificial Intelligence capabilities for understanding and reasoning with clinical text data with an emphasis on standard Clinical Terminologies for data interoperability and analytics.

HEALTH INFORMATICS

Automating Clinical Data Registries

Cancer notifications to Cancer Registries remain typically paper based – meaning that the statistics about data incidence can be many years out of date. This paper based approach to cancer statistics reporting is delaying the delivery of more timely cancer information due to the extent of manual processing and an out-dated information collection system.

In partnership with the Queensland Cancer Control Analysis Team (QCCAT), Queensland Health, the AEHRC is extracting information about cancers from the free-text contents of pathology HL7 messages for cancer notifications, synoptic reporting and cancer staging. This is enabling QCCAT to build a real time cancer registry which processes pathology reports on a nightly basis and provides cancer incidence data for activities such as cancer monitoring, health service planning and research.

This medical text analytic service uses the AEHRC Medtex platform to automatically read and analyse the pathology reports.

Reconciling medical records to prevent missed diagnoses

The checking of radiology imaging and pathology laboratory reports to ensure abnormalities or positive results, respectively, are not missed and that patients receive appropriate follow-up once discharged from the Emergency Department (ED) is an essential but laborious task. Due to a busy ED and resourcing issues, it can often be days after the patient's initial presentation to the ED that this checking process is performed. This process results in time inefficiencies with delays in reporting, delays in checking reports, and delays in recalling patients. A timelier and efficient process is therefore required to improve patient outcomes and staff resources.

In partnership with the Royal Brisbane and Women's Hospital, Gold Coast University Hospital and The Prince Charles Hospital EDs, we have developed algorithms and models to reliably identify abnormal or positive results from radiology and pathology reports, respectively, and link these with patients' disposition as recorded in the Emergency Department Information System to provide decision support to the, currently manual, checking process. Future work will develop software to demonstrate the clinical and patient benefits arising from the technology-based solution.

Diagnosis coding from electronic health records

Clinical coders abstract relevant information from patients' medical records and decide which diagnoses and procedures meet the criteria for coding as per Australian Coding Standards. The process mainly relies on manual inspections and experience-based judgments from clinical coders, and the effort required for information abstraction is extremely labour and time intensive and prone to human errors.

In partnership with the Gold Coast University Hospital and Health Service, we have developed algorithms and models for automating the diagnosis coding (ICD-10-AM) process from hospital progress notes. Promising results were achieved when compared to what was projected as possible from a diagnosis code validation study.

Health record search & analytics

Search technologies are critical to enable clinical staff to rapidly and effectively access patient information contained in free-text medical records. Health search is challenging as it suffers from the semantic gap problem: the mismatch between the raw data and the way a human being interprets it. Valuable domain knowledge explicitly represented in structured knowledge resources such as ontologies (e.g. SNOMED CT) can be leveraged to support such semantic inferences. The focus of our research is on health record searching and analytics using text, concepts, annotations, and SNOMED CT subsumption and relation querying.

To support the need for Evidence-based Medicine we have developed a search engine providing clinicians easy access to the vast and ever changing body of medical literature. A key, novel aspect of the search engine is that it is specifically tailored around the three clinical tasks of searching for diagnoses, searching for treatments and searching for tests.

All results are displayed, and the clinician can interact with the system, according to these three clinical tasks. An empirical evaluation of the systems showed both better quality results and time savings from the task-oriented approach.
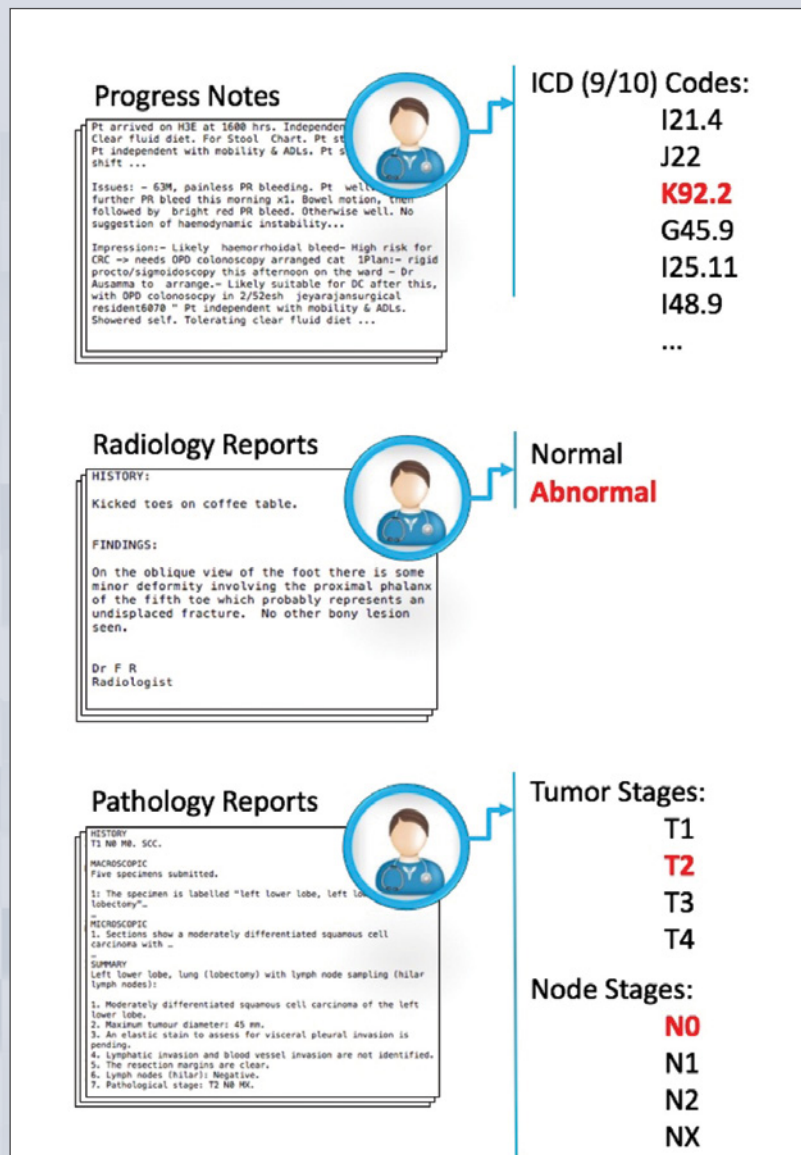

Figure 2. Medical free-text analytics applications for three different clinical document classification tasks: (i) identification of the ICD-10-AM diagnosis codes from progress notes (ii) identification of abnormalities from radiology reports; and (iii) classification of cancer stages from pathology reports.

HEALTH INFORMATICS

Health Text Analytics *(continued)*

Collaborators:

- Queensland Cancer Control Analysis Team (QCCAT), Queensland Health
- Department of Emergency Medicine, Royal Brisbane and Women's Hospital
- Department of Emergency Medicine, The Prince Charles Hospital
- Department of Emergency Medicine, Gold Coast University Hospital
- Gold Coast Hospital and Health Service
- Department of Radiology, Princess Alexandra Hospital

Project Highlights for 2016/17:

- Developed a new high throughput computational framework for Medtex – to support faster and accurate processing and analytics of large-scale clinical narrative reports.
- Deployed the new Medtex within Queensland Health to process and analyse both the historical and live pathology feeds for cancer notifications from public and private pathology laboratories across the State of Queensland.
- Application of new machine learning techniques and algorithms based on deep learning achieved competitive and/or improved classification performances compared to traditional state-of-the-art machine learning methods for the tasks of abnormality identification and diagnosis coding.
- Developed a search engine for evidence-based medicine tailored to the three clinical tasks: diagnosis, testing and treatment. Developed an automated method to match patients to eligible clinical trials based on their electronic patient record.

Project Aims for 2017/18:

- Automatically abstract important clinical indicators for cancers to extend the cancer stage and synoptic reporting capabilities within Queensland Health.
- Develop medical record checking decision support application for clinical interaction.
- Investigate the application of deep learning for developing a good computational representation of both the structured data and unstructured free-text in EHRs that could be leveraged across a wide range of clinical classification tasks – patient classification, disease risk stratification and treatment outcome.
- Extend the health text search and analytic technology solutions to other health applications and report types.

PhD Student Profile

Name: Mahnoosh Kholghi

AEHRC PhD Top-Up

Scholarship Queensland University of Technology

Active Learning for Concept Extraction from Clinical Free Text

A draw back to machine learning approaches for processing medical text is the large human annotated corpus needed to train the machine learning classifiers to achieve the best performance. Within the healthcare domain such annotations require the participation of domain experts, incurring significant costs.

This thesis investigated and developed a novel Cost-efficient Enhanced Active Learning (CEAL) framework to expedite the clinical concept extraction process by significantly reducing the actual annotation cost, while ensuring high quality extracted concepts. It was built on novel active learning approaches, namely, semi-supervised learning, unsupervised learning, representation learning, along with the use of domain knowledge resources. Additionally, an AL-assisted pre-annotation scheme was also introduced, in which the learning models built across the AL process generated high quality pre-annotations to be reviewed by human annotators. This further accelerated the annotation process, by significantly reducing the number of manual annotations that must be added or corrected compared to annotation from scratch.

Health Data Analytics

The health data analytics team develops and delivers technologies to improve the safety, quality and efficiency of our healthcare system. These tools provide information on the performance of the system to help meet patient flow performance targets, whilst solving the challenge of overcrowding and system bottlenecks. Examples include patient flow modelling and implementation research to provide hospitals with analytics, optimisation, and operational decision support tools that can help hospitals to meet patient flow related performance targets.

The work demonstrates an intimate knowledge of the Australian health system and associated datasets as well as knowledge of the regulatory frameworks of working with sensitive health data and potential quality issues associated with health data. The Health Data Analytics team include several statisticians, engineers and implementation research scientists to ensure statistical rigour in every analysis.

Patient Risk-stratification Model (PRM) for Health Care Homes

In 2016/17, the team were successful in tendering as part of a consortium for the federal Government's Health Care Homes initiative aimed at the primary health care system. In this project, the team is responsible for the development and validation of algorithms to be used in the program at a GP practice-level to identify potentially eligible patients and stratify patients according to their risk of unplanned hospital admission in the next 12 months.

The benefits of such a risk stratification tool for chronic disease include reduced level of dependency and improved health outcomes for chronic disease patients due to early clinical intervention; cost savings as a result of reduced readmission rate; reduced acute length of stay; reduced emergency presentations; improved equality in health care access based on actual need; more effective and coordinated health service planning based on health needs; and facilitation of person based health care planning through the provision of risk scores to treating practitioners.

This work will be delivered in 2017/18 and currently the team are working through significant data preparation challenges such as linking primary care data to hospital episode information.

Re-admission Risk Project

Throughout 2016/17, the team continued their work developing a web-based risk stratification algorithm that can be used to identify chronic disease patients with a high risk of re-hospitalisation. Logan Hospital has been identified as the partner site for this project which involves employing routinely collected administrative and clinical datasets for model development, followed by a 12-month trial to quantify the impact on chronic disease readmissions and care planning process.

Candidate risk stratification algorithms have been developed, the design of the web interface is underway and the trial will get underway at Logan Hospital in early 2018.

Identifying choke points in the ED-ambulance interface

The team undertook a quantitative analysis of Queensland Ambulance Service and Queensland Health data to assess the variation in Patient Off Stretcher Time and maximum waiting time for transfer to ED care, derive a continuous count of ambulances awaiting patient offload at any time-point for each site and model the relationship between NEAT, POST, ambulance arrival rate, and ambulances waiting. Among the findings is an association between higher levels of ED occupancy and both the number of ambulances waiting to transfer care of patients at the ED and the average POST time across most sites. The results of this analysis can improve resource utilisation and assist performance improvement initiatives in both Queensland Health and QAS.

HEALTH INFORMATICS

Health Data Analytics *(continued)*

Generating an evidence base for inform policy around after-hours care

There is a need to deliver healthcare in a manner that maximises outcomes for patients. In 2016/2017, the AEHRC undertook a formal evidence based scientific analysis commissioned through the Queensland Clinical Senate to investigate whether outcomes are different for patients who seek care at public hospitals outside of normal business hours compared to other times of the week.

The main outcome measure of interest was mortality due to the wide acceptance of death being the ultimate outcome based quality measure. Other outcomes assessed in the study included ED and inpatient length of stay, inpatient readmission rate, ED and inpatient costs and ED patient experience. The results provide evidence around variation in patient outcomes associated with after-hours care and have been presented to senior executives of Queensland Health. Importantly the work is identifying factors that may influence observed variation to support improved health service delivery.

Developing an evidence base to better target efforts to improve the scheduling of surgery in public hospitals

In 2016/17, the team successfully delivered a project involving statistical modelling of surgical and inpatient data for the major public surgery centres across Queensland (31 hospitals). The key findings from the project included new insights related to:

- The relationship between planned and actual utilisation of operating theatres.
- The efficiency of surgery sessions measured in terms of unused time, delays within a session, late starts for anaesthetics and surgery, and cancelled bookings within 48 hours.
- The change in volume and consistency in Surgery Time, exploring variations of these with respect to hospital, day of week, seasonal patterns, session specialty, patient fitness and surgery type.
- Variations in the value and consistency of pre-operative Anaesthetic Time (where it occurs before Surgery Time) with respect to hour of day and day of week, seasonal patterns, session type, session specialty, patient fitness and surgery type.
- Variations in pre-operative and post-operative inpatient length of stay with respect to facility, session speciality, DRG, discharge status, urgency category and surgery type.

These insights into scheduling can be used by administrators in targeting efforts to address current challenges in surgery scheduling practice.

HealthLinks Chronic Care Evaluation

HealthLinks Chronic Care (HLCC) is a 3.5 year pilot program by the Victorian Department of Health and Human Services (DHHS) and evaluated by CSIRO. It is well established that integrated, coordinated care can result in better health outcomes for people living with chronic disease. There is also evidence that current funding mechanisms can limit health services from providing a cohesive and coordinated model of care that integrates hospital, ambulatory and community-based services. Therefore this project aims to remove some of those barriers, enabling health services to trial innovative models of integrated care.

The HLCC funding model is to provide capitation funding to health services for patients at risk of multiple unplanned (re)admissions that the health service may be able to impact through better discharge planning, better streaming to existing (clinical and social-economic driven) programs or new service models for community management. A novel risk algorithm will identify the eligible cohort of patients who are at high risk of unplanned readmission to hospital and these patients will be enrolled in the HealthLinks program. Ten Health Services in metropolitan Melbourne are part of this evaluation.

CSIRO aims to evaluate the effectiveness of this flexible funding model as means of reducing hospital re-admissions in a patient cohort that are at high risk of multiple unplanned hospital admissions. A secondary aim is to evaluate the effectiveness of alternative models of care.

Analysis of patient journeys throughout hospital

This work quantified delays at various waypoints in a patient's journey through hospital across a multi-site setting. The team built simulation models to determine the impact of reducing each process delay on flow efficiency, and recommended specific bottlenecks associated with the greatest improvement on flow-related Key Performance Indicators.
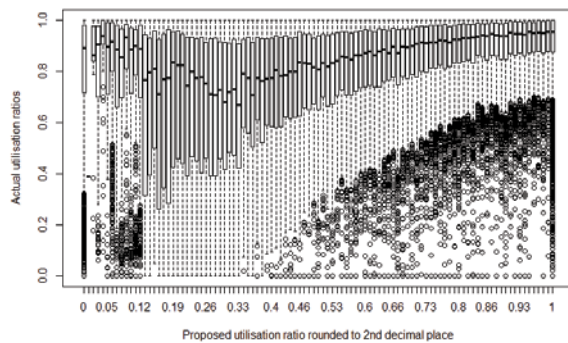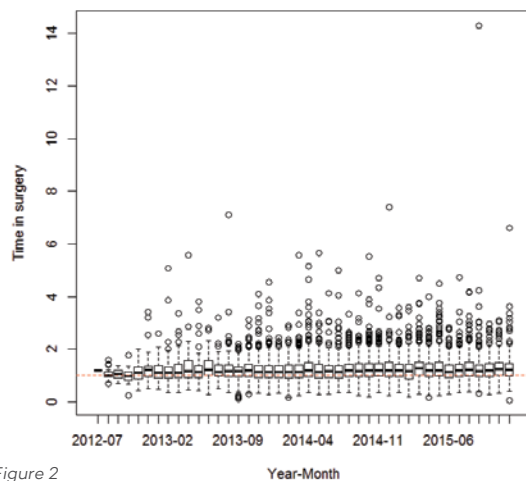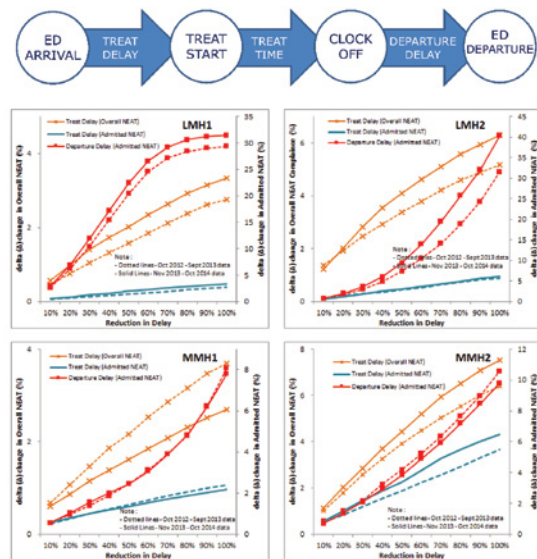
Figure 1

Figure 2

Figure 3

Figure 1 – Utilisation of Surgery Sessions. For efficient surgery processes, actual utilisation should equal proposed utilisation. The figure indicates actual utilisation mostly higher than proposed utilisation (responsive operationally but underplanned) and the biggest difference is when proposed utilisation is low.

Figure 2 – Analysis of surgery duration and variation over time; For most surgery specialties, variation and surgery times are increasing with time. To control surgery efficiency, we need to be able to predict surgery duration with no variation.

Figure 3 – Quantifying the improvement in flow performance resulting from reducing ED delays. The figure shows the change in NEAT at 4 hospitals, resulting from simulated reduction in treatment delay and departure delay.

HEALTH INFORMATICS

Collaborators:

- Federal Department of Health
- Victorian Department of Health and Human Services (DHHS)
- Precedence Health Care/Sonic Health Services
- Queensland Ambulance Service
- Healthcare Improvement Unit, Queensland Health
- Metro South Hospital and Health Service, Queensland Health
- Metro North Hospital and Health Service, Queensland Health
- Sunshine Coast Hospital and Health Service, Queensland Health
- Health IQ/Telstra Health

Project Highlights for 2016/17:

- The Health Data Analytics team continued to be recognised by CSIRO with winning the 2016 Health & Biosecurity Impactful Publication Award for their seminal work on hospital performance targets published in the MJA.
- Research outputs generated by the Health Data Analytics team was licenced to Telstra-Health and included in subsequent sales to hospitals.
- Analysis conducted by the team in 2016 quantified the impact of winter on state-wide hospital bed planning to form the basis of winter bed plans for all of Queensland Hospital and Health Services. The results were directly incorporated into the 'Winter Beds Strategy 2016' published by the State of Queensland via their Healthcare Improvement Unit.

Project Aims for 2017/18:

- Identifying chronic disease patients with high risk of hospital readmission.
- Development and validation of a risk stratification tool for the Department of Health's Health Care Homes Initiative
- Continued support, validation and extension of the Patient Admission Prediction Tool with Qld Health.
- Trail of risk stratification of patients at discharge underway at Logan Hospital.

Health Data Engineering

Our world class Health Data Engineering team are a dedicated team of software engineers that work with our scientists across the AEHRC in delivering solutions to our customers and partners. With specialists skills in mobile app design and development; web based software development as well as specialist knowledge in health IT standards such as HL7, the team contribute to projects across the Australian e-Health Research Centre.

Over the past 12 months the team have continued to develop our MoTER mobile phone platform to support our mobile health projects; worked with our clinical terminology specialists to deliver on the National Clinical Terminology Service; developed a new version of our MedText medical narrative processing software and developed FHIR based resources for use across our projects. The team also continue to support a number of clinical trials with various Clinical Trial software packages.

MoTER Chronic Disease Platform

Many of the projects from the Mobile Health group involve testing the effectiveness of new care models delivered through Mobile technologies like smartphones and wearables and sometimes passive sensors. The engineering team manage a common framework to deliver these projects, attempting to maximise reuse while not hindering innovation, known as the MoTER Platform. The platform consists of iOS, Android native applications and a Web Portal for clinicians to review the collected data.

AEHRC on FHIR

Activities included participating in Connectathons and Hacking Health to build skills and awareness, using the Medications Resource to represent medications from the Australian Medicines Terminology and other sources, using ValueSets for medication input in mobile apps, experimenting with the use of FHIR ConceptMaps for MedText, investigation into the use of FHIR to represent and exchange clinical trials data, both as a view of ODM/CDISC data and natively, dynamic generation of Angular-based data entry user interfaces from FHIR Profiles, and an extended version of the HAPI FHIR Server that delegates to Ontoserver for its terminology subsystem to take advantage of its advanced SNOMED capabilities.

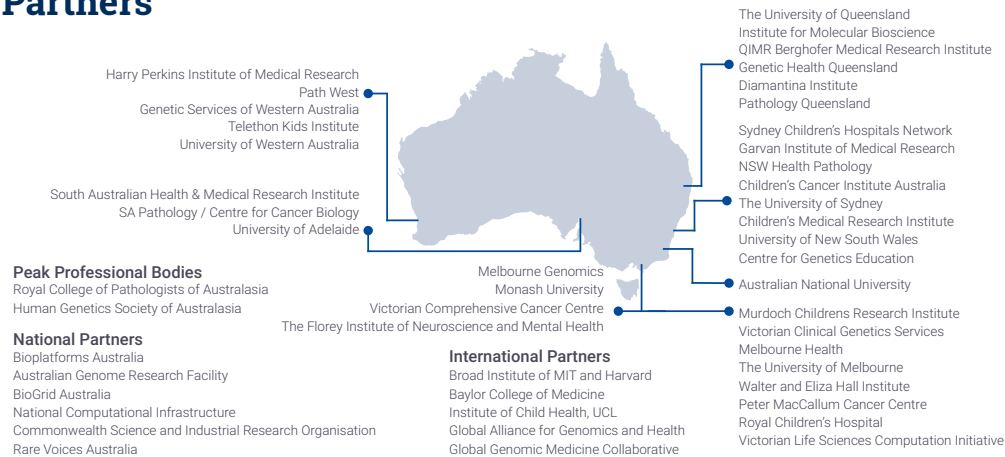### Delivery of Technology into the Health System

Impact of projects is greatly enhanced when adopted by the health system for, business as usual. The engineering team provide the bridge between research outcomes and deployment of technology into the Health System by productizing, deployment and support. As an example, PAPT has been made into a product and is deployed into Queensland Health and licensed to Telstra Health.

Clinical Trial Support

The engineering team provide support for clinical trial data management systems like REDCap and OpenClinica as well as custom data collection solutions.

Genomics and Health

Australian Genomics Health Alliance
Partners

Harry Perkins Institute of Medical Research
Path West
Genetic Services of Western Australia
Telethon Kids Institute
University of Western Australia

South Australian Health & Medical Research Institute
SA Pathology / Centre for Cancer Biology
University of Adelaide

Peak Professional Bodies
Royal College of Pathologists of Australasia
Human Genetics Society of Australasia

National Partners
Bioplatforms Australia
Australian Genome Research Facility
BioGrid Australia
National Computational Infrastructure
Commonwealth Science and Industrial Research Organisation
Rare Voices Australia

The University of Queensland
Institute for Molecular Bioscience
QIMR Berghofer Medical Research Institute
Genetic Health Queensland
Diamantina Institute
Pathology Queensland

Sydney Children's Hospitals Network
Garvan Institute of Medical Research
NSW Health Pathology
Children's Cancer Institute Australia
The University of Sydney
Children's Medical Research Institute
University of New South Wales
Centre for Genetics Education

Australian National University

Murdoch Childrens Research Institute
Victorian Clinical Genetics Services
Melbourne Health
The University of Melbourne
Walter and Eliza Hall Institute
Peter MacCallum Cancer Centre
Royal Children's Hospital
Victorian Life Sciences Computation Initiative

Melbourne Genomics
Monash University
Victorian Comprehensive Cancer Centre
The Florey Institute of Neuroscience and Mental Health

International Partners
Broad Institute of MIT and Harvard
Baylor College of Medicine
Institute of Child Health, UCL
Global Alliance for Genomics and Health
Global Genomic Medicine Collaborative

Partners in the Australian Genomics Health Alliance

Genomics is increasingly being used in the delivery of clinical care - in both diagnosis and treatment decision making. The AEHRC's health informatics and transformational bioinformatics teams combine the key technologies which will be needed to mainstream the use of genomics in clinical care - health informatics to integrate genomic information into electronic medical records and bioinformatics tools to extract useful information out of genome sequence. In the future information from other modalities - imaging, environment etc - will be used to gain a wide and deep phenotype to inform the association between genotype and phenotype.

The AEHRC is partnering in a number of initiatives around Australia to make genomics a part of regular clinical care.

Qld Genomics Health Alliance

The Qld Genomics Health Alliance was funded with a $25m grant from Queensland Health in 2016. The first phase of the QGHA has funded four clinical demonstration projects and five capability projects with the goal of positioning Queensland as a world-leader in the translation of genomics research into healthcare practice.

The AEHRC has recently partnered with the Queensland Institute of Medical Research Berghofer, Queensland Cyber Infrastructure Foundation, The University of Queensland and Queensland University of Technology to lead the Genomic Information Management capability project, getting underway in August 2017.

Melbourne Genomics Health Alliance

The AEHRC is leading CSIRO's involvement in the Melbourne Genomics Health Alliance, an alliance of 10 leading healthcare and research organisations dedicated to bringing the global knowledge of genomics to benefit the individual care of Victorians.

AEHRC currently has three staff seconded to the Melbourne Genomics project team, with Kate Birch in the role of Data and Technology Program Lead. CSIRO staff Ian Pham is leading the work on Data Governance while Andrew Patterson is working with our clinical terminology team on clinical tools to support the use of genomic and related data by clinicians.

Australian Genomics Health Alliance

The AEHRC is leading CSIRO's involvement in the NHMRC $25m Australian Genomics Health Alliance, with over 30 organisations partnering in Alliance. David Hansen and Denis Bauer are among 100 Investigators on the NHMRC grant.

David Hansen is a co-lead of Program 2 - "A national data repository: scalable, shared and standardised". AEHRC staff are leading in the development of tools for capturing and using clinical phenotype information and in the use of phenotype and genotype data.

HEALTH INFORMATICS

Biomedical Informatics

2015/16 Science and Impact Highlights

- Several of our leading scientists are chief investigators in multiple NHMRC clinical studies and clinical trials, including two very large multi year studies on Alzheimer's and ALS, funded as part of the Dementia Boost NHMRC initiatives.

- Important medical findings based on our analysis and using our technologies were published in prestigious scientific journals and received wide press coverage such as the role of iron in brain disorders or the characterisation of genetic and ageing profiling in Dementia.

- Our cloud computing platform includes now 2 automated analysis pipelines that have been used to analyse more than 3000 MRI and PET scans automatically, triggering commercial interest from several companies.

- Machine learning techniques have been deployed in numerous tools, and the genomics applications around clustering and genome editing deployed on cloud computing have received broad coverage including iAwards.

- The first clinical trial using MRI to guide prostate radiotherapy is now underway relying on several important technologies developed by the Biomedical Informatics Group.

- The recognition of our capabilities in clinical study data management is increasing with multiple studies relying on our support and expertise.
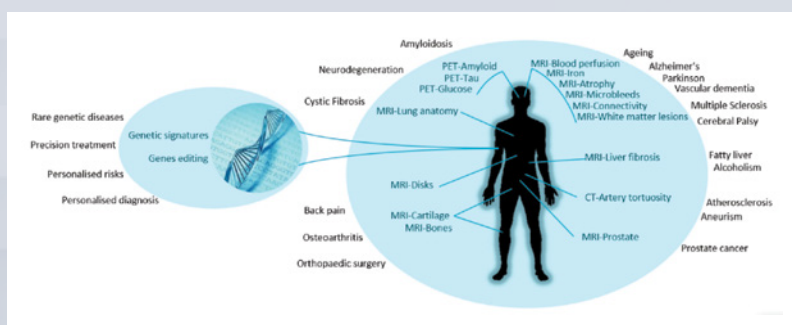
Our portfolio of technologies covers (blue) a vast areas of disorders (white)

Biomedical Informatics Group Leader: Olivier Salvado

Our Biomedical Informatics research develops innovative medical technologies to quantify genotyping and phenotyping. By developing software and imaging techniques, we aimed at creating value around three main aspects:

- More precise and more affordable diagnosis/screening
- Personalised and more effective therapy
- Selection of individuals for clinical studies and trials

Medical Image Analysis Team Leader: Jurgen Fripp

Our medical image analysis is leading a paradigm shift in radiology from qualitative to (semi-) quantitative imaging and a new generation of "imaging biomarkers". Our technology turns images into information which can be used to improve diagnostic and screening tools, provide new insights and reduce healthcare costs.

Clinical Imaging Team Leader: Nicholas Dowson

Our clinical imaging research optimises the identification of injury, pathology, and treatment response using advanced medical imaging technology. This involves developing novel imaging techniques and translating those techniques into the clinical environment to improve patient management and outcome and provide efficient hospital workflows.

Transformational Bioinformatics Team Leader: Denis Bauer

Our transformational bioinformatics develops clinically usable tools for the incorporation of large, complex and diverse life science datasets (such as high throughput sequencing, gene expression, proteomics) to facilitate better patient treatment and improved clinical outcomes.

Biostatistics Team Leader: James Doecke

Behind every large scientific finding seen in the newspaper, on the web, or in scientific journals is a team of statisticians working to answer the biological questions posed by leading scientists today. Our team of statisticians here at CSIRO Health and Biosecurity, Biomedical Informatics are well placed to analyse biomedical data with the view to interpret some of the world's most important medical research questions.

Projects

Medical Image Analytics

The medical image analytics team's primary goal is automating the extraction of quantitative imaging biomarkers that act as surrogate measures for a patient's diagnosis or clinical outcome. This research can then be applied in a wide range of clinical applications and involves technical developments in both informatics and analytics.

Imaging biomarkers for Neuro-degenerative diseases

Neurodegenerative diseases refer to a group of age-related brain illnesses that result in progressive loss of brain tissue and cognitive function. Early detection is now recognized as the critical path to effective treatment for various forms of neurodegenerative diseases, including Alzheimer's disease, as it may allow interventions prior to widespread tissue loss.

In collaboration with the researchers of Austin Health, Florey Institute of Neuroscience, McCusker Alzheimer's Research Foundation (MARF) and Edith Cowan University (ECU) we have been involved in the Australian Imaging and Biomarker and Lifestyle (AIBL) study. The AIBL study has provided strong evidence that Aβ-amyloid (Aβ) plaque accumulation commences 10-20 years before clinical symptoms. More recent work has found that cortical atrophy is locally associated with tau neurofibrillary tangles accumulation. In addition, cortical iron accumulation in combination with elevated Aβ may accelerate disease progression (Figure 2. Right). This new finding has been accepted in a high impact journal (Brain, IF 11) and three provisional patents have been lodged around iron measurement and its quantification.

As part of this collaborative research, our team has been providing:

a) MRI based biomarkers (hippocampal volume, cortical atrophy, brain blood flow and markers of iron concentration) for detection and prediction.

b) PET based biomarkers (Aβ, Tau and glucose metabolism) for earlier detection and differential diagnosis.

Validation of CapAIBL against histopathology

One example of our software is CapAIBL® (Computational Analysis of PET from AIBL), which automatically extracts Aβ PET measurements without the need to acquire an additional MRI. This biomarker information is then provided as a quantitative clinical report (designed in collaboration with our clinical partners, Austin Health in Melbourne).

18 F-florbetaben is a diagnostic radiopharmaceutical that can be clinically used in a Positron Emission Tomography (PET) scanner to visually assess the presence of Aβ-amyloid (Aβ) pathology in the brain. This marker is being used for recruitment to clinical trials and as outcome measure in therapeutic trials. This test is visually read by trained physicians, so the development of an accurate and reproducible automated quantification would facilitate more widespread use.

Recently, we compared the accuracy of our MR-less CapAIBL 18 F-florbetaben quantification (using Centiloid units) using histopathology as the standard of truth. Quantification of 18F-florbetaben PET scans using MR-based and MR-less CapAIBL® approaches showed high agreement and concordance. This suggests that reproducible quantification of Aβ levels in the brain can be obtained without an MRI. Based on the histopathological results, a Centiloid threshold band of 27±4 reliably distinguishes high from low Aβ burden. This finding is important for both clinical research and likely in the future as a marker for clinical treatment.

Iron and other advanced imaging markers

Recent studies have demonstrated that the combination of iron burden and Aβ in the brain is associated with changes in longitudinal (7 year) cognitive outcomes. In collaboration with the CRC for Mental Health and the Florey Institute of Neuroscience, we are extending this work by using advanced MRI to improve our understanding of the role of iron in healthy ageing and Alzheimer's disease. For this, the two ultra high field MRI (7T) machines installed in Australia (University of Melbourne and University of Queensland) are being used to perform iron quantification using techniques like quantitative susceptibility mapping (QSM, Figure 1). In addition, the higher field strength can also be leveraged to increase image resolution and reveal subtle anatomical structures that would not be visible on clinical MR scanners, such as the subparts of the hippocampus.

BIOMEDICAL INFORMATICS

Medical Image Analytics *(continued)*

Imaging Markers for Osteoarthritis

Osteoarthritis (OA) is a joint disease that is characterized by the breakdown of joint cartilage and underlying bone. Traumatic injuries, such as a tear of the anterior cruciate ligament (ACL) increase the risk of developing OA and provide a targeted way to investigate early pathophysiological changes in cartilage and intervene in the disease process.

Our current research involves developing techniques using advanced magnetic resonance imaging (MRI) and image processing that can be used to improve the clinical picture of the pathophysiological processes preceding the development of OA. The algorithms we have developed can be used for automated segmentation of joint cartilages that are used for computation of morphological and biochemical imaging biomarkers of the cartilage damage (Figure 2).

To evaluate and explore novel biomarkers, we are running a clinical trial with patients after knee or hip injury (ACL rupture, labral tear) and healthy controls. The novel MRI protocols and processing techniques are also evaluated on clinical data from our academic and industrial partners (Steadman Philippon Research Institute, USA). Results of these studies have been presented clinical (e.g. European Journal of Radiology) and technical (e.g. Medical Physics) international journals. The developed software "ChondralHealth" (overview in Figure 3) was shared with our industrial partner (Siemens Healthcare, Germany) who is running validation studies at multiple centres.

Results of this research will provide tools for medical practitioners to improve the diagnosis and clinical management of OA worldwide.
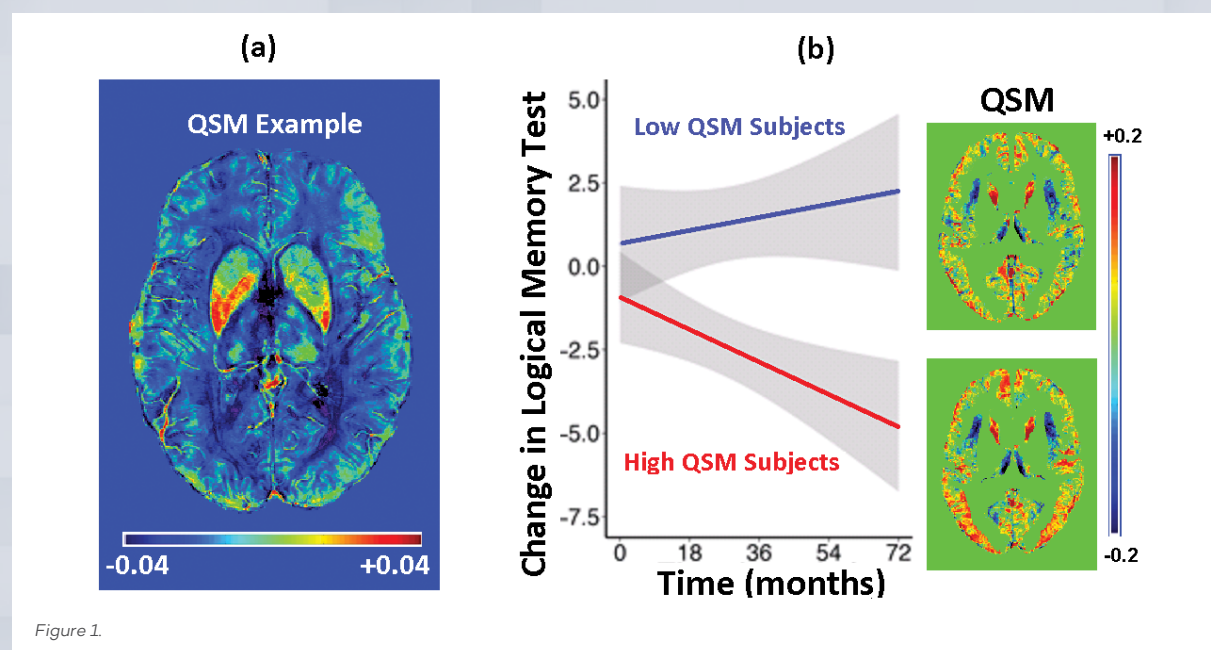
Figure 1.

Figure 1. Quantitative susceptibility mapping (QSM) provides a surrogate measure of iron concentration. (a) An example of a QSM image of a healthy elderly subject and (b) Relationship between QSM and longitudinal cognitive outcomes in Aβ positive subjects. Visual representations of the effect of baseline neocortical QSM in Aβ positive subjects on longitudinal cognitive performance on WMS-R Logical Memory Test when Individuals were designated to a low or high QSM group, based on the median QSM value.

Figure 2. Workflow of the developed software: Structural (upper left) and biochemical (bottom left) MRI images of the knee are acquired for the automated cartilage assessment. The cartilage is automatically segmented in 3D from the structural MRI scan using in-house software (middle column). The biochemical MRI scan is fused with the structural scan and statistical analysis of the biochemical MRI signal in different cartilage regions are reported for clinical analysis (right column).
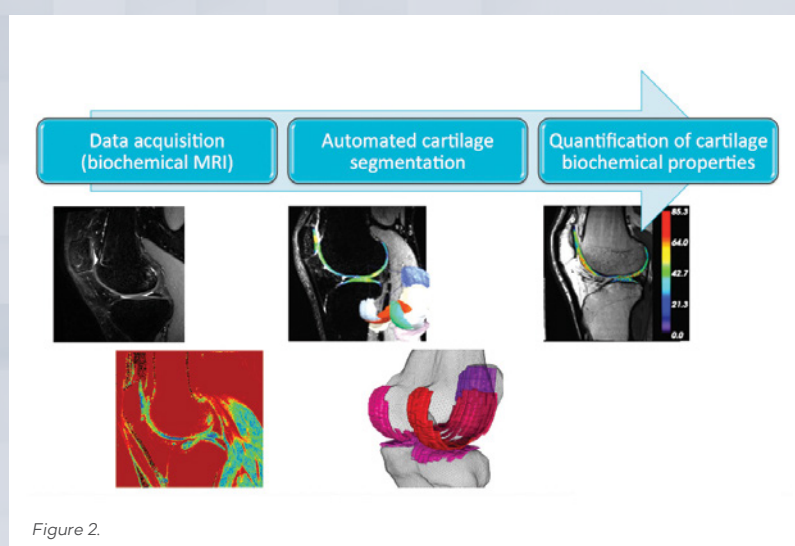

Figure 2.

Collaborators:

- Austin Health
- Brain Research Institute
- Royal Melbourne Hospital
- The AIBL study group
- Florey Institute of Neuroscience
- Queensland Institute of Medical Research
- McCusker Foundation
- Australian Infectious disease research centre
- Queensland Cerebral Palsy and Rehabilitation Research Centre
- University of Queensland
- Siemens Healthcare
- University of Western Australia
- Steadman Philippon Research Institute

Project highlights for 2016/17

- CapAIBL and CurAIBL neuroimaging software provided to Australian researchers on the NECTAR cloud.
- Validation of CapAIBL for reliably computing Centiloid measures for all Amyloid PET tracers.
- Prototype of ChondralHealth software delivered to Siemens for internal evaluation.
- Development of a method to quantify Tau from PET tracers.
- Development of a method to quantify structures from neonatal MRIs.
- Development of a method for improved regional measures of the cartilage from biochemical MRIs at 3T/7T.
- Development of a method for automated detection of small lesions on MRI images
- Journal papers in top rated medical imaging and clinical journals.
- Successful grant funding, including NHMRC

Project Aims for 2017/18:

- Validation of CapAIBL for extracting Tau and cholinergic imaging biomarkers from PET images.
- Validation of methods for contrast synthesis and segmentation based on deep learning.
- Clinical evaluation of iron measures for assessing ageing and interventions.
- Evaluation of ChondralHealth software in a multicentre study.
- Further develop approaches to quantify Iron and hippocampus subfields from advanced 3T and 7T MRI sequences.
- Develop approaches to quantify visceral fat from 3T MRI.

BIOMEDICAL INFORMATICS

PhD Student

Name: Miles Seidel

University of Queensland

The effect of preterm birth on hippocampus, thalamus, and related cortical structures and the relationship to neurodevelopmental outcomes

Brain development during the neonatal period plays a decisive role in the formation of adverse neurological outcomes associated with very preterm birth, including motor impairments, cerebral palsy, and cognitive deficits. While structural brain abnormalities evident on MRI at term-equivalent age are predictive of poor neurodevelopmental outcomes, definitive diagnosis is rarely made until early childhood and many infants without brain abnormalities also develop neurological deficits.

In this PhD project, the goal is to improve the early identification of high risk infants using advanced structural and diffusion MRI imaging data collected at preterm and term-equivalent age. First, a combination of manual segmentation, automatic segmentation, and shape analysis methods will be developed to quantify longitudinal structural changes that occur in deep gray matter regions between preterm and term equivalent age. Second, segmentations of the thalamus and hippocampus will be used as seed regions for delineation of white-matter tracts to explore longitudinal changes in connectivity measures in associated tracts. The last aim is to investigate the relationship between structural measures, diffusion measures, and neurological outcomes at 3 and 12 months of age in a large cohort of neonates born very preterm.

Name: Saba Momeni

Griffith University

Microbleed detection using deep learning

Cerebral microbleeds are new asymptomatic neurological finding associated with increased cognitive decline. Detection of microbleed is time consuming and laborious, and an automatic algorithm for clinicians could be of a great help. In her PhD project, the first goal is to generate a large number of accurate and reliable synthetic microbleed datasets and then apply a new deep learning algorithm with novel features. In the last step, her aim is to classify different microbeads with applying transfer learning methods. The final algorithm will be developed as a software package facilitating microbleed detection.

BIOMEDICAL INFORMATICS

Clinical imaging

Radiological imaging is critical to achieving further improvements in outcomes for patients and in driving efficiencies across the health system. This is being achieved in a number of ways ranging from better stratification of patients to avoid futile procedures such as Endovascular Aneurysm Repair, to better understanding the factors involved in achieving good outcomes in Cerebral Palsy, and to allowing refinement of radiotherapy plans during the treatment of prostate cancer to reduce side effects, amongst other applications.

The clinical imaging team combines their knowledge of the clinical challenges that their collaborating physicians have, with a deep knowledge of medical instrumentation, image processing and machine learning algorithms to automatically extract and present pertinent information to physicians and researchers to enable optimal clinical decision making and define the most promising directions for future research.

Neurodevelopment of the preterm infants

Very preterm infants (born between 23-31 weeks gestation) have a high risk of an adverse neurodevelopmental outcome. One in ten of these infants may end up with cerebral palsy, while half of these infants have later learning and behavioural difficulties. However, if high risk infants are identified early (within the months immediately after birth) there is substantial scope to reduce and even prevent later difficulties because at this stage the brain has a very large capacity for repair via the mechanism of neuroplasticity. Early identification and tailored therapy at an early stage is critical to achieving the best possible outcomes for these infants.

This project is developing an approach to model the normal neurodevelopment of the infant brain and identify abnormal development by differences in the structures seen within the brain on MRI. The project is also examining how the white matter pathways develop with age, the extent to which different parts of the brain communicate, and unique approaches to resolve the presence of motion. Together with our collaborators at the Lady Cilento Hospital, our internationally recognised team is using the methods to predict the potential for adverse neurodevelopment earlier and to more accurately identify those in need of therapy.

The research will enable major advances in the management of preterm babies, and has the potential to reduce the burden of Cerebral Palsy on the health system, while increasing the integration of these children into society.

Neuroimaging of children with cerebral palsy

Cerebral Palsy (CP) remains the world's most common childhood physical disability with total annual costs of care and lost wellbeing of AU$3.87b. Our neuroimaging work in children with CP aims to analyse brain injury and measure neuroplasticity in response to therapy.

Two early intervention studies (REACH and GAME) are currently underway in collaboration with UQ and CP Alliance, where different physiotherapy approaches are trialled in children at high risk of CP, aged 3 months to 2 years for the first time. Our neuroimaging will inform what brain changes occur in response to the different therapies. This information will help identify which therapy may provide the greatest benefits for the individual infant at risk of CP.

In a population-based cohort study, the Predict-CP study provides a longitudinal follow-up of children who participated in MRI and clinical studies at age 2-5. This study will enable development of prediction models of outcome from early assessments, and assess the relationship between brain structure and motor, cognitive, and communication outcomes at school age.

Risk Stratification of Aortic Aneurysms

The repair of endovascular aneurysms is an increasingly common but complex surgical procedure. Patients may have subsequent complications either due to poor health or the complexity of the procedure, potentially rendering the surgery futile. In this project we have developed an approach that extracts important features from the anatomy of the iliac arteries and the extent of calcification and uses these to estimate the risk of problems within 30 days of surgery, later than 30 days of surgery and death.

The model that has been developed generalises to unseen data and achieves the among highest reported classification accuracy reported to date. These results are allowing doctors and scientists to assess the role of technical difficulty and patient health in the adverse events after procedures. With our collaborators at the University of Adelaide and the Royal Adelaide Hospital, we are using the outcomes of this project to better support surgeons during planning and for appropriately stratifying patients for surgery.

Assessing Liver Fibrosis from Texture Analysis

Working with our partner, Resonance Health, we have devised new approaches to improve the accuracy when estimating the extent of liver fibrosis from MR images. The project also identified promising avenues for further investigation once further data becomes available. This will allow the identification of liver fibrosis at an early stage when it can be resolved comparatively inexpensively. This has the potential to reduce the adverse impact on health systems of the increasing frequency of non-alcoholic fatty liver disease.

Targeting existing therapies with innovative technology platforms to improve survival in brain cancer

This project is using PET imaging to identify the key factors at play in our current inability to cure glioma. As they are within the brain, these tumours cannot be completely removed during surgery and often regrow rapidly. For this reason, after surgery, both chemotherapy and radiotherapy are given to patients to deal with the remaining cancer cells, but the cancer usually returns with devastating consequences. This research is important because brain cancer, although rare, can occur at any time of life including childhood and the ability of brain cancer to overcome therapy is poorly understood. A better understanding of brain cancer will be useful for other cancers as well.

MRI based paediatric lung structure and function assessment

This project is a collaboration between the Lady Cilento Children's Hospital, Siemens Healthcare, the Herston Imaging Research Facility and the CSIRO. The aim is to improve health outcomes for children with Cystic Fibrosis (CF) and Ataxia-Telangiectasia (A-T) by developing methods to use MRI to provide information on lung status.

Currently the most informative method for lung imaging in these children is computed tomography (CT) scanning. CT scans combine a large number of x-ray images and repeated CT scanning increases a child's cancer risk due to the radiation dose delivered. This is a critical consideration, particularly as the life span of people with CF and A-T increases from improved treatment. For this reason children currently only have CT scans every two years during which time untreated, asymptomatic infections can permanently damage their airways. Clinicians are also unable to quickly and accurately evaluate response to treatment. Children with A-T are extremely radio-sensitive and cannot have CT scans. Non-invasive monitoring of disease progression and treatment response is vitally important in managing disease onset and extending life for these patients.

To address this clinical need we are developing image acquisition methods and software to extract quantitative disease status metrics from MRI. This work is supported by a CSIRO OCE postdoc position and external funding from the Ataxia Telangiectasia Children's Project.

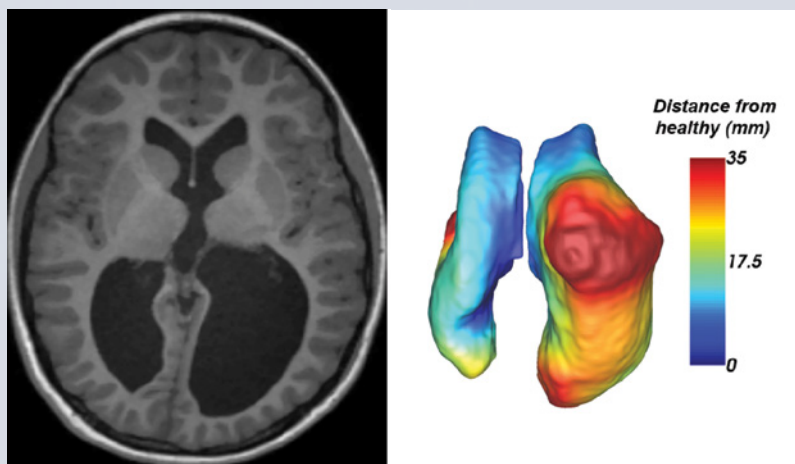BIOMEDICAL INFORMATICS

Clinical imaging *(continued)*

Figure 1. Structural MRI of patient with cerebral palsy displaying severely enlarged lateral ventricles. The extent of enlargement relative to healthy ventricles is displayed on the right.

MR alone radiation therapy planning for Prostate Cancer

In collaboration with the Calvary Mater Newcastle Hospital, and with funding support from the Prostate Cancer Foundation Australia and the NSW Cancer Council, CSIRO have developed the first atlas-based method to map accurate electron densities to MRI scans for dose calculations. This method is now being used in the clinic for the first time to refine radiotherapy planning during treatment to reduce side effects of prostate cancer patients. These improvements are also leading to cost savings arising from the reduced need to manage side effects.

Radiotherapy treatment for prostate cancer – a change in practice based on direct evidence for targeting and toxicity effects using real outcomes data

Radiotherapy, if delivered accurately, can provide an effective treatment for locally advanced prostate cancer. Several factors stand in the way of optimal use of radiotherapy in this context, and this NHMRC funded project aims to use an extensive, high-quality clinical trial dataset, in combination with innovative techniques developed by this project's investigators, to address those factors.

This study will allow; 1. quantification of the impact of observer definition of the prostate on treatment efficacy, by correlating long-term treatment failure with prostate segmentation uncertainties; 2. assessment of the impact of magnetic resonance (MR) imaging as a standard tool for identification of the prostate organ for informing radiotherapy treatment; 3. identification of anatomical regions that are being consistently under-dosed leading to treatment failure, by mapping regional radiotherapy dose distributions to treatment failures; and 4. identification of the anatomical origins of treatment-related toxicity, by mapping regional radiotherapy dose distributions to observed normal tissue toxicities.

Reducing the greatest uncertainty in radiotherapy

Radiotherapy is a well-established, cost-effective treatment which has an evidence-based indication for approximately 50% of cancer patients. The weakest link in treatment is the definition of treatment volumes (contouring). Lack of accuracy and consistency in clinical trial contouring has been shown to result in reduced patient outcomes. However manual review of contouring is resource intensive, expensive and for advanced treatments unachievable in a timely fashion. This NHMRC funded project in collaboration with the major Australian radiation oncology centres, involves the development of the first automated approach to contouring assessment using 4 large clinical trial datasets with the aim of changing practice for future studies and enabling consistent assessment in the clinic.

Collaborators:

- Lady Cilento Children's Hospital
- Departments of Radiology & Hepatology, Princess Alexandra Hospital
- Departments of Neurosurgery, Radiology, Radiation Oncology, and Nuclear Medicine, Neonatology, Royal Brisbane and Women's Hospital
- Department of Vascular Surgery, Royal Adelaide Hospital
- Queensland Cerebral Palsy and Rehabilitation Research Centre
- Stella Maris Institute, Pisa
- University of Queensland
- University of South Australia
- Genesis Healthcare
- Resonance Health
- Helsinki University Hospital, Finland
- Trans Tasman Radiation Oncology Group (TROG)
- Ingham Institute for Applied Medical Research
- Calvary Mater Newcastle Hospital
- Sir Charles Gairdner Hospital
- Liverpool and Macarthur Cancer Services
- Peter MacCallum Cancer Centres
- University of Newcastle
- University of New South Wales
- University of Western Australia
- University of Melbourne
- University of Sydney

Project highlights for 2016/17

- Successful completion of a follow-up project with commercial partner, Resonance Health, to improve assessments of liver fibrosis using texture analysis. The project was co-funded by the Department of Industry and Science.
- International multi-centre prospective clinical trial for MRI-alone, external beam radiation therapy for localised prostate cancer.
- Validation and publication of a new generalised method for scanning with multiple PET tracers simultaneously.
- Development of new model to accurately predict the likelihood of early or late problems using anatomical features from the iliac arteries and the extent of calcification in individual anatomical regions.
- Initiation of a new project aimed at MRI based non-invasive lung structure assessment for children with cystic fibrosis.
- Acceptance of 4 journal papers on the analysis of MR images of children with Cerebral Palsy.
- Acceptance of 2 journal papers in the areas of multiplexing and PET kinetic analysis.
- Acceptance of 8 radiotherapy papers in areas of MR-alone planning, MR-linac, and automatic identification of organs from scans.
- All papers in high impact journals.

Project Aims for 2018/19

- Develop approaches using imaging to assist surgeons in planning partial hepatectomies.
- Complete development of method to assess interstitial fluid pressure within tumours non-invasively.
- Start development of motion correction methods to improve the analysis of dynamic image data.
- MRI-based non-invasive and zero radiation paediatric lung structure and function evaluation (for cystic fibrosis and ataxia telangiectasia).
- Development and validation of methods for automatic clinical trial quality assurance and linked information extraction from retrospective radiation oncology data sources.
- Develop approaches to predict adverse outcomes from neurosurgery in adults using structural and/or diffusion MRI.

PhD Student

Name: Ashley Gillman
University of Queensland
APA Scholarship and PhD Top-up Scholarship

MOTION CORRECTION OF POSITRON EMISSION TOMOGRAPHY IMAGES
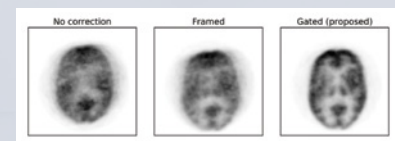
Patient motion is an important consideration in modern PET image reconstruction. Advances in PET technology, especially the introduction of combined PET/MR, mean motion is becoming an increasingly important influence on image quality, and motion-induced artefacts can have adverse effect on clinical outcomes, including missed diagnoses and oversized radiotherapy treatment volumes.

In this PhD, improvements to several bottlenecks to accuracy in the motion compensation pipeline are being addressed. Methods for the use of a camera to track head motion, and the tracking of head motion directly from raw PET data in three dimensions have been devised. A particular focus of the project is the previous under-researched area of PET motion correction in the thoracic area, where novel methods utilising the capabilities of the newly available PET/MR scanners.

This work has the potential to benefit future clinical patients and the wider scientific community. Clinicians stand to gain an improved confidence test results, leading to improved clinical decision making. Patients will be able to avoid rescans where motion corruption rendered the original scan unusable. Researchers may be able to run previously unachievable tests, such as dynamic modeling of deformable regions, such as the abdomen and pelvis. The software developed is also intended to foster and accelerate PET/MR motion correction efforts by the research community.

BIOMEDICAL INFORMATICS

Transformational Bioinformatics

The transformational bioinformatics team develops novel bioinformatics solutions for research and industry using the latest in cloud and BigData infrastructure. We specifically focus on population-scale 'omics (genomics, transcriptomics, methylomics) analysis as well as genome engineering applications as the two high impact life science areas. We engage with the rest of the program on developing algorithms that can jointly harnesses information from diverse sources like genomic profiles, personal sensing devices, and electronic health records to build "smart analytics" systems that are predictive of health outcomes.

NHMRC Dementia Team Grant: Motor Neurone Disease and Dementia

CSIRO is a partner in this Dementia Team Grant led by Prof Ian Blair at Macquarie University – one of only 6 funded applications. The project aims to uncover the molecular mechanisms of Amyotrophic Lateral Sclerosis (ALS), the disease Stephen Hawking suffers from. CSIRO is responsible for the genomic data analysis of 800 Australian WGS ALS samples, as well as the data integration of other 'omics data collected through the lifespan of this 5 year project. This effort contributes towards the international Project MinE, which will analyse the genomes of 15,000 ALS patients and 7,500 healthy controls in a bid to understand the genetic origins of these devastating neurodegenerative diseases.

Outcome

- Publication in Nature Communications (IF=12, citation=2), ranked in the 99th percentile of articles with a similar age.
- The work will be presented at one of the most prestigious Motor Neurone Disease conferences hosted in Boston, USA
- CSIRO has developed a Spark-based algorithm for idetnifyng familial relationship in allegedly unrelated ALS patients, which will boost statistical power for disease gene classification.

Cloud-based genome analysis tools

The cloud-based genome analysis project aims to design and develop novel approaches for population-scale cohorts of whole genome information (i.e. common and rare variants). This year we extended our published VariantSpark package, which is listed amongst the top 5% of all research outputs as scored by Altimetric, to perform more sophisticated machine learning tasks, such as supervised learning. Specifically, this new CursedForest Version incorporates a novel parallelisation approach on Apache Spark to enable the training of machine learning methods on high-dimensional genomic data. This allows researchers to identify novel disease genes (epistatic interactions) or stratify patrons based on their full genomic profiles.

Outcome

- Databricks featured VariantSpark on their Engineering Blog "Breaking the 'curse of dimensionality' in Genomics using 'wide' Random Forests" and it was highlighted in the CIO magazine article 'CSIRO to stick more infrastructure in the cloud'.
- Collaboration with QUT on Bone Mineral Density dataset, submitted for publication
- VariantSpark is available at https://github.com/aehrc/VariantSpark and was featured in keynote talks by an influential Cloud Evangelist.

Figure 1. Genome Engineering Symposium in Canberra
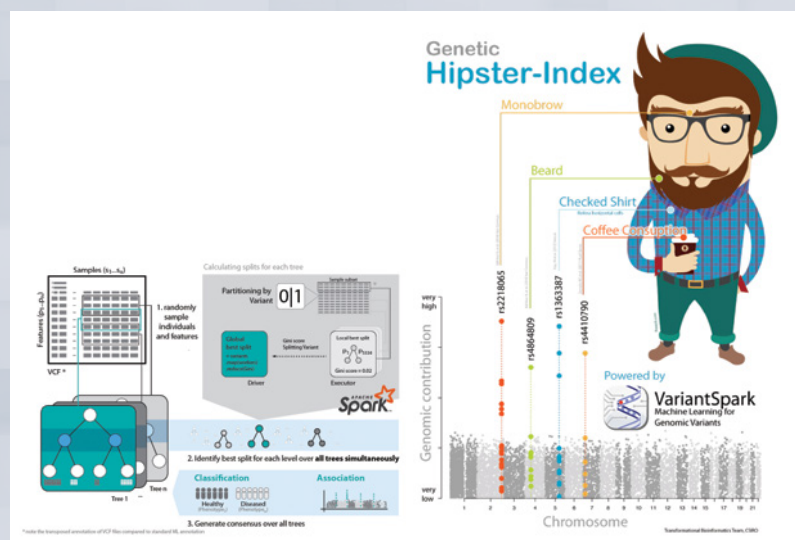

Figure 1. Novel machine learning methods for disease association (here synthetic phenotype hipster-index)

Computational Genome Editing services

The Computational Genome Editing project aims to develop computational solution that improve the accuracy of genome engineering applications (on-target scoring, SNP-aware off-target search) to enable novel application areas in high-precision applications such as human health.

Collaborators:

- Macquarie University
- National Measurement Institute
- University of Newcastle
- QUT
- Australian National University
- Australian Genomics Health Alliance
- Melbourne Genomics Health Alliance
- Graven Institute for Medical research
- ProjectMine (Europa)
- Guangzhou Medical University

Project Highlights for 2015/16:

- The team has published 10 journal papers (3 first author papers, and 5 in IF>10) and 10 conference papers (7 oral presentations).
- Our tools were featured in 4 international media articles (AWS, GenomeWeb, CIO Magazine, Databricks)
- The team has secured $600K in competitive funding

Project Aims for 2016/17:

- Establish VariantSpark internationally as the technology of choice for large cohort analysis to capture part of the 19.99 Billion (2020) Genomics Market.
- Develop technology for ImmonoEngineering in collaboration with Guangzhou Medical University to capture part of USD 7.5 billion (2024) Genome Editing Market Global Market Insights, Inc.
- Publish high impact journal publication featuring original research using our technology.

Outcome

- Amazon web services featured GT-Scan2 on the Jeff Barr Blog 'Genome Engineering Applications: Early Adopters of the Cloud' and recorders of a promotional video for their 'This is my architecture' series on YouTube (currently in post-production).

- GT-Scan2 was featured on Genome Web 'Australian Team Puts CRISPR Design on Amazon Cloud' and presented in keynote talks by an influential Cloud Evangelist.
- Publication in BMC Bioinformatics (under peer-review).

Student Profile

Name: Denise Thiel
Masters Students through the German Bioinformatics Exchange Program

Topic: Systematic Identification of Non-Conventional Transcripts from Human Cells

Identification of non-conventional RNA molecules such as fusion and read-through transcripts is an important step towards comprehensively characterising the functional readout of the human genome. Using RNA-PET data from the ENCODE project, we find that 33% match known transcripts, 16% are fusion products mostly using internal exons, another 44% have alternative start or stop sites and the remaining 6% represent novel transcripts. By including an RNA-PET replicate, histone marks, TFBSs, DNase activity, termination sites and overlap with known transcripts as support we can distinguish real sites from transcriptional noise and experimental errors. Aggregation plots of these marks around TSSs and TTSs help us identify which marks are actually involved in transcription. Lastly, we compare our results to transcripts in other cells to find a possible functional relationship between non-conventional transcripts and diseases.

Name: Sara Hetzel
Masters Students through the German Bioinformatics Exchange Program

Topic: Developing a SNP-aware off-target detector to improve Genome engineering accuracy

Genome engineering is currently hampered by sequence variation, such as mutations and indels. We compare our SNP-aware off-target detector against traditional approaches when scoring the genomes of individuals or population, and demonstrate the efficiency gain obtained from adopting this practice. In addition, a machine learning model following the off-target screening predicts the activity of the detected off-targets and provides a ranking based on those scores. In addition, we integrate our previously published on-target activity predictor to provide the most complete prediction for CRISPR-Cas9 activity. We will highlight the implementation details of using AWS Lambda functions, which makes the tool highly scalable.
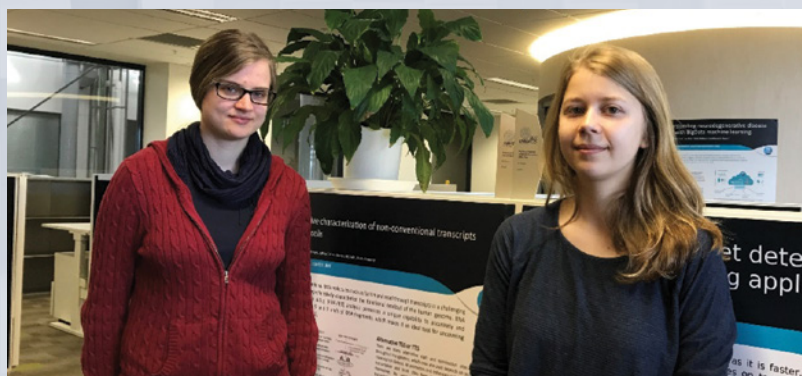

Figure 3. Denise Thiel (left) and Sara Hetzel (right)

BIOMEDICAL INFORMATICS

Biostatistics

The AEHRC biostatistics team combines data from multiple modalities to answers clinical research questions. This involves using statistical methods to combine data from imaging, genetics, genomics, proteomics, neuropsychology and clinical biomarkers. The team works with internal and external collaborators to investigate destructive pathological processes in Alzheimer's disease.

CRC for Mental Health

The team are key members of the CRC for Mental Health. The core mandate for the CRC is undertaking research to identify and validate biomarkers for the early detection and treatment of neurodegenerative disorders and psychoses. By bringing together industry, end users and health care providers, the CRC aims to develop and commercialise our research findings in order to deliver changes to treatment in medical and health care practices.

This year the biostatistics team's research in biomarkers for the early detection of Alzheimer's disease led to 20 publications and 12 conference presentations. Key research from the team led to many strong publications, including papers in top ranking journals such as Neurology and Lancet Neurology.

CRC in Cognition and its Disorders

Members of the team provide a key role in a further project studying disorders of cognition and mental health, including Parkinson's disease, Alzheimer's disease and Cerebral Palsy. Providing key statistical support and project guidance, team members analyse project data to align with research hypotheses and define novel pathways into disease ethology.

In Alzheimer's disease, the team conduct research into biomarkers from CSF to align with PET imaging. Research from this project has led to a real bench to bedside outcome, with results from biomarker studies guiding decisions made on disease diagnosis in the clinic. In Parkinson's disease, the team assesses genomic biomarkers that align with the presence of disease physiology, and in Cerebral Palsy, the team provides statistical guidance on MRI data to assess cognitive function from children with the terrible disease. This research has led to six journal publications in high-ranking journals.

Instrumental relationship with Pharmaceutical companies

Team members are working closely with international pharmaceutical companies Roche and Biogen to assess the cognitive trajectory of Alzheimer's Disease from it's very early stages (prodromal and pre-clinical) through to late stage clinical AD. Research is focussed around changes in cognition, blood and CSF based biomarkers and pathological proteins via PET imaging. Along with collaborators from world leading laboratories, team members are instrumental in round table discussions to discuss the best way forward in conducting research across multiple countries. Figure 1 shows the disease progression model developed in collaboration with partners at the Florey Institute for Mental Health, a figure which is widely cited and used in the literature.

Genome Engineering for Cancer Treatment Conference

Team members are part of the organising team for the CSIRO funded Cutting Edge Biosciences conference. This year Dr Denis Bauer (Transformational Bioinformatics) and Dr James Doecke (Biostatistics) were awarded $30,000 based on a proposal to host a conference around the new genomic technology CRISPR. The conference has three international invited speakers, plus a range of national experts to talk about the latest breakthroughs in genomic technologies around CRISPR. The conference will be held in November 2017 at the ANU in Canberra and is expected to attract up to 200 participants.
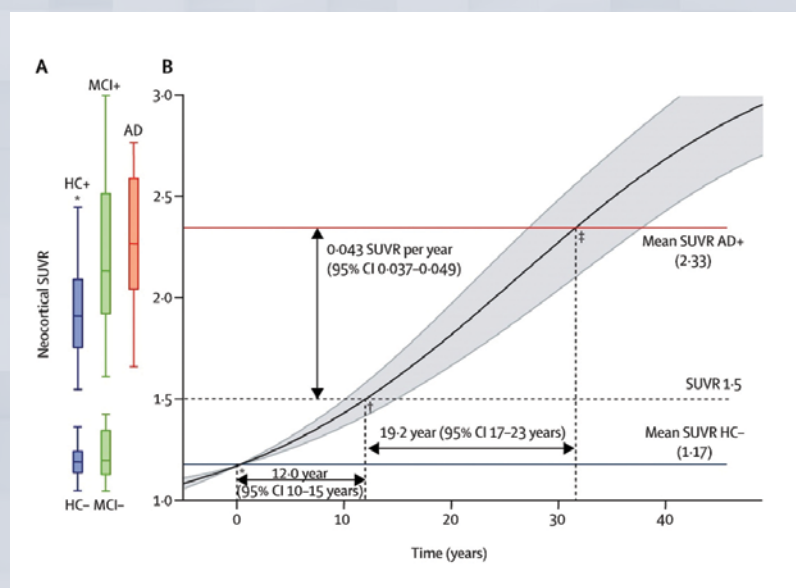

Figure 1. Alzheimer's disease progression model

Collaborators:

- CRC for Mental Health
- CRC in Cognition and its Disorders
- Australian Imaging Biomarkers and Lifestyle (AIBL) study
- Centre for Applied Statistics, University of Western Australia
- University of Melbourne
- Florey Institute of Neuroscience and Mental Health
- Nuclear Medicine and Centre for PET, Austin Health
- School of Medical and Health Sciences, Edith Cowan University
- Institute for Future Environments, QUT
- Brisbane Inflammatory Bowel Disease group
- International Inflammatory Bowel Disease Genetics Consortium
- MD Anderson Cancer Center
- Departments of Neurology, Harvard Medical School
- Maurice Wohl Institute for Clinical Neuroscience, Kings College London
- Institute of Health Informatics, University College London

Project Highlights for 2016/17:

- Real beach to bedside research with biomarker studies leading to changes in clinical practice.
- 20 published journal articles – including first author papers in Lancet Neurology (IF22) and Neurology (IF8)
- 12 conference presentations

Project Aims for 2017/18:

- Develop new statistical methods
- Pursue novel science projects
- Engage external collaborators
- Inclusion as chief investigators on successful grant bids with external collaborators
- Grow the team through employment of a post-doctoral scientist
- Answer pertinent research questions resulting in peer reviewed journal publications and conference presentations

PhD Student Profile

Name: Charley Budgeon

PhD Student with the Centre for Applied Statistics at the University of Western Australia.

Topic: Personalised survival analysis in Alzheimer's Disease

Charley was successful in obtaining a CSIRO top-up scholarship for her project and is co-supervised by Sam Turnham in our Floreat office in Perth WA. Charley presented her work on combining multiple short-term follow-up data on individuals on the Alzheimer's disease course to map the full disease trajectory at AAIC 2015 (the "Big" Alzheimer's conference) in Washington.

This work is particularly important as AD represents a major economic and social burden which requires a cure to avoid crippling health services, the best chance for a cure or delay to onset is believed to exist in therapeutics administered at the earliest stages of disease. However, without an understanding of the full disease course, determining the appropriate window for treatment is challenging. Charley's work has identified methods to "stitch" such short-term follow-up data, from many individuals, together to try to underpin the full disease trajectory.

BIOMEDICAL INFORMATICS

Health Services

2015/16 Science and Impact Highlights

- The AEHRC was successful in its first spin out company, Cardihab, from the first validation of the Mobile Phone Based Delivery of Cardiac Rehabilitation program. Cardihab Pty. Ltd. is located in Level 3, 315 Brunswick Street, Fortitude Valley, QLD 4006.

- The extension of MoTER platform to other mobile health trials. There are now four home care disease management trials underway – in COPD, Insulin stabilisation for Type 2 diabetes, Gestational Diabetes and Peritoneal dialysis. These trials are being done in collaboration with Metro North and South Health Services.

- The Mobile Health delivery of Total Knee Replacement is undertaking validation through a national clinical trial among 300 patients in 5 hospitals around Australia.

- The AEHRC's innovative aged care Smarter Safer Homes platform was successful in being awarded the Dementia and Aged Care grant to undertake validation in service delivery in various geographical setting, including remote and rural sites.

Health Services Group Leader: Mohan Karunanithi

Mohanraj Karunanithi has a doctorate in Biomedical Engineering, University of New South Wales. He has over 10 years of experience in cardiac research and 5 years of medical industries' experience. At AEHRC, he manages and coordinates the Health Services Group undertaking research in translating in services in the screening, diagnosis, management and delivery of chronic diseases and aged care to the community.

Mobile Health Systems Team Leader: Marlien Varnfield

With the wide uptake of smartphone, Internet and health monitoring technologies in people's everyday lifestyle technologies, the Mobile Health Systems is translating the delivery of health care from acute care setting into the community to relieve the undue pressures the hospitals are facing managing chronic diseases/illnesses. Our Mobile Health Systems team has demonstrated capabilities as being a world leader in providing scientific evidence supporting m-health. The team's objective is to make prevention of and management of chronic disease services accessible to all people from their home or community. To enable this, the team works closely with clinical partners, already providing such services, to develop new innovative care models and technology-based systems and test through a clinical trial for evidence-base.

Health Internet of Things: Qing Zhang

The advent of wireless sensors, mobile, and health technologies being pervasive in everyday use, new and rich source of data are now accessible to determine people's lifestyle and its influences in their health and wellbeing. The Health Internet of Things (HIoT) team are at the frontier of having developed an innovative home-care platform that can access and aggregate these data wirelessly from the environment and/or wearable devices, and mobile/internet devices. The HIoT have been developing and exploring smart data analytics (though machine learning and Artificial intelligence) on the aggregated data sets to better support the older community and those with disability to live longer in their homes and also the carers/services.

Digital Health Engagement Team Leader: Dana Bradford

For effective adoption of new health intervention delivery, particularly using technology, consumer/provider driven design is paramount. Our Digital Health Engagement team aim to provide closely aligned consumer/provider design and evaluation for new technology based care delivery systems. The team is equipped with expertise across Human Computer Interaction, Personalisation & Recommendations, Persuasive Technology and Neuroscience. The team designs technology based interventions that can be used by clinicians to improve workflow and enhance service delivery; and by individuals to support them in playing an active role in their health management to meet short or long term health and lifestyle goals. The team collaborates across health services group, e-Health program and other CSIRO Business Units, to contribute to the delivery of consumer design prototype for testing in clinical trials.

Australian Tele-health Research and Development Group Director: Yogi Kanagasingam

The Australian Tele-health Research and Development Group is our partnership with the Western Australian Department of Health and our Western Australia node of the Australian e-Health Research Centre (AEHRC). The team based in Perth is centred on research that provides digital disease screening and diagnosis using telemedicine to enable healthcare accessible to rural and remote Australia. The team's main focus is the development of novel telemedicine technologies to deliver non-invasive ocular imaging techniques for chronic diseases such as Diabetes, neuro-degenerative diseases such as Alzheimer's disease and stroke, burns and wound care management.

Projects

Mobile Health Solutions

Mobile health (m-Health) uses mobile phones, tablet computers, patient monitoring and other wireless devices to collect health information to improve the delivery of health care. The smartphone is the most popular and convenient device in m-health and has become a viable platform for delivery of health interventions in care for individuals living with chronic conditions. Smartphones have been rapidly adopted by Australians, and researchers have explored smartphones as tools to monitor and manage health problems including: adopting healthy behaviours, delivering education for awareness, symptom monitoring and dispatching patients' information and reminders.

Our Mobile Health Systems Team have been designing (via consumers and service providers engagement), developing and testing innovative mHealth solutions for supporting well-being, management, and optimisation of care delivery for individuals living with chronic diseases. Our work has been recognised by the national and international community, placing AEHRC as a world leader in providing scientific evidence supporting m-health.

MoTER- Cardiac Rehabilitation at Metro South Health

Recent Australian data have indicated that greater uptake of cardiac rehabilitation (CR) can lead to net financial saving of $46.7 – $86.7 million. In Victoria, benefit cost ratio were 5.6 and 6.8, if uptake was increased to 50% and 65% respectively over 10 years (compared to status quo of 30%). An m-Health care model using smartphones and the Internet, demonstrated previously by AEHRC to be an effective in delivery of home-based CR, is being implemented in three CR Services within Metro South HHS in Brisbane to improve CR participation by 15% (50% to 65%).

A variety of CR programs are available to patients according to their individual circumstances and choices and include the traditional centre based program, the home-based program or a hybrid program with switch-over from centre-based to home-based. The study aims to recruit 400 subjects (Dec'16 to Oct'17) and compare participation data with historical data. As of March 2017, CR participation has increased from 52% to 67%. Recruitment to the study will continue until the end of November, 2017.

PD BUDDy – mobile technology can provide support in home-based peritoneal dialysis to patients with chronic kidney disease

The PD BUDDy platform was developed in collaboration with Logan Hospital (Metro South Health) and uses smartphone technology and the internet to support the management of patients on peritoneal dialysis (PD) treatment. The platform allows patients to enter health parameters (e.g. dialysis fluid intake, weight and blood pressure), medications, exercise, symptoms and exit site photos to a smartphone app which automatically uploads to a password protected clinician portal.The PD BUDDy app also allows delivery of educational multimedia content, electronic reminders to assist in medication management and appointment scheduling.

The aim of this project is to assist all users (both patients and clinicians) during their PD procedure, reduce possible PD-associated complications, improve quality of life for patients and reduce the financial burden on the health-care system mainly through time saving.

A pilot study is currently being conducted at Logan Hospital. Patient recruitment started in July 2017 and 20 patients were recruited by the end of August 2017. Recruitment will continue until end September 2017 and 30 patients are expected to test the platform over 10 months. The primary outcome of this initial trial is use of the system and user satisfaction, while also aiming to reduce time spent at clinics and number of PD-associated infections (peritonitis).

HEALTH SERVICES

Figure 1. The PD BUDDy platform to support patients on peritoneal dialysis

Mobile Health Solutions *(continued)*

m-Health interactive system to support the management of women with a first time diagnosis of Gestational Diabetes Mellitus

Gestational diabetes mellitus (GDM) is a condition that occurs during pregnancy for some women and is one of the most common medical complications of pregnancy. It is becoming increasingly common in Australia, affecting between 5% and 10% of pregnant women.

In this project, AEHRC in collaboration with Redland Hospital designed and developed the M♥THer system, a mobile platform to support the management of women with first time diagnosis of GDM. The M♥THer solution integrates the internet, smartphones, measurement devices and multimedia content to support women with GDM throughout diagnosis to child birth. The M♥THer paltform is being tested in a pilot study at the Redland Hospital. The overall aim of the project is to not only support the women who are pregnant, but also improve the multidisciplinary care co-ordination between healthcare practitioners providing care and thereby:

- Reduce the number of low utility clinic visits and
- Expedite access to GDM antenatal services when required.
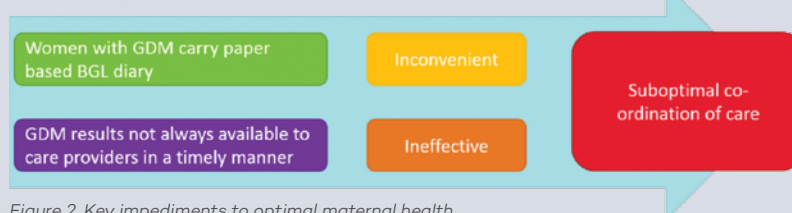
Figure 2. Key impediments to optimal maternal health
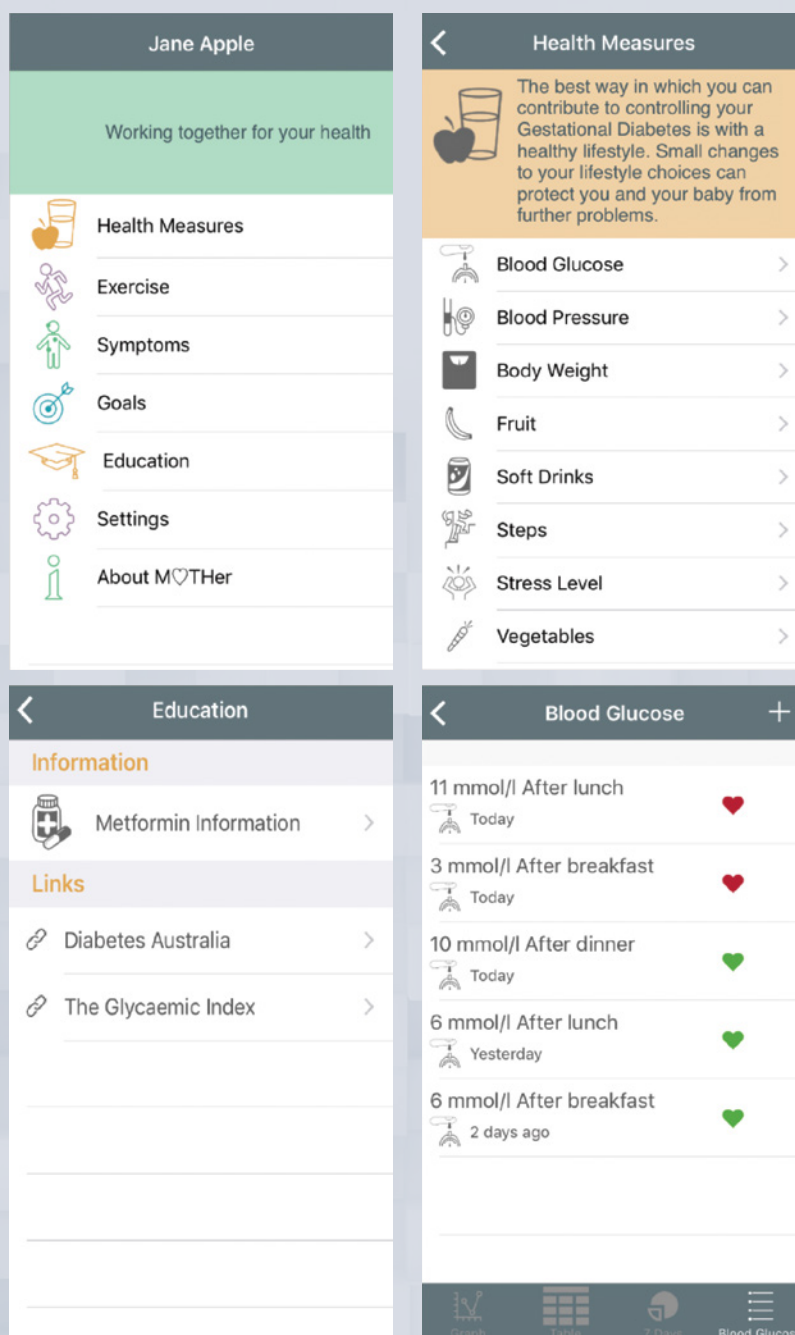
Figure 3. Selected screenshots from the iOS M♥THer App

Mobile Health for Insulin Dose Adjustment

The increasing prevalence of diabetes has led to a huge burden to the insulin dose adjustment services nationally. Additionally, the traditional data collection using paper-based diary is time consuming for clinicians, and many diabetic patients are unable to adhere to the monitoring requirements for the clinical interventions. To address this, CSIRO Mobile Health project commenced in 2015 a collaborative project with the Princess Alexandra Hospital and the University of Queensland Centre for Online Health to develop and evaluate innovative delivery model for Insulin Dose Adjustment service. To undertake this projects, the following core components and features were developed:

- A mobile application (app) for both iOS and Android operating system to be used by the patients
- Wireless transfer of the blood glucose readings using a Bluetooth-enabled glucose meter (Accu-Chek® Aviva Connect by Roche Ltd.) for timely and quality data collection by the patients
- Self-management tools for diabetic patients to record blood glucose levels, insulin dosages, and assessments by self-observation
- Clinicians' dashboard with basic clinical decision support system for clinical management of the patients
- Scheduling tools for collaborative care and clinical follow-ups
- Mobile messaging system to enhance nurse-patient communication
- Structured reporting and discharging forms

To evaluate the mobile health system for insulin dose adjustment service, two clinical trials were planned to evaluate the proof-of-concept and feasibility of this system. In the proof-of-concept trial that was completed in 2017, ten people with diabetes used the system to record and upload their blood glucose levels using a Bluetooth-enabled glucose meter. The study showed that the acceptance of the mobile health application by the patients was high. The feasibility trial is currently being conducted, the aim of which is to evaluate the health outcomes and its efficiency as a service to the clinic.

This mobile-based system for insulin dose adjustment will also be tested as an intervention in a randomised controlled trial (RCT) designed to evaluate the outcomes of a new model of care for the management of people with diabetes in the outpatient setting. In this RCT, 40 patients will be recruited in two groups (intervention and control) and followed-up for six months to compare the clinical and economical outcome of the new model of care for diabetes management
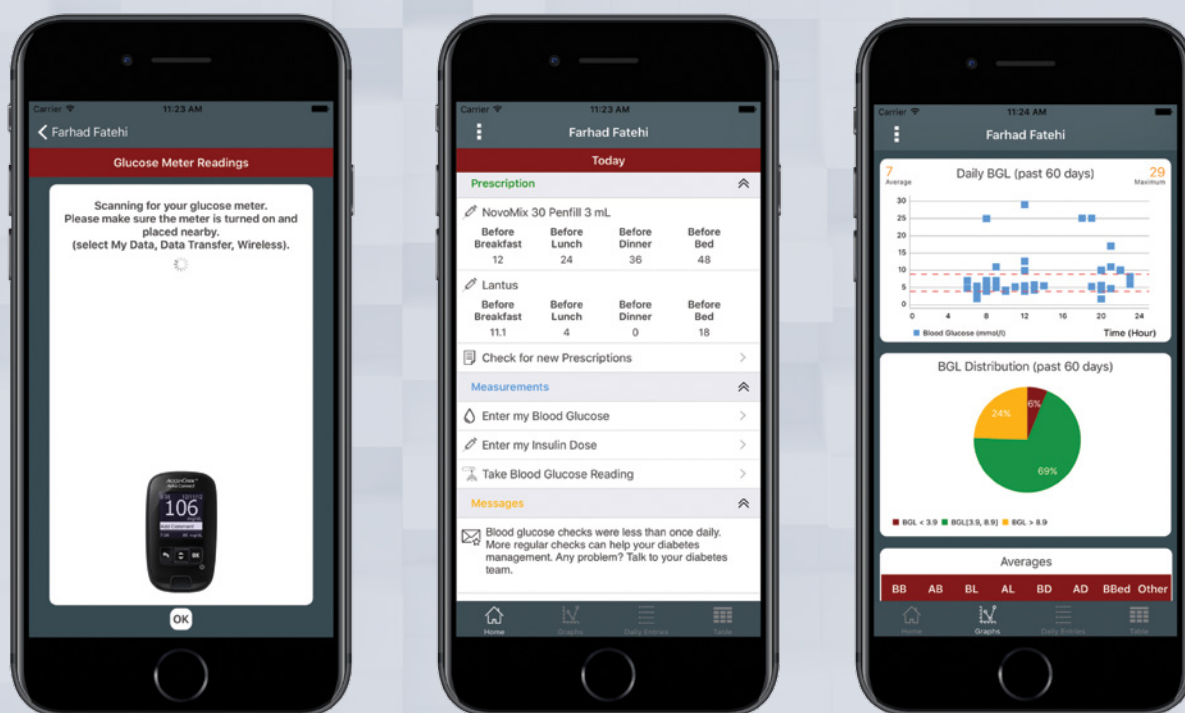
HEALTH SERVICES

Figure 4. Selected screenshots from iOS PAH-ISS App

Mobile Health Solutions *(continued)*

Mobile Health for managing COPD patients

COPD is the third leading cause of death worldwide, and leads to direct health care costs of estimated 8.8 billion dollars annually in Australia. Although evidence-based clinical guidelines for the management of COPD have been available and recommended, compliance by patients with COPD remain poor, consequently, leading to high risks of COPD exacerbations and associated hospital readmissions. To address these issues, the CSIRO Mobile Health team initiated in 2015 a collaborative research project with The Prince Charles Hospital (TPCH) and the Lung Foundation Australia (LFA) to improve the delivery of the guidelines for the management of Chronic Obstructive Pulmonary Disease (COPD). This included the customisation of the innovative MoTER platform to deliver an enhanced clinical care program that integrated the following components:

- Structured automated delivery of the educational program by the LFA

- Monitoring of COPD symptoms for timely interventions

- Promotion of physical activity in compliance with COPD guidelines

- Electronic COPD action plan

- Automated smoking cessation program

- Inhaler technique and monitoring of inhaler medications.

To evaluate the mobile health enhanced COPD program, a randomized controlled trial is being conducted under the TPCH foundation grant. In the trial, the participants (n=100) will be randomized into the mobile health intervention (n=50) and usual care (n=50) groups. The trial is expected to be completed 2018.
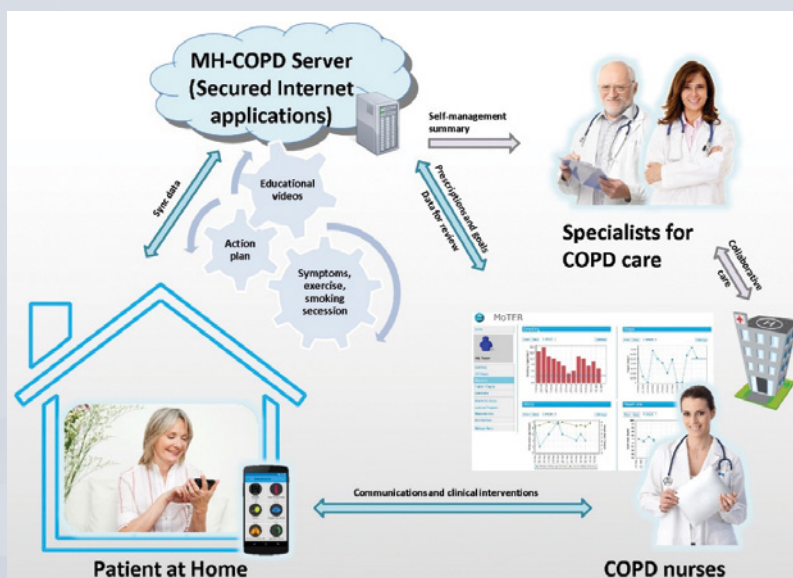
Figure 5. The care model of the MH-COPD program includes the components of COPD education, electronic action plan, symptom management, physical activities, cigarettes cessation, inhaler technique, and nurse-led collaborative care.

Figure 6. (a) Dialog excerpt between HARLIE and an adult diagnosed with autism spectrum disorder

HARLIE: chatbot for e-health applications

People with neurological conditions such as autism spectrum disorder, Parkinson's disease and dementia can have trouble communicating. This invariably results in frustration, social isolation, and other mental health issues. The mobile health team has been developing a smartphone application that aims to allow people to engage in speech therapy tasks and practise general conversation in the privacy of their own home.

Using artificial intelligence for the processing of natural language, the team has developed a conversation agent, or chat-bot called HARLIE. HARLIE is acronym for Human and Robot Language Interaction Experiment. HARLIE engages the user using voice operation on various topics while capturing the users voice and language abilities. Over the last two years, HARLIE has been tested at numerous community groups including knitting groups and mens sheds. Here is a excerpt between HARLIE and an adult diagnosed with autism spectrum disorder as well as a photo of testing HARLIE at a local knitting group.

Remote Logging of daily activities and pain for people with chronic pain

In collaboration with Metro North HHS a pilot study started in mid-2017 within the mobile health team that involved the development of an Android application for people with chronic pain. The application remotely logs daily activities, medications and the level of pain whilst streaming accelerometer data from a wearable device. The data collected by the application is sent to a portal where an Occupational Therapist is able to see a visualization of the data and advise the participant on how they might manage their pain and daily activities to encourage a better well being.
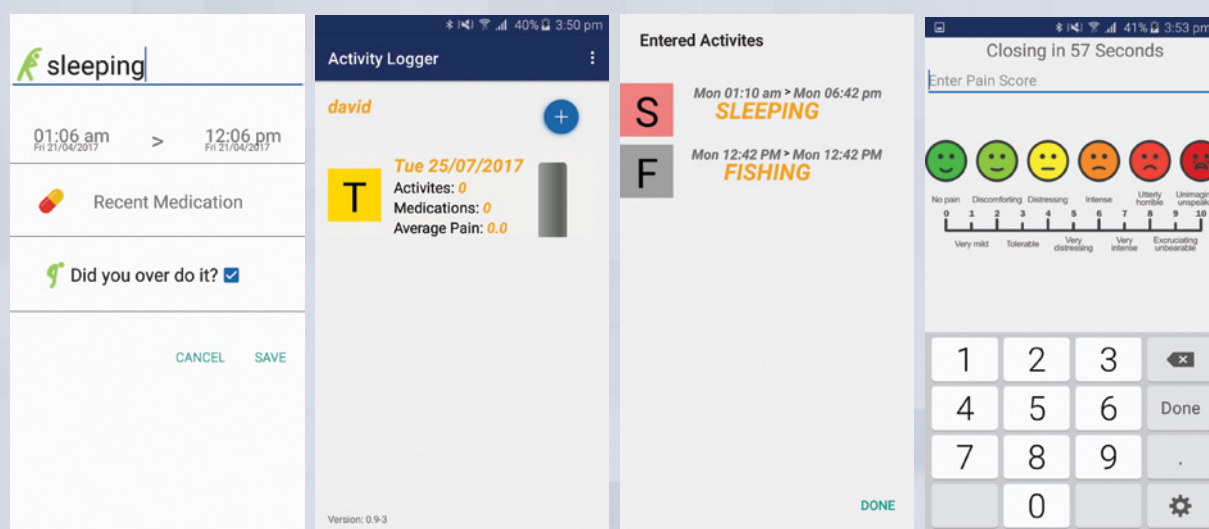

Figure 6 (b) A participant speaking to HARLIE about spending more time with her family.

Figure 7. Screenshot of the Android application that logs daily activities and pain logs.

Centre of Excellence in the Dynamics of Language

During 2016 and 2017 Dr. David Ireland was on secondment for a 6-month period with the Centre of Excellence in the Dynamics of Language (CoEDL), in which he contributed to variety of projects including:

- Identifying speakers in high-noise acoustics signals
- Visualization of features in time-varying acoustic signals
- Mapping phonetic sounds from autistic children to semantic meaning for emphasis on AI engagement during story telling
- Development of first-order logic algorithm to build language semantics from chat-bot conversations.

Mobile Health Solutions *(continued)*

Highlights for 2016/17:

- The implementation trial, offering MoTER as an optional cardiac rehabilitation program as well as a hybrid option, which offers switch over from centre-based to home-based program, is nearing completion at Metro South Health CR services. Early indications are that delivering a variety of CR program options has the potential to improve overall CR service use. Demonstrating an increase in CR uptake to 65% and more, can reduce the burden of disease, directly translating to significant benefits to health services and the economy; and to date the uptake has increased to 67%.

- Development of a smartphone- and Internet-based interactive system to support the management of women with a first time diagnosis of Gestational Diabetes Mellitus has been completed and a feasibility trial to test the solution commenced with first participants recruited in August 2017. The mobile solution, M♥THer, was a winner at the Health Round Table Innovations Awards in July 2017.

- A feasibility study to test PD BUDDy, the mobile health system to support peritoneal dialysis patients, commenced in July 2017 and recruited 20 patients by Aug. PD BUDDy was awarded 'People's Choice' at the Renal Society of Australasia (RSA) conference and was selected as oral presentations at HIC and Aust New Zealand Society of Nephrology Annual Scientific Meeting '17.

- HARLIE innovation received wide media release, including radio interviews, television and "The Conversation" articles.

- App and portal developed for Metro North Health management of chronic pain, commenced a pilot study which remotely logged daily activities, pain- and movement levels for people with chronic pain to correlate with their pain medication.

Aims for 2017/18:

- To extend the innovation of the mobile health platform to incorporate gamification features.

- To complete feasibility studies for mobile health delivery care models in diabetes, kidney disease and pain management and secure funding for larger efficacy studies.

- To conduct feasibility trials of the mobile cardiac rehabilitation platform in internationally diverse CR service delivery sectors

- Extend mobile support delivery to mental health patients e.g through collaboration with Macquarie University, Sunshine Coast HHS and others.

- Extend HARLIE for wider health conditions such as Autism and other language disorders

- Development of an AI based augmentative and alternative communication application to improve Autistic individuals' expressive language, and promote more complex communication with other humans.

PhD Student or Postdoc Highlight

Name: *Nazli Ghafouryan*

PhD topic/title
AEHRC PhD Scholarship

The aim of this research is to develop and validate a mobile based virtual clinic via customising a recently validated mobile health platform (MoTER) for the clinical management of patients with Acute Coronary Syndromes (ACS). This research study consist of Phase1 (pre-study survey and pilot trial) and Phase 2 (randomised controlled trial).

The aim of the pre-study survey is to conduct structured interviews with patients and a focus group with healthcare professionals to define the requirements for customising the MoTER platform for ACS. Between January and March 2017, the pre-study survey

was conucted in patients (N=30) diagnosed with ACS post intervention from outpatient clinic, The Prince Charles Hospital. Using two surveys including Australian version of Short Test of Functional Health Literacy (STOFHLA) and the Cardiac patients Learning Needs Inventory (CPLNI), pre-study identified ACS patients' with preferred learning needs and health literacy level. These will be used as part of the framework for the mobile based educational interventions.

In May 2017, one hour focus group was conducted to investigate healthcare professionals' expectations of a smartphone based application and its portal to empower patients. The focus group session with clinicians (N=10) resulted in useful feedback regarding different contents and features of MoTER application.

Based on the results of pre-study survey and focus group, educational topics and self-management interventions were identified from published materials available from CSIRO and Heart Foundation. Furthermore, to investigate the current model of care for patients after discharge from hospital, an online survey was designed by the students and conducted with 20 cardiologists. The results of this survey along with the literature review of mobile health models of care will be used to propose a model for the clinical management of ACS patients.

Upon completion of the Mobile virtual clinic system for ACS management (MoTER-ACS), a pilot study will be conducted in 54 patients over 12 weeks. Following this, Phase 2 trial will evaluate the virtual clinic effectiveness in a Randomised Controlled Trial (RCT) and assessing participants' clinical outcomes, quality of life and psychosocial wellbeing at baseline, 8 weeks and 6 and 12 months.

Health Internet of Things

The Internet of Things (IoT) refers to a network of internet-connected devices that collect and transmit data through embedded sensors. The Health Internet of Things team uses IoT to build solutions for health and aged care.

Smarter Safer Homes (SSH) for Aged Care

The Smarter Safer Homes (SSH) platform takes advantage of the latest wireless communication technologies in home and health monitoring sensors to provide a smart home through consumer design interfaces and engagement of informal (eg. family) and formal (aged care and clinical) support services. To enable support of one's functional independence, SSH platform features novel analytics to determine an objective and personalised measure of an individual's functional independence.

The SSH platform project is led by CSIRO's Australian eHealth Research Centre with multidisciplinary collaboration including universities, aged care service providers and local clinicians. The SSH platform uses cutting edge pervasive communication and wireless sensor and monitoring technology, and features a novel, personalised measure of functional independence, indexed through the "Objective Activity of Daily Living". The potential benefits of these technologies are multiplied where distance separates families and adds substantial costs to delivery of health and other services.

The SSH platform has been piloted in Australia senior homes with various settings, including independent living, homes with nursing care and/or home care services. The SSH platform was deployed to homes connected to either cable, broadband or mobile network. These pilot studies helped design and develop the SSH as a technology service platform towards remote delivery of nursing and home care services to elderly people living at home.
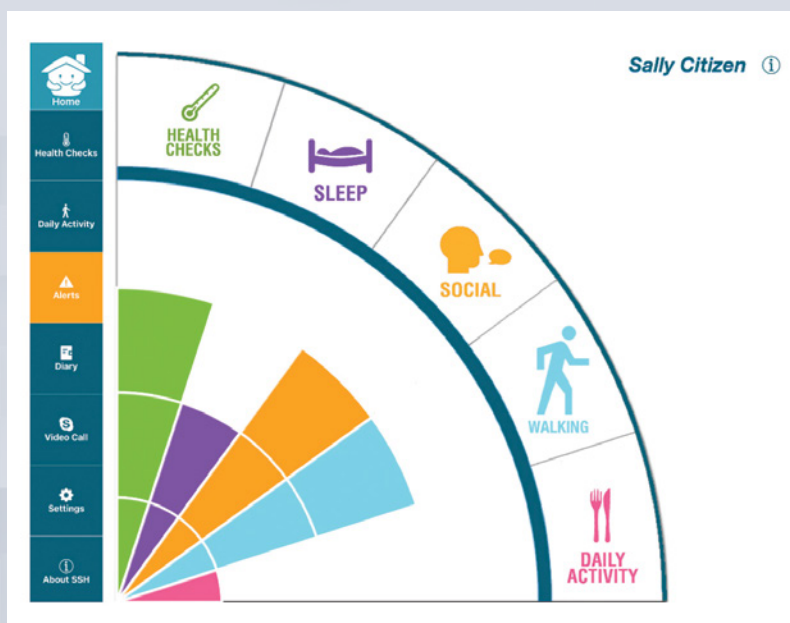

Figure 2. SSH iPad application allows residents to view data derived from the sensors and medical devices.
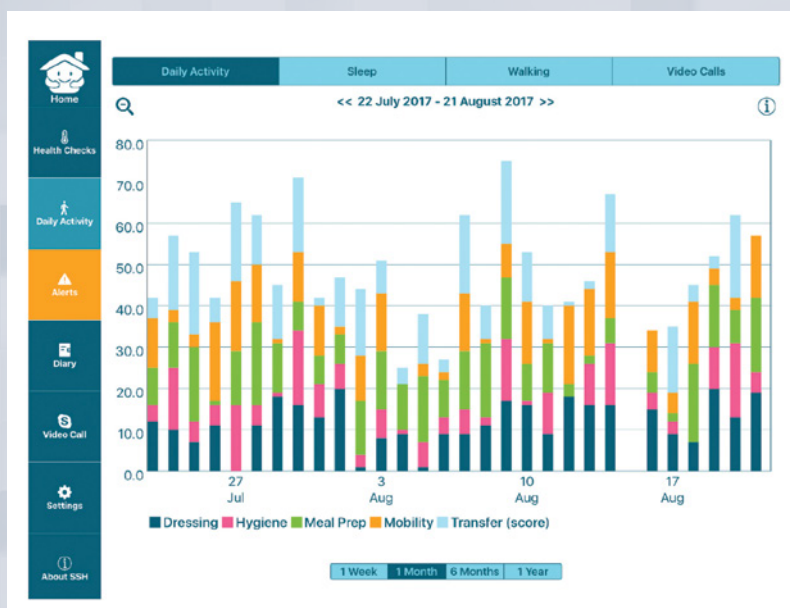

Figure 3. Objective-Activity of Daily Living (OADL) scores of the SSH App to represent everyday's health and wellbeing status

HEALTH SERVICES

Health Internet of Things *(continued)*

Smart Home Activity Recognition

For smart home with single resident, existing approaches mostly adopt supervised learning from well-annotated sensor data. However it is always prohibitive to obtain labelled data in real home scenarios due to either the privacy violation concerns of using cameras, or the low adherence of self-reporting by home residents. We thus proposed a novel unsupervised Bayesian nonparametric model to automatically discover activities which needs neither labelled training data, nor prior knowledge of the number of interesting activities. Compared to existing methods, our method is practical and can be easily deployed in smart home applications with minimal user interference.

For smart home with multiple residents, various Markov Models have been used to discover different types of interactions between residents. To achieve better accuracy, we proposed a novel mixture model (MDM) that aims at recognising all types of interactive activities between residents. The experiments on three public available datasets demonstrate the superiority of this new model.

Non-wearable Sensor for Human Identification

To achieve satisfactory accuracy on activity recognition in home with multiple residents, we designed two novel environmentally deployed human identification sensor systems to collect evidence with regards to which resident is passing the sensor's detection zone. The Bluesound system uses ultrasound sensors to collect residents' height as a bio-feature to efficiently differentiate multiple residents, and achieves 78% accuracy among 5 individuals. The ultra-wide band (UWB) system uses different reflected UWB radar signals to collect residents' body shape and height as features to distinguish residents, and can achieve 80% accuracy among 8 individuals.
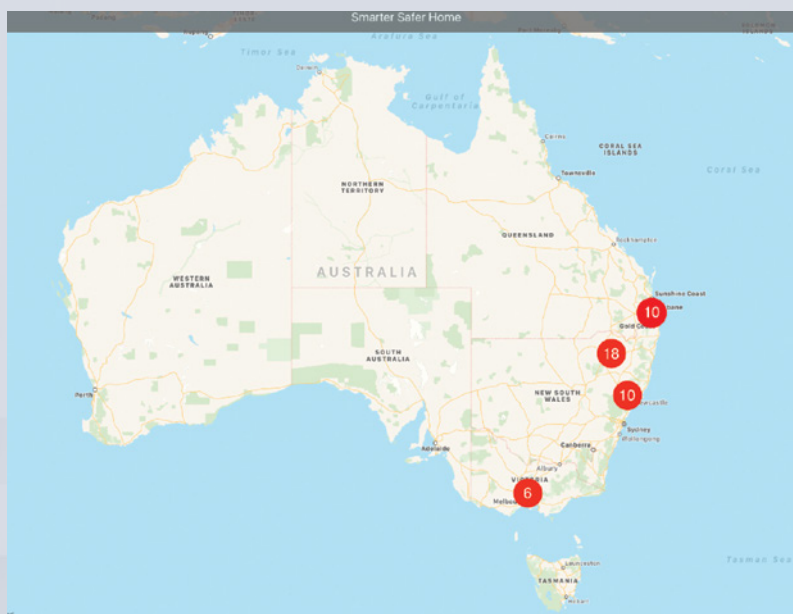

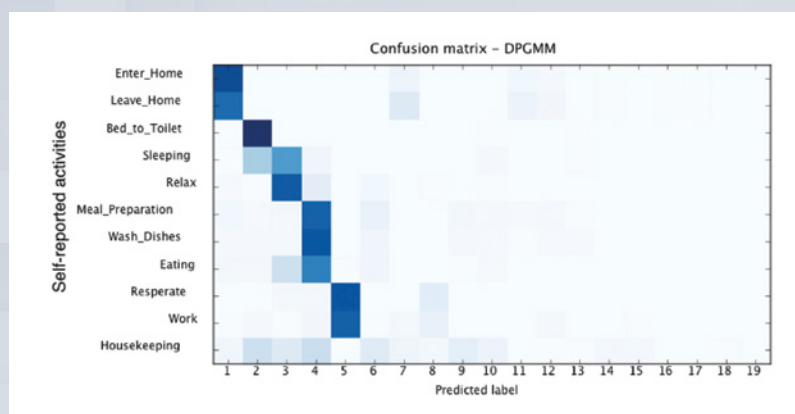Figure 4. SSH clinical trials location, period and number of homes

Figure 5. The confusion matrix shows highly correlated auto-discovered (predicted) activities and resident self-reported ones.
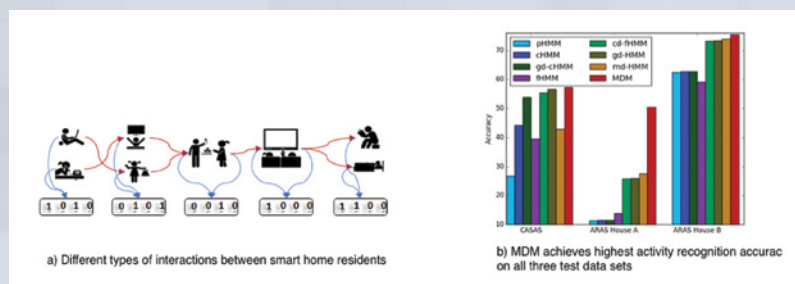

a) Different types of interactions between smart home residents

b) MDM achieves highest activity recognition accurac on all three test data sets

Figure 6. A mixed statistical model to discover interactive activities of multiple residents in smart home.

Energy Efficient LoRa GPS Tracker for Smart Home Residents with Dementia

Dementia is the leading cause of disability in seniors and wandering is a common symptom that can often result in injury to the resident and stress for caregivers and family members. GPS trackers are often used to assist caregivers in the monitoring of dementia patients and to quickly respond to risky wandering events that occur. However the battery of existing trackers for dementia patients using 3G/4G usually lasts only a couple of days under active GPS tracking mode. To bring peace of minds to carers, we have designed this energy efficient tracker which uses novel IoT communication technology (LoRaWan) and power optimizing techniques, that can achieve a long battery life, up to six weeks active GPS monitoring.
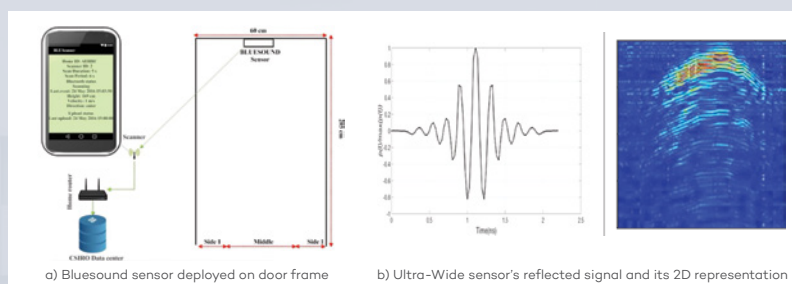

a) Bluesound sensor deployed on door frame   b) Ultra-Wide sensor's reflected signal and its 2D representation

Figure 7. Two non-wearable human identification sensors.

a) The GPS tracker and its components   b) The real-time tracking app

Figure 8. LoRa GPS tracker for dementia wandering monitoring supports.

HEALTH SERVICES

Collaborators:

- Data 61/Energy Flagship, CSIRO
- Aged care service providers
- QIMR Berghofer Medical Research Institute
- ORCATECH of Oregon Health & Science University, USA
- Lyon University, France
- Academy of Science, China

Team Highlights for 2016/17:

- Conducted a smart home clinical trial with aged care service providers in Newcastle, NSW.
- Two novel non-wearable human identification sensors were developed and evaluated in lab environment
- An energy efficient GPS tracker prototype, using the latest LoRa communication technical was developed

Team Aims for 2017/18:

- To validate the SSH platform in real-practice, the team will undertake customising the platform to service models across different geographical sectors prior to testing in clinical trial
- To establish testing of prototype modules for SSH platform, a 100-home test bed project will be implemented
- Develop an accurate multiple residents activity recognition system through integrating non-wearable human identification sensors
- Develop a z-wave universal vibration sensors to detection object movements in smart home environment

Digital Health Engagement

The Digital Health Engagement team draws on expertise across Human Computer Interaction, Personalisation & Recommendations, Persuasive Technology and Neuroscience to be a leading team in the design and evaluation of technologies to facilitate the provision of equitable health care. The team designs technologies that can be used by clinicians to improve workflow and enhance service delivery; and by individuals to support them in playing an active role in their health management to meet short or long term health and lifestyle goals. The team has a strong collaborative approach, leading and contributing to projects across the e-Health program and into several other CSIRO divisions. In 2016/2017 the team engaged primarily with industry partners to deliver excellence in science.

Figure 1. Activate TKR app: Home screen.

Figure 2. Activate TKR app: Physio Coach screen. Exercise programs are configured by physiotherapists from a library of videos typically used for TKR rehabilitation.

Figure 3. Activate TKR app: Today screen. Shows data from the activity tracker (daily step, stairs, and sleep) and self-reports (pain and knee ROM).
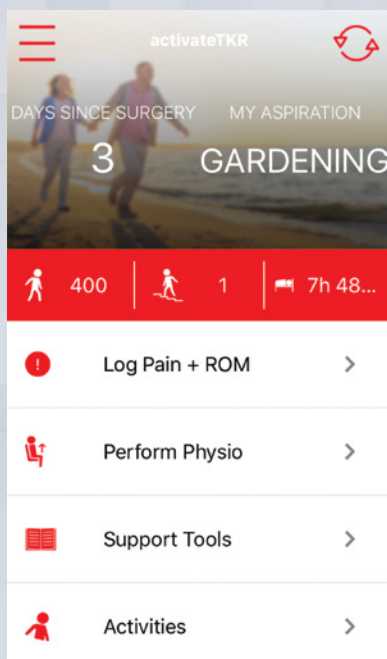
Activate TKR: Mobile Support for Orthopaedic Surgery

Summary

Total knee replacement (TKR) surgeries have increased in recent years. Exercise programs and other interventions following TKR can facilitate the recovery process. With limited clinician contact time, patients with TKR have a substantial burden of self-management and limited communication with their care team, thus often fail to implement an effective rehabilitation plan.

The Australian eHealth Research Centre at CSIRO, together with Johnson & Johnson Medical Devices Australia, are looking at new ways to address the challenges of motivating and assisting patients to complete rehabilitation programs while also reducing the communication gap that exist between clinicians and patients.

We have designed and developed Activate TKR, an orthopaedic support technology platform, which comprises a mobile phone application (app), a wearable activity tracker, and a clinical web portal. The technology platform aims to assist patients in managing their surgery preparation and speed up recovery.; and to bridge the communication gaps between clinicians and patients.

The purpose built app includes behavioural coaching, practical hints and tips for surgical preparation, video based exercise demonstrations, and tools for self-monitoring of daily activities including progress collected through the activity tracker.

The app transmits patient-gathered data to a purpose built web portal where clinicians can view patient progress and configure exercise programs remotely. Activate TKR is designed to provide flexibility in care delivery, and increased engagement with rehabilitation services.

A study will evaluate the technology platform through a randomised controlled trial (RCT), conducted at multiple sites in a number of states in Australia, with ~300 patients undergoing TKR surgery. Participants will be randomised to either a control group or the intervention group; both receiving usual care as provided by their surgeon or hospital. The intervention group will receive the app and wearable activity tracker in addition to usual care. This trial will investigate the clinical and behavioural efficacy of the app, and impact of the technology platform components in terms of service satisfaction, acceptance, and economic benefits of the provision of digital services. The trial will run for a period of 13 months for each patient.
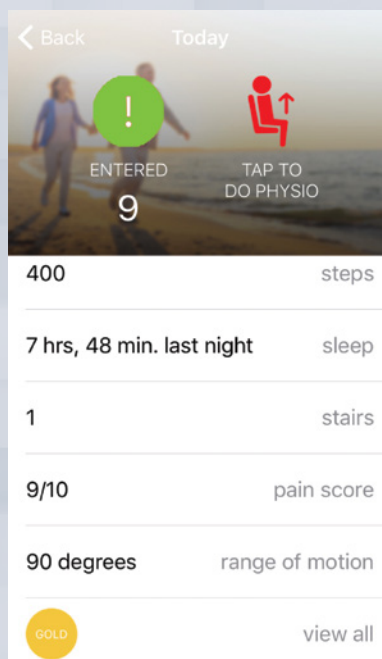

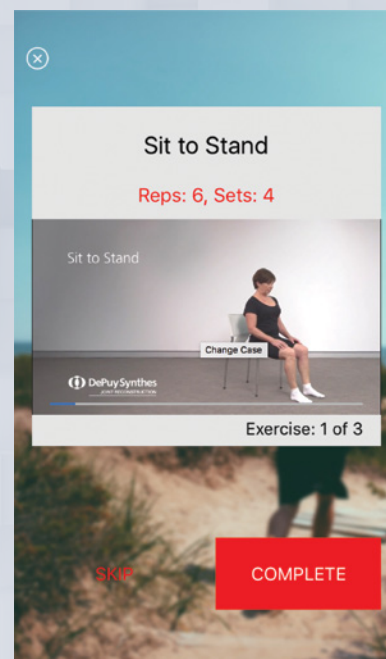*Figure 1.*

Figure 2.

Figure 3.

Outcomes

- Increase patient engagement with rehabilitation services (surgical preparation and recovery)
- Bridge the communication gaps between clinicians and patients
- Provide flexibility in TKR care delivery; particularly in rural, remote, or busy lifestyles, and has potential to achieve same clinical outcomes as normal business as usual care

Impact

- J&J's interest in application to other joint replacement studies
- Health care industry's application to health & wellness solutions

Outputs to date

- Development of the technology platform (patient app and clinical portal)
- RCT trial launched in November 2016; kick-off with 6 trial sites in NSW, QLD, and SA
- First media release in March 2017
- Showcased project together with Johnson & Johnson Medical Devices at the 'Bennelong Innovation Summit' in Parliament House (March 2017)
- Research protocol paper published in JMIR; Hussain MS, Li J, Brindal E, van Kasteren Y, Varnfield M, Reeson A, Berkovsky S, Freyne J "Supporting the Delivery of Total Knee Replacements Care for Both Patients and Their Clinicians With a Mobile App and Web-Based Tool: Randomized Controlled Trial Protocol" JMIR Res Protoc 2017;6(3):e32

Outputs expected in 2017/18

- Preliminary trial data analysis (clinical efficacy, patient/carer satisfaction, economics)
- Publications: 1. van Kasteren Y, Freyne J, Hussain MS "Total knee replacement pathways: How can technology support patient cocreation for improved outcomes?" JMIR (major revision); 2. preliminary 4 week pre-surgery & 12 week post-surgery tech usage
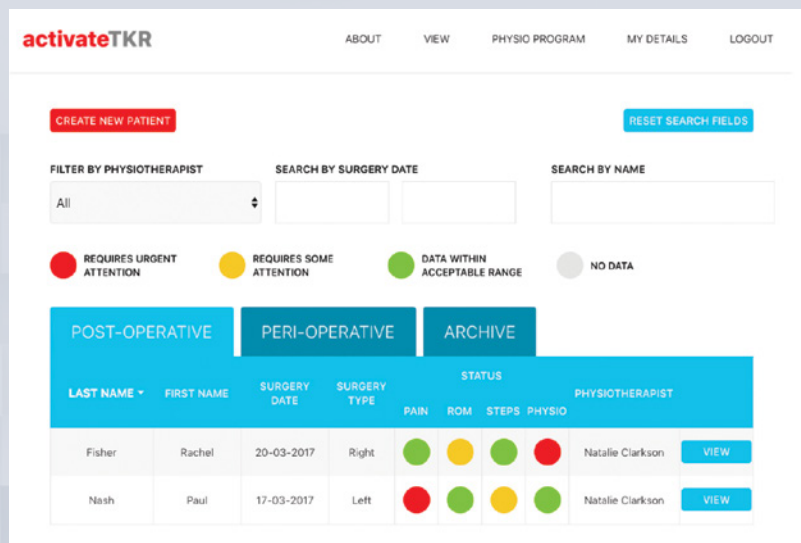

Figure 4. Activate TKR clinical portal. The web portal allows clinicians (e.g., surgeons, physiotherapists) to view patient data and configure exercise programs for individual patients.

Evaluation of Butterfly Systems Solutions

Butterfly Systems has developed mobile applications (apps) to support the appropriate management of surgeons' preference cards which are fundamental to facilitate the flow of surgical instruments and materials to the surgical areas. Supported by a Commercialisation Acceleration grant, the Butterfly Systems will test these apps in multiple hospitals around Australia.

The Australian eHealth Research Centre at CSIRO is providing guidance to the Butterfly Systems during the development and execution of their trial, while also assisting with the evaluation study design, data analysis and report.

This project brings together our evaluation and human computer interaction expertise to guide the Butterfly Systems technology trial. We have developed a comprehensive evaluation framework which aims to understand the impact of the digital preference cards on clinical efficiency, accuracy of surgical item data and stock requirements as well as staff work practices.

Outcomes

- Technology trial of the surgeons preference cards which aim to improve clinical efficiency, data capture accuracy and surgical item management
- Engaging with the company to conduct evaluation in operating theatre area which is a vital centre of care for patients

Impact

- Become a preferred partner to support technology startup companies and SMEs that have strong focus on health systems
- Develop our capability on the design of multi-method evaluations focused on the impact of ICT technology

Outputs to date

- Delivered to the company an Evaluation Framework report to guide the technology trial in a number of hospitals
- CSIRO team has conducted a qualitative study at Calvary John James Hospital to understand the implementation of the apps and potential impact of introducing the apps
- CSIRO team has engaged with the company to propose a new project in evaluating a new app-mySupply which is an extension of the existing apps
- An extended abstract/poster has been presented in HIC2017 conference

HEALTH SERVICES

Digital Health Engagement *(continued)*

Work It Out

To prevent and manage chronic conditions in urban Indigenous Australians, the Institute for Urban Indigenous Health (IUIH) has developed a range of programs including Deadly Choices and Work It Out. The Work It Out program is a face to face chronic disease management and rehabilitation program designed to empower Indigenous Australians to manage a range of chronic conditions such as diabetes and cardiovascular disease.

The Australian eHealth Research Centre at CSIRO partnered with IUIH and Aboriginal and Torres Strait Islander participants of the Work It Out Program to develop and trial a mobile health platform to support the Work It Out program. This included tailoring a health mobile application (app) to record diet, exercise and lifestyle factors on participants' mobile phones, developing a digital version of the Work It Out program for mobile delivery and customising a clinical portal to allow exercise physiologists to view daily data in order to guide and support participants in developing autonomy in healthy practices.

Outcomes

- Two trials were conducted with Work It Out clients in two sites.
- Clients found it useful to have physiological records they could show their GPs.
- Some clients had greater insight into how health factors, such as stress and mobility were related for them personally.

Impact

- Insights into how lifestyle factors interact with health measures have the potential to influence health behaviours.
- This project demonstrated that it is possible to modify existing technologies to augment programs designed for Aboriginal and Torres Strait Islander adults managing chronic health conditions.

Outputs to date

- Conference paper and Co-presentation, AEHRC and IUIH at the Developing Northern Australia Conference 2017
- Digital version of the Work It Out Program

CALD Assist

The CALD Assist app translates key phrases for nursing and allied health staff into 10 common languages (in addition to English) using pictorial, video, written and voice-over prompts to ensure appropriate and timely care for inpatients.

Effective communication in the hospital setting is vital to ensure appropriate care and reduce the risk of adverse events. Research indicates a variance in access and quality of healthcare provided to people from Culturally and Linguistically Diverse backgrounds (CALD) and their English speaking peers, which can be reduced with the use of interpreters, however, demand for these services often exceeds supply. Interpreter demand is unsurprising given the communities served by Australian hospitals vary in cultural diversity, with some hospitals, such as Western Health in Victoria, serving communities where more than 150 languages are spoken. Unmet demand for interpreter services means that non-English speaking patients are sometimes unable to access timely care, causing inequity in service delivery and often frustration and anxiety for patients, their carers and clinical staff.

Researchers from the AeHRC's Digital Health Engagement team, together with clinicians at Western Health designed, developed (2014) and evaluated (2015) CALD Assist – Allied Health, a novel communication app designed to facilitate initial assessment between clinicians from five allied health disciplines (dietetics, speech pathology, podiatry, physiotherapy and occupational therapy) and CALD patients, when an interpreter is not present. As a response to multiple awards (Branko Cesnik Award for Best Academic/ Scientific paper; 'Improving health equality and closing the gap', Victorian Public Healthcare Awards), senior nursing staff expressed a significant need for a nursing based app using a similar platform. In 2016, CALD Assist was expanded to meet the specific needs of the nursing workforce. The inclusion of nursing specific material will enable nursing staff to better meet the daily care needs of their CALD patients, reduce variance in practice, and provide a timely and positive patient experience. A three month efficacy trial will evaluate the efficacy of the app, and impact to patients and nursing staff.
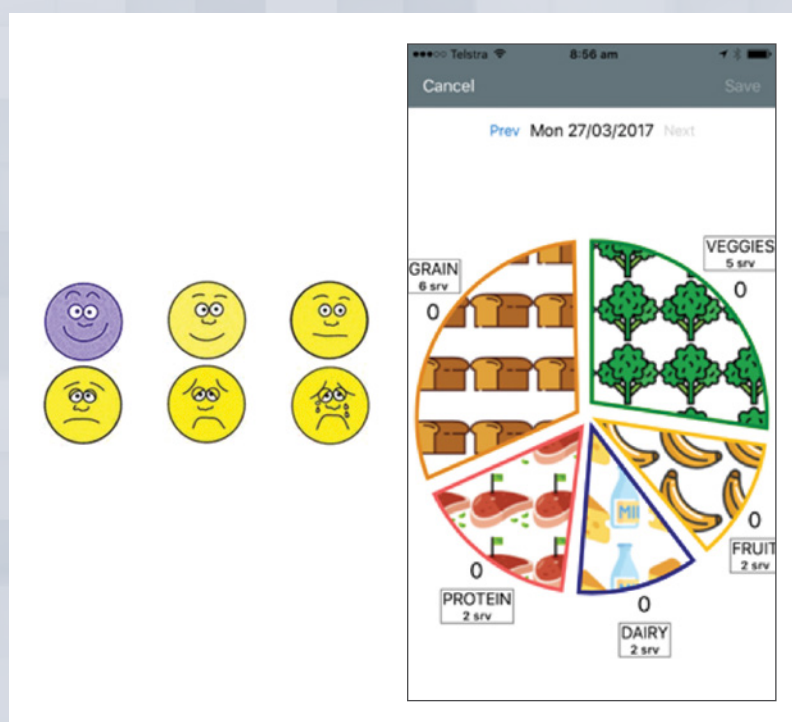

Figure 5. Smiley faces give a rating for monitoring mental wellbeing, and interactive food plate allowed monitoring of daily consumption by food group.

Outcomes

- User needs analysis was conducted with nursing staff and patients in three different sites.
- A new app was developed that includes nursing-specific content
- Baseline data collection (as part of the evaluation trial) was finalised
- It was confirmed that interactions between nursing staff and CALD patients are less successful than those with English-speaking patients.

Impact

- Improve the clinicians ability to adequately assess and respond to patient needs in a timely manner
- Improve the frequency and quality of communication between staff and CALD patients.

Outputs to date

- Freyne, J., Pocock, C., Bradford, D., Harrap, K., Brinkman, S. Designing technology for assessments of CALD patients. HIC Brisbane 4th August 2015.
- 2015 Health Informatics Society Australia, Branko Cesnik Award for Best Academic/Scientific paper
- 2015 Gold 'Improving health equality and closing the gap'. Victorian Public Healthcare Awards
- 2017 The Health Roundtable Innovations Award 'Improving the Continuum of Care'

Outputs expected in 2017/18

- Evaluation results CALD Assist – Nursing
- J. Freyne, D. Bradford, C. Pocock, D. Silvera-Tawil, K. Harap, S. Brinkmann. Developing digital facilitation of assessments in the absence of an interpreter: a participatory design and evaluation with allied health groups.
- D. Silvera-Tawil, C. Pocock, D. Bradford, K. Harap, S. Brinkmann. CALD Assist – Nursing: Improving Patient Communication in the Absence of Interpreters
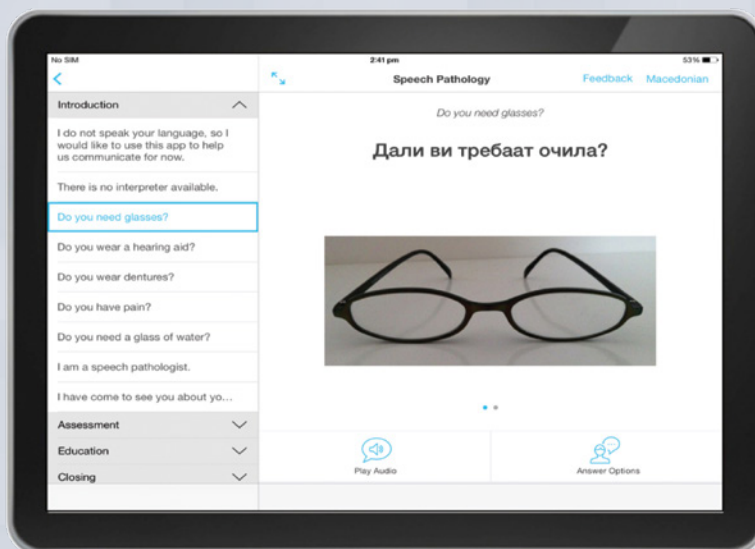

Figure 6. CALD-Assist app: upon selection of an individual phrase, translated text and appropriate image is displayed on the screen.

Collaborators:

- Johnson and Johnson Medical AU
- Butterfly Systems
- Institute for Urban Indigenous Health
- The Project Factory
- Movember
- Melbourne Genomics Health Alliance
- Western Health

Project Aims for 2016/17:

- Commence clinical trial for Activate TKR program
- Complete Review of Butterfly Systems technology
- Complete trial of Work it out at (location)

HEALTH SERVICES

PhD Student or Postdoc Highlight

Name: Geremy Farr-Wharton

Geremy Farr-Wharton joins the AEHRC as a Postdoctoral Social Scientist. His current focus provides qualitative leadership to a number of CSIRO projects, including the Total Knee Replacement (TKR) Project in eHealth, Future Cities in Land & Water, and the South Australian Power Networks (SAPN) Project in Energy. His expertise also positions him to help support and drive a number of other key CSIRO projects across Health & Biosecurity, Land & Water, and Energy.

Geremy is a transdisciplinary mixed-methods researcher whose background stretches across a breadth of fields, such as Health, Energy, Food, Consumer Behaviour, Information Systems, and Computer Science. Geremy's PhD explored aspects of Human Computer Interaction, Design and Consumer Behaviour to reduce domestic food waste in Australian homes. His previous Postdoctoral experiences have helped him to build strong ties with industry (nationally and internationally),

including several tech start-ups, PricewaterhouseCoopers, Ernst and Young, and QMI Solutions. Through his Postdoctoral positions, Geremy has applied his skillset to some of the largest digital transformation projects in Australia.

Australian Tele-Health Research and Development Group

Director: Yogi Kanagasingam

The Australian Tele-health Research and Development Group is our partnership with the Western Australian Department of Health and our Western Australia node of the Australian e-Health Research Centre (AEHRC). The three year grant from the Department of Health was renewed from July 2015 for a further three years.

The ATRDG aims to be a world leading Telehealth research and development group. The research and development program aims to transform the way health services are delivered to address pressing and emerging areas of healthcare delivery, particularly in respect to the provision of high quality services to rural and remote populations and to high-needs groups. The aim of this research has been to improve health outcomes in Western Australia and increase the productivity and efficiency of health service delivery in Western Australia.

There are three research key areas:

- Remote Delivery of Clinical Services – supporting health services and clinicians by using telemedicine and related technology to develop new ways of delivering health services.
- Chronic Disease Management – using mobile phone based chronic disease monitoring and home based care to provide services directly to patients.
- Disease diagnosis and screening technologies – developing new, mostly ocular, screening technologies for early detection of Alzheimer's disease, stroke, mental health disorders and hypertension.

Projects

Remote Delivery of Clinical Services

Artificial Intelligence based Clinical Decision Support System for Diabetic Retinopathy

We have obtained a NHMRC development grant to develop and validate a smart eye screening system for early detection of Diabetic Retinopathy. The system uses deep learning techniques to grade each retinal image as disease or no-disease. To increase the sensitivity and specificity we developed an image quality control system that identifies the images which are of unacceptable quality to provide an automated grading system. The system, subsequently, will alert the screener to take another image. The grading system is also capable of grading the disease levels as mild, moderate or severe.

System development

We have developed a color fundus image quality assessment (QA) system by applying AI algorithms for classifying the image as good quality or not and providing instant alert to the screener to obtain an acceptable quality image. The system was trained on 2000 images and tested on 1000 images and achieved 97% accuracy.

We have developed a rule-based DR grading system which can segment DR pathology for DR grading and also developed a Deep Learning based (DL-based) DR grading system for patient Referral/No Referral recommendation.

The DL-based system was trained on approximately 7,000 images and tested on approximately 2,000 images and achieved 91% accuracy for DR disease/no disease classification.

Clinical trial

We conducted a clinical trial at the GP Superclinic at Midland, from September 2016 to June 2017. 214 patients were recruited for retinal imaging in this trial.

Based on the ophthalmologist grading as gold standard, there were 1 severe, 1 moderate and 9 mild DR patients. Our AI based grading system was able to identify all the diseased patients correctly.
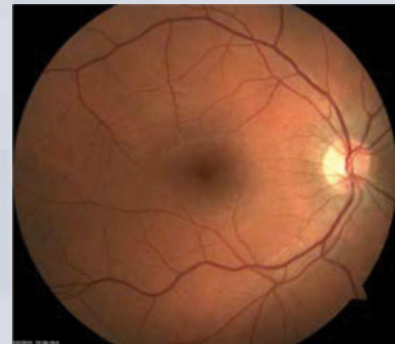
Normal retina (Top) and retina with signs of diabetic retinopathy (Bottom)

AUSTRALIAN TELE-HEALTH RESEARCH AND DEVELOPMENT GROUP

Remote Delivery of Clinical Services *(continued)*

## Medical Image Communication and Exchange (MICE) App for Burns Applications

Using the Medical Imaging and Communication Exchange App, junior doctors, specialists and nurses can now seek expert real time diagnostic advice about various conditions by securely sending burns images through the mobile device to a Burns's specialist. By way of streamlining the medical image capture and storage process, the app introduces a secure way of sending medical images to the specialist. Images captured through the app are not saved on the mobile device and can only be viewed by the specialists and related doctors. Medical records and images are managed through our award winning store and forward telehealth system (Remote-I). This system can be accessed via web or mobile and maintains secure access rights for all the users.

Highlights on MICE Trial (Apr 2017 – June 2017)

- 30 Users – ranging from iPhone 5 to 7
- 4 user roles (Medical Illustrations, Specialists, Project Coordinator, Admin)
- ~ 40 Patients (Mainly captured after hours)
- ~ 120 Images with ~ 200 image tags
- Agile: On-site agile development within the hospital – App was co-developed with hospital staff to cater for their direct clinical requirements.
- Barcode: Patient Record Integration using barcode scanning feature
- Reporting: Reporting functionality for hospital systems integration
- Image Tagging: Images taken from the app are tagged to indicate which body part. This assists in searchable clinical images.
- Engagement: Engaged with many other hospital departments (such as plastics, orthopedics, business intelligent unit, security, IT)

MICE App Screen Shots

(A)
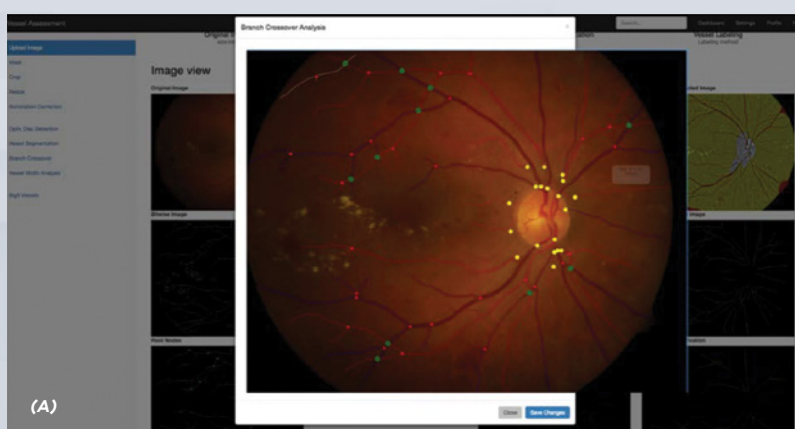
Vessel Analysis Software Platform (VASP)

Our scientists and researchers have been working on a retinal analysis platform with user interaction capability. This platform leverages automated image processing techniques with user interaction to analyse retinal parameters. This web based software platform streamlines data collection for retinal parameters and we are analysing over 10, 000 retinal photographs to identify longitudinal changes of the eye for any disease conditions. VASP could be used to deliver retinal analysis service for remote regions. This platform also utilises cutting edge imaging technologies and cloud processing to produce the results.

(B)

(C)
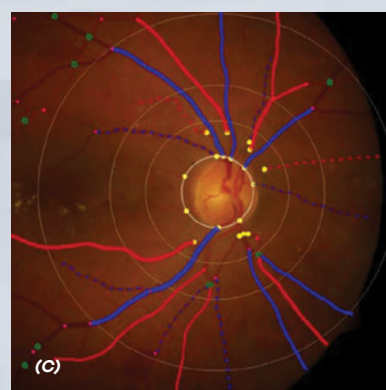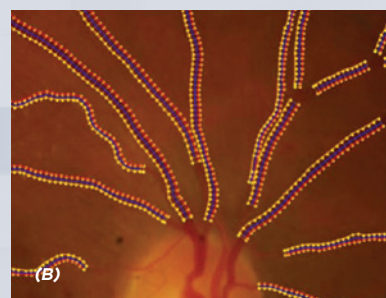
Postdoctoral Fellow

Name: Sajib Saha, *PhD*

Dr. Sajib Kumar Saha is a postdoctoral fellow at the E Health Research Centre of CSIRO and working towards the development of machine learning techniques for the automated detection and progression analysis of sight threatening eye disease, specifically diabetic retinopathy (DR) and age related macular degeneration (AMD). Dr Saha joined CSIRO in August 2015 and during this time he has proposed and developed several artificial intelligence (AI) methods for the automated analysis of retinal pathologies. His core developments include a novel retinal image registration method, an automated image quality assessment method for DR screening, an automated non- uniform/poor illumination correction method for fundus images, a novel color normalization method to eliminate intersubjective color variability to facilitate automated analysis, a deep learning method for the 'disease', 'no-disease' grading of AMD, and a deep learning method for the detection and classification of DR pathologies. He has published numerous research articles in top ranked journals including 'Investigative Ophthalmology & Visual Science (IOVS)' journal (IF 3.43), 'Journal of Medical Systems' (IF: 2.46).

Dr. Saha has led to the establishment of a collaboration with the University of California, Berkley and Stanford University in California to use their retinal image dataset and to develop novel techniques for the analysis of the disease. Dr. Saha is also working with researchers from Sankara Nethralaya, India and Khulna University, Bangladesh.

Dr. Saha acts as a reviewer of the journals titled IEEE Transactions on Broadcasting, Biomedical Signal Processing and Control, Biomedical Physics and Engineering Express, Computer Methods in Biomechanics and Biomedical Engineering, Computers in Biology and Medicine, Journal of Digital Imaging, and Journal of Cultural Heritage. He is an editorial member of the journal titled 'Ophthalmology'.

Collaborators:

- Prof Fiona Wood, Director, Burns Unit at the Fiona Stanley Hospital
- WA Health
- GP Superclinic, Midlands, Perth
- WA Country Health Service
- Telemedc

Project Highlights for 2016/17:

- Diabetic Retinopathy grading system evaluation on training data set completed
- Image quality control system evaluation completed
- MICE App developed for iOS (iPhones)
- MICE app trial is completed by the specialists and junior doctors at Fiona Stanley Hospital and the hospital executive commitee is supporting the project for statewide rollout

Project Aims for 2017/18:

- Refine the diabetic retinopathy grading system to run faster (less than 1 min per image) and test on much larger data set which was obtained from multi-ethnic population (colour of the retina varies).
- Explore roll out of the diabetic retinopathy grading system to other clinics
- Publish the trial outcomes in high impact journals
- Apply for funding to expand MICE app to other medical applications (e.g. wounds, dermatology)
- License MICE to WA Health for use at different hospitals.
- Explore opportunities to commercialise and bring the MICE app to market.
- Further develop MICE App on other mobile platforms and disease conditions
- Finalise the VASP system development and start testing on various data set

AUSTRALIAN TELE-HEALTH RESEARCH AND DEVELOPMENT GROUP

Chronic Disease Management

ATRDG is also interested in delivering management of complex and chronic conditions in the home using telehealth, particularly to the state of WA. This is undertaken in collaboration with the Mobile Health team to extend mobile health trials currently underway to Western Australia arms. One of the initiative is to undertake a multi-centre trial of chronic obstructive pulmonary disease (COPD) with specialists among health and hospital services in Perth, Brisbane and Melbourne. This work will be an expansion of the pilot study conducted previously at the Royal Perth Hospital in collaboration with Dr Yuben Moodley (now posted at the Fiona Stanley Hospital).

Collaborators:

- COPD: Dr Yuben Moodley, Fiona Stanley Hospital (Respiratory Physician)

Project Aims for 2017/18:

- Chronic Obstructive Pulmonary Disease (COPD): To expand from the preliminary study, using a new version of Mobile Technology enabled Rehabilitation (MoTeR), developed by the Australian e-health Research Centre for COPD, to include 50 patients in a follow- on multi-State trial. We will submit a grant proposal for a multi centre study to NHMRC.

Disease diagnosis and screening technologies

Ocular biomarkers for Alzheimer's Disease

The ATRDG has been developing ocular biomarkers for early detection of Alzheimer's disease. The goal of the study is to see if a non-invasive and inexpensive eye test can detect people on the pathway to Alzheimer's disease.

The trial involves two visits by volunteers to the McCusker Alzheimer's Research Foundation, where they will have their eyes tested using retinal image fluorescence photography. Between appointments, volunteers take a curcumin supplement. Curcumin is a natural ingredient used in cooking; it also gives the spice, turmeric, its fluorescent yellow colour. We use curcumin to light up the amyloid-beta plaques in people's retinas. If what we see in the eye tests correlates with what is occurring in their brains, then we will have the makings of a screening tool for Alzheimer's. It may enable us to identify people very early in the development of the disease, which could enhance our ability to intervene and stop or delay Alzheimer's progression.

Clinical data collection has been completed for the following studies:

N=200 Nidek device

N=100 Longitudinal study

N=20 Young controls

Preliminary results have been presented at the Alzheimer Association International Conference and the Alzheimer's disease Parkinson's disease international conference. A manuscript communicating these results is in preparation.

Retinal imaging equipment, protocols and image analysis techniques have all been improved as a result of these studies. The latest technology is being utilised for recruitment into the A4 AD- therapeutic trial (http://a4study. org/), and being tested in our current clinical trial of N=284 participants across Perth and Melbourne AIBL sites (N=100 completed).

We have also recently published a paper in the Journal of Ophthalmology, reporting on changes in the way the pupil responds to light in Alzheimer's disease. These changes were also evident in pre-clinical Alzheimer's participants, suggesting that eye testing could be useful for detecting Alzheimer's many years prior to symptoms, allowing earlier testing of interventions.

Ocular biomarkers for mental health disorders

This is a collaborative research project between Hollywood Private Hospital and ATRDG. The research project will investigate whether the retina can allow specialists to more effectively detect and monitor brain disorders such as post-traumatic stress, anxiety, eating disorders, major depression and alcohol dependence. Research will include identifying eye biomarkers that are specific to different disorders and determine if they can predict the success of different treatments.

These questions will be addressed using retinal photography, optical coherence tomography and pupillometry. We already know that there are multiple structural and physiological disturbances of the eye related to schizophrenia, and we are eager to learn what else the retina can tell us about other disorders and their treatments. We believe the retina may provide a window to detect and monitor brain disorders. As a developmental outgrowth of the brain, the eye provides central nervous system access through live, non-invasive optical imaging with great detail.

Unfortunately for sufferers, current methods of diagnosis are complex and subjective, therapeutic options are limited, and misdiagnosis may often occur. We hope that this study will help to resolve these issues.

UWA Master's Student Katrina-Anna De Ruyck is collecting data in collaboration with Hollywood Hospital clinicians, retinal images for 50 participants have been collected.
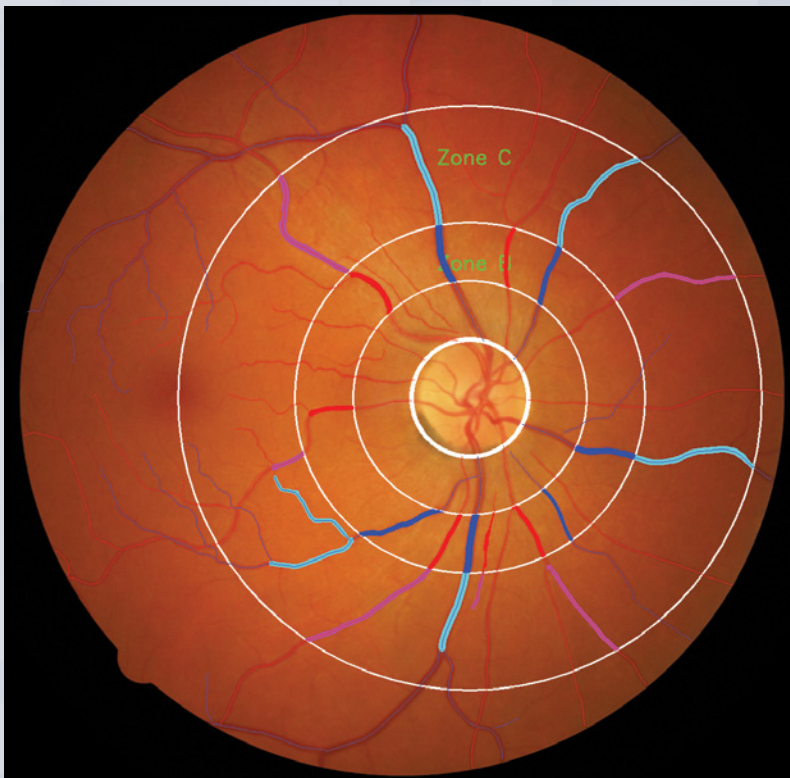

Figure 1. Retinal image analysis software interface – VASP

AUSTRALIAN TELE-HEALTH RESEARCH AND DEVELOPMENT GROUP

Disease diagnosis and screening technologies *(continued)*

Retinal biomakers to predict stroke

Improvements in acute care of stroke patients have decreased mortality, but survivors are still at increased risk of future vascular events and mitigation of this risk requires thorough assessment of the underlying factors leading to the stroke. The brain and eye share a common embryological origin and numerous similarities exist between the small vessels of the retina and brain. Recent population-based studies have demonstrated a close link between retinal vascular changes and stroke, suggesting that retinal photography could have utility in assessing underlying stroke risk factors and prognosis after stroke.

The retinal microvasculature is highly accessible, with modern imaging equipment facilitating precise measurement and monitoring of vascular features. However, use of this equipment is a challenge in the stroke ward setting as patients are frequently unable to maintain the required seated position, and pupil dilatation is often not feasible as it could potentially obscure important neurological signs of stroke progression.
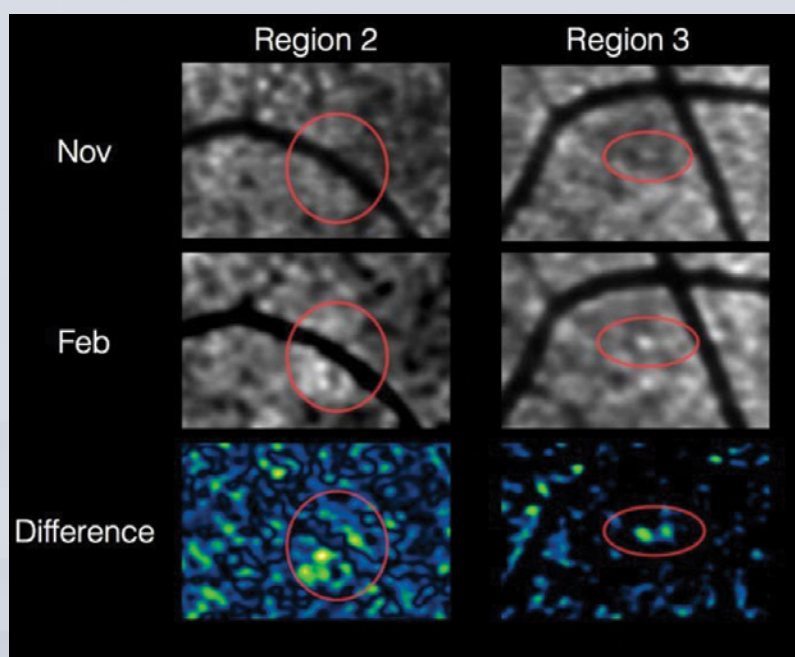
Figure 2. Retinal fluorescence image – identifying AD plaques in retina and how they increase over time

This pilot study investigated the utility of a novel handheld, non-mydriatic retinal camera in the stroke ward, and explored associations between retinal vascular features and stroke risk factors. This camera circumvented the practical limitations of conducting retinal photography in the stroke ward setting.

The study results were published in the Journal of Stroke and Cerebrovascular Diseases in March 2017. A positive correlation was found between carotid disease and both mean width of arterioles ($r = 0.40$, $p = 0.00571$) and venules ($r = 0.30$, $p = 0.0381$). The results provide further evidence that retinal vascular features are clinically informative about underlying stroke risk factors, and demonstrate the utility of handheld retinal photography in the stroke ward.

Collaborators:

- Neurovision Imaging, Sacramento, California

- Hollywood Private Hospital (Ramsay Health Care)

- Royal Perth Hospital

Project Highlights for 2016/17:

- Clinical trial started with external funding, next generation retinal fluorescence imaging in AD

Project Aims for 2017/18:

- Complete new AD trial with new imaging technology and protocols

- Develop RPH studies into hypertension and effects of tropicamide on retinal vasculature

- Start HPH trial on H.Pylori infection and retinal inflammatory markers

- Screen more mental health patients and start analysing the data

- As the stroke clinic at Royal Perth Hospital has been closed and moved to Sir Charles Gairdner Hospital we will be seeking to establish similar study with a new cohort

- Redefine the stroke study to explore people with secondary stroke
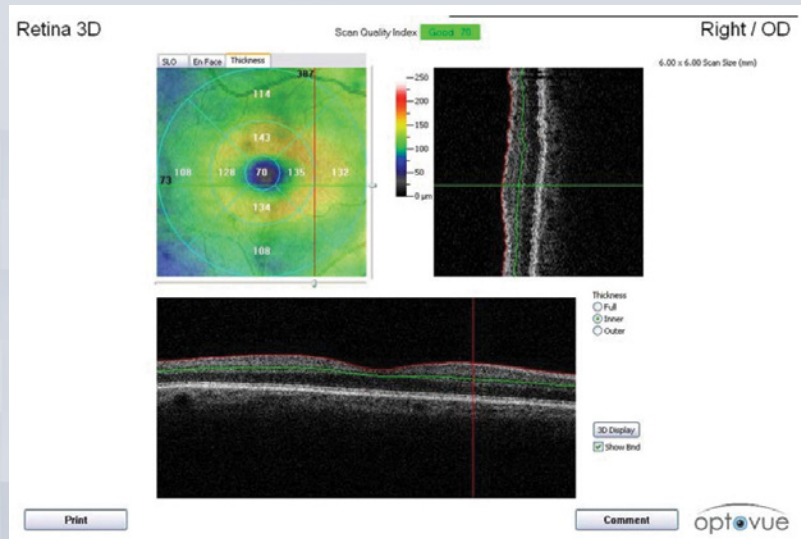
Figure 3. Retinal optical coherence tomography (OCT) identifying inflammation and subsequent atrophy in retinal layer thickness

Postdoc Highlight

Name: Shuang Yu, PhD

As a Postdoctoral Research Fellow at CSIRO, Dr. Shuang Yu joined the Australian e-Health Research Center on September 2015. Her research is focused on the automatic analysis of retinal vascular structures with graph theory and machine learning algorithms. Currently she is working on algorithm development of VASP, a cloud based retinal Vessel Analysis Software.

Her research has greatly increased both accuracy and computing speed of retinal vascular structure analysis and enabled measurement of various retinal vascular parameters of strong clinical interest. Dr. Yu's work has been presented at ARVO 2017 and EMBC 2017 (oral presentation).

AUSTRALIAN TELE-HEALTH RESEARCH AND DEVELOPMENT GROUP

AEHRC Publications 2016-17

Journals – Refereed

1. A. Armin, G. Chetty, H. De Visser, C. Dumas, F. Grimpen, O. Salvado, "Automated Visibility Map of the Internal Colon Surface from Colonoscopy Video", *International Journal of Computer Assisted Radiology and Surgery,* vol. 11, pp. 1599-1610, Sep 2016.

2. C. Bell, S. Puttick, S. Rose, J. Smith, P. Thomas, N. Dowson, "Design and utilisation of protocols to characterise dynamic PET uptake of two tracers using basis pursuit", *Physics in Medicine and Biology,* vol. 62, pp. 4897-4916, May 2017.

3. L. Bell, J. Dowling, E. Pogson, P. Metcalfe, L. Holloway, "Atlas based auto-segmentation technique incorporating inter-observer delineation uncertainty", *Journal of Physics: Conference Series,* vol. 777, pp. 1-4, Feb 2017.

4. R. Buckley, P. Maruff, D. Ames, P. Bourgeat, R. Martins, C. Masters, S. Rainey-Smith, N. Lautenschlager, C. Rowe, G. Savage, V. Villemagne, K. Ellis, "Subjective memory decline predicts greater rates of clinical progression in preclinical Alzheimer's disease", *Alzheimer's & Dementia,* vol. 12, pp. 796–804, Jul 2016.

5. R. Buckley, K. Sparks, M. Dekhtyar, C. Martin, S. Burnham, R. Sperling, D. Rentz, "Computerized iPad cognitive testing using NIH Toolbox and Cogstate C3 for use in clinical trials", *Journal of Prevention of Alzheimer's Disease,* vol. 4, pp. 3-11, Mar 2017.

6. S. Burnham, C. Rowe, D. Baker, A. Bush, L. Cobiac, J. Doecke, K. Ellis, N. Faux, R. Head, H. Kiiveri, S. Laws, R. Martins, P. Maruff, L. Macaulay, G. Savage, D. Ames, C. Masters, W. Wilson, V. Villemagne, "Predicting Alzheimer's disease from a blood-based biomarker profile: results from AIBL at 54 months", *Neurology,* vol. 87, pp. 1093-1101, Sep 2016.

7. S. Burnham, P. Bourgeat, V. Dore, O. Salvado, "The Different Clinical and Cognitive Trajectories of Healthy Older Adults with SNAP or Alzheimer's disease pathology: A Six-year Follow-Up Study", *Lancet Neurology,* vol. 15, pp. 1044-1053, Sep 2016.

8. M. Cespedes, J. Fripp, J. McGree, C. Drovandi, K. Mengersen, J. Doecke, "Comparisons of neurodegeneration over time between healthy ageing and Alzheimer's disease cohorts via Bayesian inference", *BMJ Open,* vol. 7, pp. e012174, Feb 2017.

9. S. Chandra, J. Dowling, P. Greer, J. Martin, C. Wratten, P. Pichler, J. Fripp, S. Crozier, "Fast Automated Segmentation of Multiple Objects via Spatially Weighted Shape Learning", *Physics in Medicine and Biology,* vol. 61, pp. 8070-8084, Oct 2016.

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11. G. Chetelat, R. Ossenkoppele, V. Villemagne, A. Perrotin, B. Landeau, F. Mézenge, W. Jagust, V. Dore, B. Miller, S. Egret, W. Seeley, W. van der Flier, R. La Joie, D. Ames, B. van Berckel, P. Scheltens, F. Barkhof, C. Rowe, C. Masters, V. de la Sayette, F. Bouwman, G. Rabinovici, "Atrophy, hypometabolism and clinical trajectories in patients with amyloid-negative Alzheimer's disease", *Brain,* vol. 139, pp. 2528-2539, Sep 2016.

12. E. Conti, J. Mitra, S. Calderoni, K. Pannek, K. Shen, A. Pagnozzi, S. Rose, S. Mazzotti, D. Scelfo, M. Tosetti, F. Muratori, G. Cioni, A. Guzzetta, "Network over-connectivity differentiates autism spectrum disorder from other developmental disorders in toddlers: a diffusion MRI study", *Human Brain Mapping,* vol. 38, pp. 2333-2344, Jan 2017.

13. D. Bradford, Y. van Kasteren, Q. Zhang, M. Karunanithi, "Watching over me: positive, negative and neutral perceptions of in-home monitoring held by independent-living older residents in an Australian pilot study", *Ageing and Society,* pp. 1-22, Feb 2017.

14. J. Doecke, Y. Wang, K. Baggerly, "Co-localized genomic regulation of miRNA and mRNA via DNA methylation affects survival in multiple tumor types", *Cancer Genetics,* vol. 209, pp. 463-473, Oct 2016.

15. J. Doecke, F. Hartnell, P. Bampton, S. Bell, G. Mahy, Z. Grover, P. Lewindon, L. Jones, K. Sewel, K. Krishnaprasad, R. Prosser, D. Marr, J. Fischer, G. Thomas, J. Tehan, N. Ning, S. Cooke, K. Moss, K. Sochi, P. DeCruz, R. Grafton, S. Connor, I. Lawrance, R. Gearry, J. Andrews, G. Radford-Smith, "Infliximab vs. adalimumab in Crohn's disease: results from 327 patients in an Australian and New Zealand observational cohort study", *Alimentary Pharmacology & Therapeutics,* vol. 45, pp. 542-552, Feb 2017.

16. N. Dowson, C. Baker, P. Thomas, J. Smith, S. Puttick, C. Bell, O. Salvado, S. Rose, "Federated optimisation of kinetic analysis problems", *Medical Image Analysis,* vol. 35, pp. 116-132, Jan 2017.

17. M. Estai, Y. Kanagasingam, D. Xiao, J. Vignarajan, B. Huang, E. Kruger, M. Tennant, "A proof-of-concept evaluation of a cloud-based store-and-forward telemedicine app for screening for oral diseases", *Journal of Telemedicine and Telecare,* pp. 1-7, Sep 2016.

18. F. Fatehi, L. Gray, A. Russell, "Mobile Health (mHealth) for Diabetes Care: Opportunities and Challenges", *Diabetes Technology & Therapeutics,* vol. 19, pp. 1-3, Jan 2017.

19. S. Fiori, A. Guzzetta, J. Mitra, K. Pannek, R. Pasquariello, P. Cipriani, M. Tosetti, G. Cioni, S. Rose, A. Chilosi, "Neuroanatomical Correlates of Childhood Apraxia of Speech A Connectomic Approach", *NeuroImage: Clinical,* vol. 12, pp. 894-901, Nov 2016.

20. S. Frost, M. Brown, V. Stirling, J. Vignarajan, D. Prentice, Y. Kanagasingam, "Utility of ward based retinal photography in stroke patients", *Journal of Stroke and Cerebrovascular Diseases,* pp. In Press, Dec 2016.

21. C. Gaff, I. Winship, S. Forrest, D. Hansen, J. Clark, P. Waring, M. South, A. Sinclair, "Preparing for genomic medicine: a real world demonstration of health system change.", *npj Genomic Medicine,* vol. 2, pp. 1-9, May 2017.

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AEHRC PUBLICATIONS 2016-17

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HSE Support – Shane Casson

Business Development Support – Dr Peter Kambouris

Business Development Support – Janet Fox

THE AUSTRALIAN E-HEALTH RESEARCH CENTRE
(An unincorporated joint venture)

SPECIAL PURPOSE FINANCIAL REPORT

30 JUNE 2017

Detailed financial information from pages 72-79 have been deliberately omitted from this report.

THE AUSTRALIAN E-HEALTH RESEARCH CENTRE

DIRECTORS DECLARATION

The directors have determined that the unincorporated joint venture is not a reporting entity and that this special purpose financial report should be prepared in accordance with the terms of the joint venture agreement and the accounting policies outlined in Note 1 to the financial statements.

The directors declare that the accompanying Statement of Comprehensive Income, Statement of Financial Position, Statement of Cash Flows, Statement of Changes in Joint Venture Funds and Notes to the Financial Statements present fairly the unincorporated joint venture's financial position as at 30 June 2017 and its performance for the year ended on that date in accordance with the terms of the joint venture agreement and the accounting policies described in Note 1 to the financial statements.

This declaration is made in accordance with a resolution of the Board.

Director: Dr Rob Grenfell
Brisbane
Date: 28th August 2017

Director Dr R. Ashby
Brisbane
Date: 28th August, 2017

Director Richard Royle
Brisbane
Date: 28 August 2017

Director Cathy Ford
Brisbane
Date: 5th Sept, 2017

SPECIAL PURPOSE FINANCIAL REPORT

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INDEPENDENT AUDITOR'S REPORT

TO THE DIRECTORS OF THE AUSTRALIAN E-HEALTH RESEARCH CENTRE

Report on the Audit of the Financial Report

Opinion

We have audited the accompanying special purpose financial report of The Australian E-Health Research Centre ("the unincorporated joint venture"), which comprises the statement of financial position as at 30 June 2017, and the statement of comprehensive income, statement of changes in joint venture funds and statement of cash flows for the year then ended, notes comprising a summary of significant accounting policies, other explanatory information and the directors' declaration.

In our opinion, the accompanying financial report presents fairly, in all material respects, the financial position of the unincorporated joint venture as at 30 June 2017 and its financial performance and its cash flows for the year then ended in accordance with the accounting policies described in Note 1 to the financial statements.

Basis for Opinion

We conducted our audit in accordance with Australian Auditing Standards. Our responsibilities under those standards are further described in the *Auditor's Responsibilities for the Audit of the Financial Report* section of our report. We are independent of the unincorporated joint venture in accordance with the ethical requirements of the Accounting Professional and Ethical Standards Board's APES 110: *Code of Ethics for Professional Accountants* (the Code) that are relevant to our audit of the financial report in Australia. We have also fulfilled our other ethical responsibilities in accordance with the Code.

We believe that the audit evidence we have obtained is sufficient and appropriate to provide a basis for our opinion.

Emphasis of Matter – Basis of Accounting

We draw attention to Note 1 to the financial statements which describes the basis of accounting. The financial report has been prepared to assist The Australian E-Health Research Centre to meet the requirements of the Joint Venture Agreement with Commonwealth Scientific and Industrial Research Organisation and the State Government of Queensland. As a result the financial report may not be suitable for another purpose. Our opinion is not modified in respect of this matter.

Responsibilities of the Directors' for the Financial Report

The directors of the unincorporated joint venture are responsible for the preparation and fair presentation of the financial report in accordance with the joint venture agreement and the accounting policies described in Note 1 to the financial report. The directors are also responsible for such internal control as they determine is necessary to enable the preparation and fair presentation of the financial report that is free from material misstatement, whether due to fraud or error.

In preparing the financial report, the directors are responsible for assessing the unincorporated joint venture's ability to continue as a going concern, disclosing, as applicable, matters relating to going concern and using the going concern basis of accounting unless the directors either intends to liquidate the unincorporated joint venture or to cease operations, or has no realistic alternative but to do so.

Auditor's Responsibilities for the Audit of the Financial Report

Our objectives are to obtain reasonable assurance about whether the financial report as a whole is free from material misstatement, whether due to fraud or error, and to issue an auditor's report that includes our opinion. Reasonable assurance is a high level of assurance, but is not a guarantee that an audit conducted in accordance with the Australian Auditing Standards will always detect a material misstatement when it exists. Misstatements can arise from fraud or error and are considered material if, individually or in the aggregate, they could reasonably be expected to influence the economic decisions of users taken on the basis of this financial report.

As part of an audit in accordance with Australian Auditing Standards, we exercise professional judgement and maintain professional scepticism throughout the audit. We also:

- Identify and assess the risks of material misstatement of the financial report, whether due to fraud or error, design and perform audit procedures responsive to those risks, and obtain audit evidence that is sufficient and appropriate to provide a basis for our opinion. The risk of not detecting a material misstatement resulting from fraud is higher than for one resulting from error, as fraud may involve collusion, forgery, intentional omissions, misrepresentations, or the override of internal control.

- Obtain an understanding of internal control relevant to the audit in order to design audit procedures that are appropriate in the circumstances, but not for the purpose of expressing an opinion on the effectiveness of the unincorporated joint venture's internal control.

- Evaluate the appropriateness of accounting policies used and the reasonableness of accounting estimates and related disclosures made by the unincorporated joint venture.

- Conclude on the appropriateness of the unincorporated joint venture's use of the going concern basis of accounting and, based on the audit evidence obtained, whether a material uncertainty exists related to events or conditions that

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may cast significant doubt on the association's ability to continue as a going concern. If we conclude that a material uncertainty exists, we are required to draw attention in our auditor's report to the related disclosures in the financial report or, if such disclosures are inadequate, to modify our opinion. Our conclusions are based on the audit evidence obtained up to the date of our auditor's report. However, future events or conditions may cause the association to cease to continue as a going concern.

- Evaluate the overall presentation, structure and content of the financial report, including the disclosures, and whether the financial report represents the underlying transactions and events in a manner that achieves fair presentation.

We communicate with the directors regarding, among other matters, the planned scope and timing of the audit and significant audit findings, including any significant deficiencies in internal control that we identify during our audit

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Peter Bray
Partner

Chatswood

Dated: 5 September 2017

SPECIAL PURPOSE FINANCIAL REPORT

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THE AUSTRALIAN

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