THE AUSTRALIAN
E-HEALTH
RESEARCH CENTRE

LEADING THE WAY IN HEALTH IT RESEARCH

ANNUAL REPORT

2017 / 2018

CSIRO

Queensland Government

RESEARCH · DISCOVERY · INNOVATION

POWERS HEALTH IN THE DIGITAL AGE


Smarter Safer Homes Platform to Enable Community and Aged Care Data Analytics
2018 iAWARDS South Australia
SA Premier's iAward
Continuous Monitoring Background Screening in SA
Department of Human Services
Celebrating 25 years of innovation
THE AUSTRALIAN E-HEALTH RESEARCH CENTRE
@theiAwa
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Celebrating 25 years of innovation
2018 iAWARDS

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THE AUSTRALIAN E-HEALTH RESEARCH CENTRE

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

Established in 2003 with initial funding from the Department of State Development and CSIRO, the partnership was extended in 2007 for a further five 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 five 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 telemedicine 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 multidisciplinary team conducts research across health informatics, biomedical informatics and health services, and includes internationally prominent researchers, software engineers and doctoral students, dedicated to serving the needs of patients, clinicians and health service providers.

FOREWORD BY THE CEO AND CHAIRMAN

The past 12 months has been another successful year of growth and impact for the Australian e-Health Research Centre. As the first year of the new 2017-2022 Joint Venture Agreement between CSIRO and Queensland Health, it was pleasing to see more adoption of AEHRC technologies by Queensland Health and the launch of a number of new projects and initiatives. This delivery demonstrates the value of the relationship – with Queensland Health benefiting from the science and innovation that CSIRO can bring and CSIRO benefiting from the deep collaborations with Queensland Health clinician and health services executives.

The AEHRC has continued to grow our engagement and delivery around Australia, with our teams in Brisbane, Sydney, Melbourne and Perth all growing over the past 12 months. In addition to our strong relationship with Queensland Health through our JV agreement, the AEHRC continues to work with Western Australia Health through our joint Australian Tele-health Research and Development Group in Perth. In Victoria the AEHRC leads CSIRO's involvement in the Melbourne Genomics Health Alliance project, partners with the Florey Institute on a number of large Alzheimer's disease trials and has a number of large projects with the Department of Health. Our Sydney-based teams work with a number of partners in New South Wales, with projects currently being developed with e-Health NSW.

There has been a significant increase in the number of trials of AEHRC technologies with Queensland Health. This includes the launch of a trial of a tool for identifying the risk of readmission of patients on discharge. The information it provides can be used by the health service to plan support services for patients to reduce this risk. There have also been three new mobile health pilot trials over the past 12 months. The PD-BUDDy trial supports patients with home based peritoneal dialysis, the MoTHER trial supports women with gestational diabetes, and the Pain ROADMAP trial aims to support people with strategies for chronic pain. There are many other trials going on with Queensland Health clinicians and researchers, including in diseases such as Alzheimer's disease and cerebral palsy. The next 12 months will see the AEHRC undertake a number of new projects with Queensland Health.

Recently the AEHRC received funding through the Cooperative Research Centre (CRC) for Developing Northern Australia to develop and trial referral pathways for remote ophthalmology, and a new CRC-P project was recently awarded with Brisbane-based startup company Maxwell MRI.

The AEHRC is well positioned to engage in a number of new precision medicine initiatives funded through the Medical Research Future Fund and other mechanisms. It has also been a key member of the Queensland Genomics Health Alliance, partnering with QIMR Berghofer, University of Queensland (UQ) and Queensland University of Technology (QUT) to lead the Genomic Information Management Workstream. This complements our contributions to the Melbourne Genomics Health Alliance and the Australian Genomics Health Alliance, and to the Global Alliance for Genomics and Health – across all these genomics projects, we are contributing clinical informatics and bioinformatics capability and technology. Our bioinformatics work, with Denis Bauer's team developing new genomic sequence analysis algorithms for the new cloud computing architectures, is receiving international attention.

We continue to deliver the National Clinical Terminology Service with the Australian Digital Health Agency. The NCTS is a key part of Australia's national digital health infrastructure with more than 50 organisations licensing the AEHRC terminology server, Ontoserver, to support the use of standardised terminology in digital health applications. This approach has attracted international attention.

FOREWORD BY THE CEO AND CHAIRMAN *(continued)*

The Biomedical Informatics group continues to lead medical image analysis for national trials in areas such as Alzheimer's disease and cerebral palsy and clinical applications such as prostate cancer.

Nationally the AEHRC is delivering significant projects for the Australian Government Department of Health. Our health data analytics scientists have developed the risk algorithm for the Healthcare Homes program – now being trialled in 200 clinics around Australia. We were recently awarded funding by the Australian Government Department of Health for a Primary Care Data Quality Foundations project, to work with industry and peak clinical bodies on standards for primary care data. These projects are in addition to the Department of Aged Care funded program for our Smarter Safer Homes Technology. We have also partnered in the NHMRC-funded Australian Dementia Network (ADNet).

The AEHRC was part of the external review of CSIRO Health and Biosecurity conducted by an external panel in November 2017. The external review resulted in a strong result for the AEHRC, with the review panel assessing the AEHRC as being Benchmark in the areas of Impact and Innovation Capacity and Strong to Benchmark in Science. This was a great endorsement of the quality of the science and the impact that the AEHRC is having on healthcare in Australia.

The AEHRC is now an established part of Australia's digital health ecosystem – contributing to the digital health and clinical research ecosystem. Going into the new financial year the AEHRC is well placed to continue to implement its 2017-2022 strategy and continue the growth of the past five years.

Richard Royle
Chairman, the Australian e-Health Research Centre

David Hansen
Chief Executive Officer

RESEARCH AND INVESTMENT ADVISORY COMMITTEE

Reporting to the Board of the Australian e-Health Research Centre, the Research and Investment Advisory Committee (RIAC) 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 2017-2018:

Chair

- **Dr Michael Steyn**, Director Department of Anaesthesia & Perioperative Medicine, Royal Brisbane & Women's Hospital (2017)
- **Prof Keith McNeil**, Chief Clinical Information Officer, Queensland Health

Members

- **Dr Andrew Staib**, Metro South Health and Hospital Service (HHS) and e-Health Queensland
- **Ms Cathy Ford**, Chief Digital Officer, e-Health Queensland, Queensland Health
- **Mr Michael Drahiem**, Chief Information Officer, 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

A number of AEHRC staff members attended RIAC meetings during 2017-2018 as guest presenters.

8 February 2017

At this meeting the RIAC discussed the research from the Health Informatics group, discussing the opportunities for further work with new initiatives within Queensland Health.

- Health data interoperability – **Michael Lawley**
- Health text processing – **Anthony Nguyen**
- Health data analytics – **Sankalp Khanna**

19 July 2017

At this meeting the RIAC discussed the 2017/18 AEHRC Annual Business Plan, with considerable discussion on the adoption of and impact from AEHRC research.

- Discussion on the AEHRC 2017-2018 project Portfolio – **David Hansen**
- Health services research – **Mohan Karunanithi**
- Health informatics research – **Michael Lawley**
- Biomedical informatics research – **Jurgen Fripp**

BOARD OF DIRECTORS

Richard Royle

Chair, the Australian e-Health Research Centre

Richard is a partner at PwC and is the national and regional digital health lead. He has over 30 years of senior executive experience in the public, for profit and not for profit private hospital sectors in Australia. Richard is a past President of the Australian Private Hospitals Association.

Richard oversaw the successful implementation of Australia's first fully integrated digital hospital in Hervey Bay as the group CEO of UnitingCare Health in 2014. In 2016 he was asked to be the startup CEO of the newly established Australian Digital Health Agency – putting into practice one of his recommendations from a landmark review he was asked to lead in 2013 for the Federal Government on 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:

- Chairman, Queensland Policy and Advisory Committee on Health Technology
- Chairman, eHealth Executive Committee
- Senior Responsible Owner, Queensland Digital Hospitals Program
- Board Member, Australian e-Health Research Centre
- Council Member, Queensland University of Technology Council.

Cathy Ford

Cathy Ford has been acting in the position of Chief Information Officer of the Metro North Hospital and Health Service since December 2017. Cathy's emphasis during this time has been on preparing the foundations for the digital transformation of the health service through targeted planning and investment activities.

Cathy's substantive role is the Chief Digital Officer of eHealth Queensland. In this role Cathy was responsible for the development of both the digital health and innovation strategies as well as the investment roadmap and associated oversight activities.

As a management & ICT professional Cathy's focus is to work with organisations to transform their business by developing strategies to make better use of people, information, systems & technology.

With over 25 years in the industry she has worked with many executives and their teams on transformation activities that delivered sustained change.

Cathy graduated from the University of Queensland with first class honours, holds a graduate diploma in IT and is a graduate of the Australian Institute of Company Directors.

Rob Grenfell

Dr Rob Grenfell, a public health physician, is the Director of CSIRO's Health and Biosecurity business unit. He leads a broad portfolio covering nutrition, e-health, medtech and diagnostics, and biosecurity from weeds to Ebola.

Rob has broad-ranging public health experience including:

- National Medical Director at BUPA Australia New Zealand
- National Director Cardiovascular Health at the Heart Foundation
- Strategic Health Advisor to Parks Victoria
- Senior Medical Advisor at the Department of Health Victoria
- Physician in charge of travel health BHP
- General Practice.

He was a member of the Safety and Quality Outcomes Committee of the Hospital Innovation Reform Council, a member of the Victorian Quality Council, Chair of General Practice Victoria, and member of the Health Advisory Committee of the National Health and Medical Research Council.

Adrian Turner

Adrian Turner is the CEO of Data61 at CSIRO and also co-Chair of the Cybersecurity Growth Centre. Data61 is the datascience arm of the CSIRO and is focused on solving Australia's largest data-driven challenges. Adrian was previously Managing Director and Co-Founder of Borondi Group, a holding company focused on the intersection of pervasive computing, platform economics and traditionally conservative industries and was also co-founder and CEO of smart phone and Internet of Things security company Mocana Corporation. Prior to this Adrian 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 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, having spent 18 years in Silicon Valley.

Richard Symonds
Minutes Secretary

Kelly Tighe
Finance Manager, CSIRO

Meetings

Board Meetings for 2017/20187 were held as follows:

28th August 2017

20th November 2017

5th March 2018

25th June 2018


EHEALTH
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2018 ANNUAL COLLOQUIUM

Over 300 people attended this year's 14th Annual e-Health Research Colloquium, hosted by the Australian e-Health Research Centre at the RBWH Education Centre in Brisbane on 27 March 2018. The Colloquium was once again a great opportunity for us to hear about Queensland and national initiatives as well as inform partners about our work.

The first session this year provided an opportunity to highlight various digital health initiatives in Queensland. Dr Claire Sullivan, Clinical Lead for the Digital Health Program Queensland Health, described how Queensland Health is using digital disruption to transform the state's healthcare – and some of the great outcomes from the iEMR program. We then had the opportunity hear from Dr Wendy Dutton, Director of Obstetrics at Redland Hospital, about the M♥THer trial and how we're working in conjunction with Redland Hospital. The M♥THer trial provides a mobile app to support women with gestational diabetes app, and this app provides information to their clinicians via an Interactive Clinician Portal. The final talk of the morning came from the AEHRC's Dr Sankalp Khanna who provided an update on the Logan Hospital trial of a big data analytics-based tool to identify patients at high risk of re-hospitalisation.

The pre-lunch session highlighted national initiatives. Our key note speaker this year was Professor Enrico Coiera, Chief Investigator NHMRC Centre of Research Excellence in Digital Health (CREiDH) and Professor of Health Informatics at Macquarie University. Prof Coiera provided a great overview of the work program of the CREiDH, of which AEHRC is a core member.

We then had talks from Robert Lee from the Australian Digital Health Agency about Australia's MyHealthRecord program; A/Professor Andrew Mallett from the RBWH Nephrology Department about using genomics in the Kidney Clinic; and Tim Blake on a new consumer-focussed digital health guide for mobile apps. The AEHRC's Jim Steel rounded out the session by discussing a new Health Informatics on FHIR course being introduced for third-year IT students at the University of Queensland in collaboration with AEHRC and Qld Health.

The afternoon session provided an opportunity for AEHRC to highlight some of our new research. David Ireland spoke about chatbots for people with autism and other neurological conditions; Natalie Twine presented on how machine learning enhances genetic variant discovery for Motor Neurone Disease; James Doecke spoke on a new blood test for early Alzheimer's disease diagnosis; Jason Dowling presented on a phase II prospective trial of MR-alone treatment planning for localised prostate cancer; and finally Alejandro Metke and Andrew Patterson provided use cases for clinical terminology and data when introducing genomics into clinical care.

Attendees had the opportunity to view posters, discuss our projects and technology with our scientists during the morning tea and lunch breaks, and observe multiple technology demonstrations.

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

MANAGEMENT AND RESEARCH LEADERSHIP

Dr David Hansen

CEO, Australian e-Health Research Centre

David Hansen is CEO of the Australian e-Health Research Centre, the national digital health program of the CSIRO Health and Biosecurity. 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.

Michael Lawley

Group Leader, Health Informatics

Dr Michael Lawley is Senior Principal Research Scientist and Group Leader with the CSIRO Australian e-Health Research Centre, part of CSIRO's Health and Biosecurity business unit. Michael leads the Health Informatics Group with teams in health data semantics, health statistics, and software engineering.

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

Jurgen Fripp

Group Leader, Biomedical Informatics (May-June)

Jurgen Fripp is the group leader for the Biomedical Informatics group at the AEHRC and completed his honours thesis and PhD in the area of medical imaging at the University of Queensland and with the CSIRO. His bachelor degree from the University of Queensland was in Science (applied mathematics) and Electrical Engineering. Jurgen's team conducts research into image analysis algorithms for applications in Positron Emission Tomography (PET), Magnetic Resonance Imaging (MRI), and Computed Tomography (CT). Their workflows developed have been applied to support various large clinical studies, including AIBL (http://aibl.csiro.au/).

Mohan Karunanithi

Group Leader, Health Services

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

Professor Yogesan Kanagasingam

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 an Australian of the Year finalist from Western Australia (2015) and also Western Australia 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.

Olivier Salvado

Group Leader, Biomedical Informatics (July-April)

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 bioinformatics 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 (two current co-supervisions).

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

NEWS AND AWARDS

News and Communications

Our research was again both nationally and internationally well represented throughout the year:

- We took part in a joint media announcement with the Florey Institute of Neuroscience and Mental Health to promote our research about the link between iron in the brain and the speed of Alzheimer's disease progression. It received national media coverage, with stories on the front page of The Herald Sun, on the ABC and Sky News, and mentions on TV news and The Project, reaching more than two million people.
- The team's work creating an eye test GPs could use to detect diabetic retinopathy, and a subsequent grant from Diabetes Research WA, received wide coverage. Yogi Kanagasingam was interviewed for stories in The West Australian, The Echo, The Post, ZDNet, Gizmodo, Pulse+IT, IT Wire, Australian Doctor, Insight News and more, reaching an audience of approximately one million.
- David Silvera's work with robots to support children on the autism spectrum was featured across national ABC TV and radio news, reaching 1.5 million people.
- Denis Bauer appeared in the "This is my architecture series" on AWS. Her team had numerous blogs published on various tech websites, along with a story in CIO online.
- Dana Bradford and David Ireland were interviewed by ABC Radio National about chatbots in the health sector.
- David Hansen was interviewed by ABC Radio about the M♥THer app for gestational diabetes.
- James Doecke was featured in articles by the ABC and The New Daily for his involvement in a project to develop a blood test that can detect Alzheimer's disease up to 20 years before symptoms begin.
- The Australian Financial Review published an article on Cardihab's commercialisation, and it also received coverage in tech media.

Awards

Our teams were successful again this year winning and placing in a number of awards nationally, including the Queensland and Victorian iAwards and the Western Australia Information Technology and Telecommunications Alliance Incite Awards (WAITTA).

- Queensland iAwards
  - merit recipient of the Research and Development Project of the Year award for the Mobile-Pulmonary Rehabilitation Platform (m-PR).
  - winners of the QLD Premier's iAward for Public Sector Innovation for the Mobile-Pulmonary Rehabilitation Platform (m-PR).
  - merit recipient of the Community Service Markets award for the PD-BUDDy: Support for Peritoneal Dialysis Patients.
  - merit recipient of the Research & Development Project of the year for the PD-BUDDy: Support for Peritoneal Dialysis Patients.
- Victorian iAwards: CALD-Assist won the Health Round Table Innovation Award.
- WAiTTA (WA Information Technology and Telecommunications Alliance Incite Awards) 2017-2018: the team was awarded the winner of "Most Innovative Enabler in Health Care" on its project titled "AEye Screening System for Patients with Diabetes" and the National iAwards Finalist of "Research & Innovation Project of the Year - Industry Award" on its project titled "Cloud-based Retinal Vascular AnalySis Platform: VASP".
- The M♥THer Gestational Diabetes Mellitus platform won the Health Round Table Innovation Award in the 'Improving Patient Centred Care' stream. It was also a finalist in the International Hospital Federation Awards.
- CONSULT Neurosurgical Planning project was a finalist in the RBWH Research Excellence Awards.
- Ying Xia won the best poster award of the World Federation of Nuclear Medicine and Biology conference, for the Neuroscience competition.
- Sajib Saha received a Rising Star Award at the Science on the Swan Conference 2018, for development of artificially intelligent methods for the diagnosis of retinal disease.
- Shaun Frost was included in the list of Top Ten Posters for the Science on the Swan Conference 2018 for his submission on 'Retinal morphology for pre-clinical detection of Alzheimer's Disease'

RESEARCH PROGRAM

Over the past five years the Australian e-Health Research Centre has developed into a full health and biomedical informatics research program. This program spans 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 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.

Our 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 at the Royal Brisbane and Women's campus in Brisbane, our scientists and engineers have strong relationships with Queensland health administrators, clinicians and researchers. As CSIRO's e-Health research program, we can also access expertise from across CSIRO.

Health informatics

The introduction of electronic health and medical records, including the national 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, and 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 visualise complex biomedical information for clinical diagnosis and screening. This information can ensure that diagnosis is precise and 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 trialling technologies to deliver health services through mobile health, and tele-health technologies for patients with conditions such as eye diseases, cardiac diseases, diabetes, stroke, and hip replacements.

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

2017/18 Science and impact highlights

- Risk stratification tool was developed to identify patients with chronic diseases who are at risk of hospitalisation. This tool is now implemented in the National Health Care Homes initiative to enrol patients from GP practices.
- The SnoMAP tool, developed with Metro South Hospital and Health Service (HHS), is being used by all Queensland hospitals deploying the Cerner iEMR to meet statutory reporting requirements with a resulting measurable increase in data quality.
- The National Clinical Terminology Service, a joint project with the Australian e-Health Research Centre (AEHRC) and the Australian Digital Health Agency, now has over 50 companies and organisations with licenses to our terminology server, Ontoserver, for implementation of state-of-the-art support for clinical terminology in their e-health products. The NCTS won two 2017 Queenslanld iAwards and a National Pitchfest award.
- 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 Queensland.
- Our Data Interoperability 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.
- We are part of the National Health and Medical Research Council (NHMRC) Centre for Research Excellence in Digital Health in partnership with Macquarie University Australian Institute for Health Innovation and the University of Melbourne. AEHRC will be working with scientists and clinicians from around Australia on clinical decision support and automating the production of systematic reviews.

Health Informatics Group Leader: Michael Lawley

Australia's healthcare system faces many challenges. One is the increasing demand for clinical information to be shared between individual health practitioners, healthcare 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 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 Interoperability Team Leader: Alejandro Metke

Data is captured about patients in a number of different formats and electronic repositories 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.

Our team also works in the genomics area, specifically around representing patient phenotype data using standards and terminologies. Our involvement in several genomics alliances in Australia and internationally has helped us position ourselves as leaders in this field.

Health Text Analytics Team Leader: Anthony Nguyen

The Health Text Analytics 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, modelling and reporting.

Health Data Analytics Team Leader: Rajiv Jayasena

The Health Data Analytics team delivers scientifically robust analytics to improve health outcomes. Our team improves performance and sustainability of the Australian health system by transforming clinical/operational data and knowledge with analytics, optimisation, real-time monitoring for decision support, risk stratification tools and evaluations.

Health Data Engineering Team Leader: Derek Ireland

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

PROJECTS

HEALTH DATA INTEROPERABILITY

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 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.

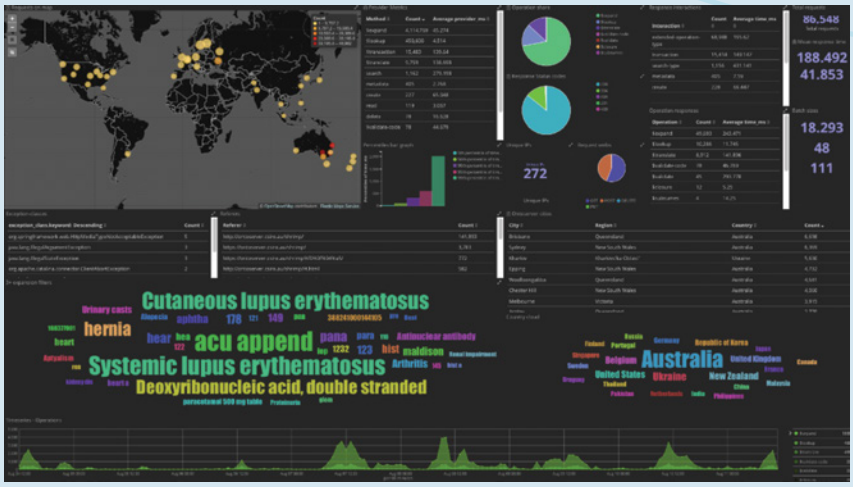


Figure 1. A typical seven days of Shrimp usage.

A National Clinical Terminology Service

We have worked with the Australian Digital Health Agency to deliver the National Clinical Terminology Service (NCTS). The AEHRC's Ontoserver is a key component of the solution and is used to deliver this service through 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, and 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 2017/18 the team finalised 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 connnectathons and workshops to ensure the resulting service delivers what is needed.

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.

There has also been considerable interest in the service from NHS Digital in the UK. We have organised a FHIR connectathon in London and licensed Ontoserver for evaluation as part of a Proof of Concept project.

HEALTH DATA INTEROPERABILITY *(continued)*

SNOMED CT in the Queensland digital hospital project

The Queensland digital hospital project introduced SNOMED CT terminology as part of the implementation of an integrated Electronic Medical Record. As part of this project we 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 the broader project dealt with the problem of continued reporting of emergency department non-admitted patients after the switch from use of ICD-10-AM to SNOMED CT. The result of this was a tool: snoMAP, which 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. The digital hospital program has now been rolled out across six Queensland hospitals and this number is growing. These additional hospitals have begun to use snoMAP, and with snoMAP content, both SNOMED concepts and ICD-10-AM codes updated twice per month, PAH and other Queensland digital hospitals can submit data for activity-based funding in near real time.

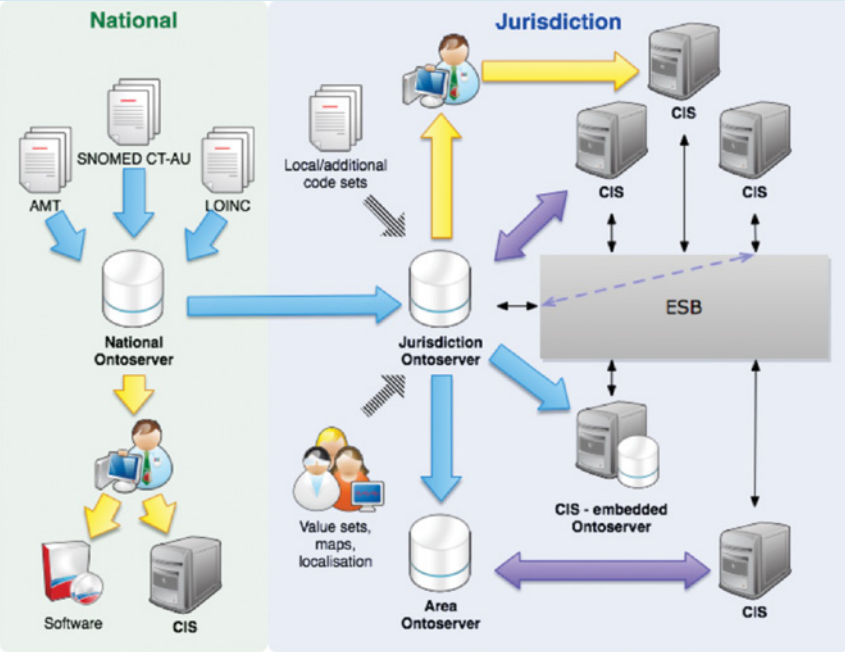


Figure 2. High-level architecture of the National Clinical Terminology Service.

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 of 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 'dashboard' reports using ICD-10-AM-encoded data.

Allied health

Terminology work has continued supporting the development of statewide data collections for the allied health sector. Various allied health disciplines have unified 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 250+ new concept requests have been generated by the allied health discipline groups and have been submitted to the Australian Digital Health Agency for addition and release. Of these, 184 have been added and released in SNOMED CT AU and 77 are currently in process. Work is now underway on the expansion of this initial mapset of 2000 concepts which will 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 professions, rather than only service event-based metrics.

RACS MALT goes SNOMED CT-native

During 2017 we continued our collaboration with the Royal Australasian College of Surgeons (RACS) after the successful transition in 2016 of their Morbidity Audit Logbook Tool (MALT) from ad-hoc terminology to using SNOMED CT-AU procedure codes natively. This included the development and maintenance of aggregation maps to support ongoing reporting processes from the MALT data. During 2016/17 RACS 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). Work also continues in the development of new procedure content for release in SNOMED CT AU. This enhances its usability and relevance in the Australian surgical domain. To date, well over 300 new concepts have been created and released in SNOMED CT AU. RACS is also considering broadening the use of SNOMED CT, so MALT will allow their users to also capture data relevant to diagnoses and outcomes.

Genomics & Clinical Phenotypes

During 2017/2018 the AEHRC has formed a valuable working relationship with a number of genomic health alliances. The Australian Genomics Health Alliance is a national research collaboration of researchers and clinicians working together to provide effective and sustainable delivery of genomic medicine in healthcare. The AEHRC is part of the Phenotype Capture project, whose objectives are to enable different sources of phenotype data to be used for research and clinical applications, and to represent different data in the same format, by transformation to computer-readable standardised ontologies such as SNOMED CT and the Human Phenotype Ontology.

Standardising research data

One of the main issues in the Australian Genomics Health Alliance is that flagships (the organisations doing clinical research) capture phenotypic data in slightly different ways, despite using the same platform (REDCap). This makes it very hard to reuse the data or interoperate with other systems. This problem was solved by designing and implementing the FHIRCap platform, a novel solution based on a domain specific transformation rules language that allows expressing how the REDCap data should be represented in standardised format, in this case the FHIR standard.

Broadening support for genomics terminologies

Many terminologies used in genomics are distributed in OWL format. FHIR has no native support for OWL ontologies and some of the characteristics of OWL are challenging to represent in FHIR code systems. A generic transformation between OWL and FHIR code systems was designed and implemented. This allowed supporting terminologies such as the Human Phenotype Ontology, the Phenotypic Quality Ontology, the Foundational Model of Anatomy and Orphanet in Ontoserver.

Aligning terminologies

In an effort to commence the standardisation of genomic data collections, a great deal of work has been done looking at the alignment and the creation of a map between the Human Phenotype Ontology and SNOMED CT. To date we have found 18% exact match alignment and work in this space continues.

Defining minimum clinical data sets

Development has commenced of flagship-specific FHIR value sets based on the data currently being collected. It is hoped that these value sets will form the basis for ongoing development of SNOMED CT genomics reference sets for use and release in the international edition. The value sets have been deployed in an Australian Genomics Health Alliance Ontoserver instance and can be browsed using a value set viewer extension of Shrimp, our terminology server browser.

HEALTH DATA INTEROPERABILITY *(continued)*

NHS Digital: evaluating future options for classifications

NHS Digital is investigating options and opportunities for the migration or implementation of future terminologies and classifications strategies in light of World Health Organization developments of ICD-11 and ICHI. We were tasked with providing an overview of the current state, and suggestions for optional approaches for continuing business-as-usual during this discovery and evaluation phase. A report was provided outlining the scope and scale of issues that will need consideration as part of a discovery work program and provide necessary evidence for the business case development for the implementation of a new classification such as ICD 11.

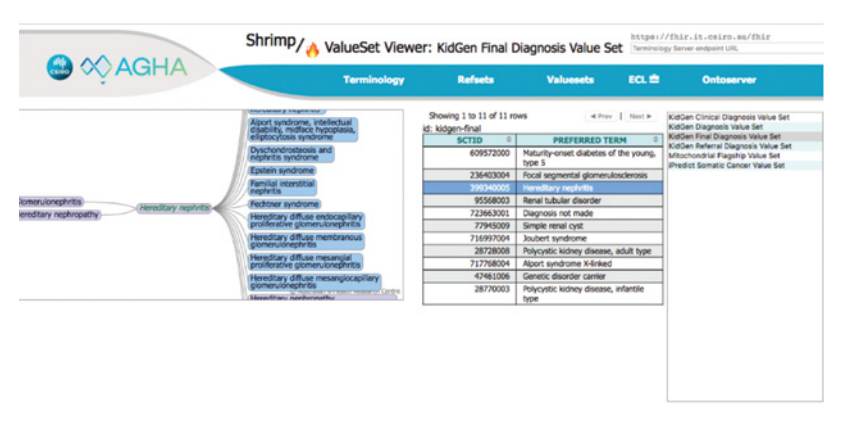


Figure 3. The value set viewer implemented for the Australian Genomics Health Alliance.

HEALTH INFORMATICS

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.

Project Highlights for 2017/18:

- 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 R4
- Organised FHIR connectathons in the UK and negotiated an evaluation license of Ontoserver with NHS Digital
- Impact and expansion of the snoMAP tool as it has been taken up at additional sites throughout Queensland
- Development of FHIRCap for the Australian Genomics Health Alliance and completion of the full mapping of the Somatic Cancer Flagship data
- Support for OWL-based ontologies in Ontoserver to support genomics projects.

Project Aims for 2018/19:

- Expand and improve terminology-enabled data analytics
- 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 clinician community to capture accurate, codeable data for documentation of patient records
- 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 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, such as clinical progress reports, imaging and laboratory reports, discharge summaries, and death certificates. 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 Health 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 health 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.

Automating clinical data registries

Statistics about cancer incidence continue to remain several years out of date. The extent of manual processing of patient records by cancer registry coders and outdated information collection systems are delaying the delivery of more timely cancer information.

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 histopathology reports for cancer notifications, synoptic reporting and cancer staging. This is enabling QCCAT to build a real-time cancer registry that processes new histopathology reports as they are available from public and private pathology laboratories across the state of Queensland. This processed information provides the capacity to support key 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 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 information technology-based solution.

HEALTH TEXT ANALYTICS *(continued)*

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.

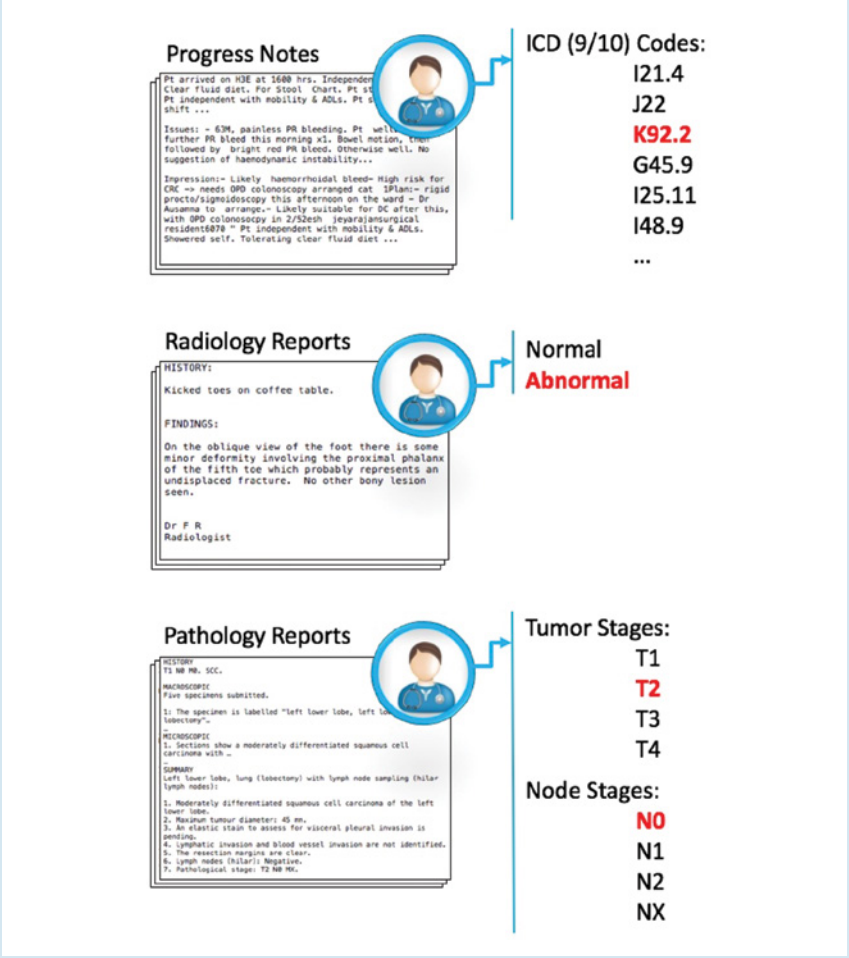


Figure 2: Medical free-text analytics applications for three different clinical document classification tasks:
(i) identification of the ICD-10-AM diagnosis codes from progress notes;
(ii) identification of abnormalities from radiology reports; and
(iii) classification of cancer stages from pathology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

Health record search and 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.

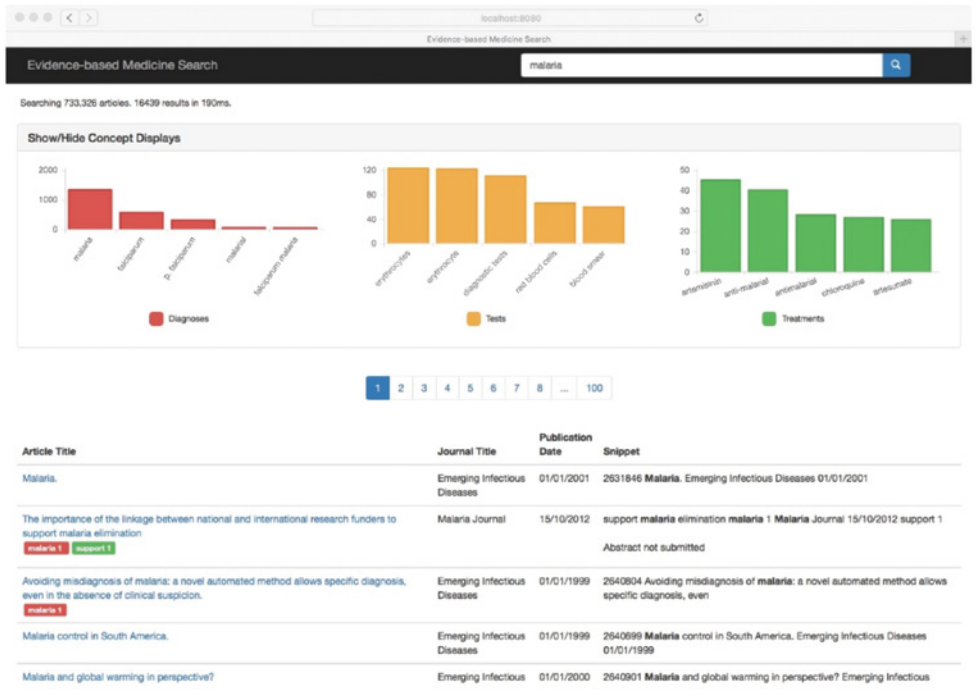


Figure 3: Screenshot of our task-oriented search engine for evidence-based medicine.

NHMRC Centre of Research Excellence in Digital Health

We are part of the NHMRC Centre of Research Excellence in Digital Health, in partnership with Macquarie University Australian Institute for Health Innovation and the University of Melbourne, and will be working with scientists from around Australia on clinical decision support and automating the production of systematic reviews.

Clinicians are often required to make decisions in the absence of best-practice evidence. As a result, treatment success of individuals with complex co-morbidities or treatment history may depend on the clinician's experience. The project proposes to use the "Green Button" concept, which leverages aggregate Electronic Health Record (EHR) data, for real-time, personalised comparative effectiveness information to empower clinicians in making evidence-based decisions in the absence of published guidelines. Using this button, clinicians are able to view and evaluate treatment approaches and outcome of "patients like theirs" in the context of their hospital or other contributing institutions. In particular, we will enhance the structured data in EHRs with text analytics of clinical text to better support clinical decision making at point-of-care, not only to reduce clinical care pathway variations but also to provide health outcomes evidence for those that do.

Systematic reviews play a key role in evidence-based medicine, informing practice and policy. Existing technology to assist with systematic review production has largely ignored the search stages of the systemic review. Existing search engine research is also often not applicable to the unique task of systematic reviews. This project will develop novel search engine technology to significantly improve the process of producing systematic reviews. This will directly impact how systematic reviews are produced and, consequently, the downstream impact of health decisions made on the basis of these reviews.

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, Logan Hospital
- Gold Coast Hospital and Health Service.

Project Highlights for 2017/18:

- Deployed Medtex within Queensland Health to process and analyse live pathology feeds from public and private pathology laboratories across Queensland to support the Queensland Cancer Registry coding process.
- Comparative analysis of conventional machine learning and deep neural network (DNN) transferability across hospitals for clinical text classification. Experiments have shown the robustness of DNN models in trivial transfer learning strategies that use source-only hospital data. Transfer learning strategies using both source & target hospital data further improve models.
- 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 2018/19:

- Automatically extract 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

Harry Scells
AEHRC PhD Top-Up

Scholarship Queensland University of Technology

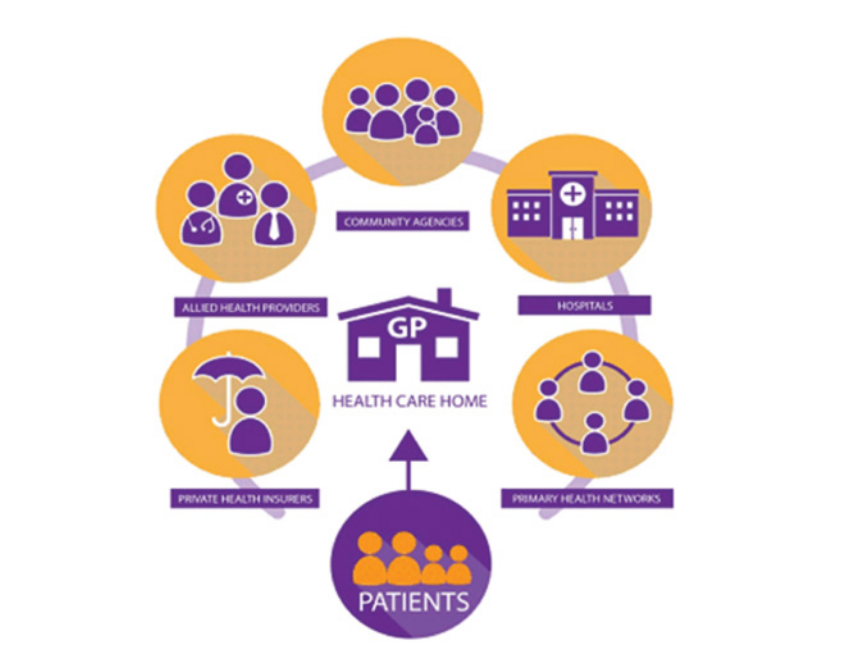
Improving systematic review creation with information retrieval

Systematic reviews, in particular medical systematic reviews, are time consuming and costly to produce. The largest contributing factors to the time and monetary costs are the searching (including the formulation of queries) and screening processes. These initial processes involve researchers reading the abstracts of thousands and sometimes hundreds of thousands of research articles to determine if the retrieved articles should be included or excluded from the systematic review. This research explores automatic methodologies to reduce the workload relating to the searching and screening processes.

HEALTH DATA ANALYTICS

The Health Data Analytics team develops and delivers scientifically robust analytics to improve safety, quality and efficiency of our healthcare system. These analytics improve performance and sustainability of the Australian health system by transforming clinical/operational data into knowledge via analytics, optimisation, real-time monitoring for decision support, risk stratification tools and evaluations.

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 includes several statisticians, engineers and research scientists to ensure rigour in every analysis.



Patient risk stratification predictive model for Health Care Homes

In 2017/18, the team successfully delivered the Predictive Risk Model (PRM) pivotal to the federal government's Health Care Homes initiative aimed at improving quality and safety of the primary health care system. Partnering with Precedence Health Care and Sonic Health Services for this project, we were responsible for the development and validation of the predictive model to be used in the program at a GP practice-level to identify potentially eligible patients, by stratifying patients according to their risk of unplanned hospital admission in the next 12 months. Patients identified by our algorithm were then contacted by the general practice and invited to undertake an assessment to further assess their eligibility and Health Care Home tier level.

The benefits of such a risk stratification tool include:

- reduced level of dependency and improved health outcomes for patients due to early clinical intervention
- cost savings as a result of reduced readmission rates
- 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
- facilitation of person based health care planning through the provision of risk scores to treating practitioners.

To date the tool has been installed in over 170 GP practices and Aboriginal Community Controlled Health Services (ACCHS) around Australia participating in the Health Care Homes program to provide services to patients with chronic and complex conditions.

Risk stratification for hospital avoidance in acute care

In 2017/18, partnering with the Queensland Health's Healthcare Improvement Unit and Logan Hospital, the team successfully delivered a real-time web-based risk stratification algorithm that can be used to identify chronic disease patients with a high risk of rehospitalisation while they are still in hospital. Model development and validation involved employing routinely collected administrative and clinical datasets that were available in real time, and a web-based clinical decision support tool was built to provide risk groups and individual patient risk profiles to care teams. A 12-month evaluation to assess the impact of the risk tool on chronic disease readmissions and care planning processes is underway at Logan Hospital.

HEALTH DATA ANALYTICS *(continued)*

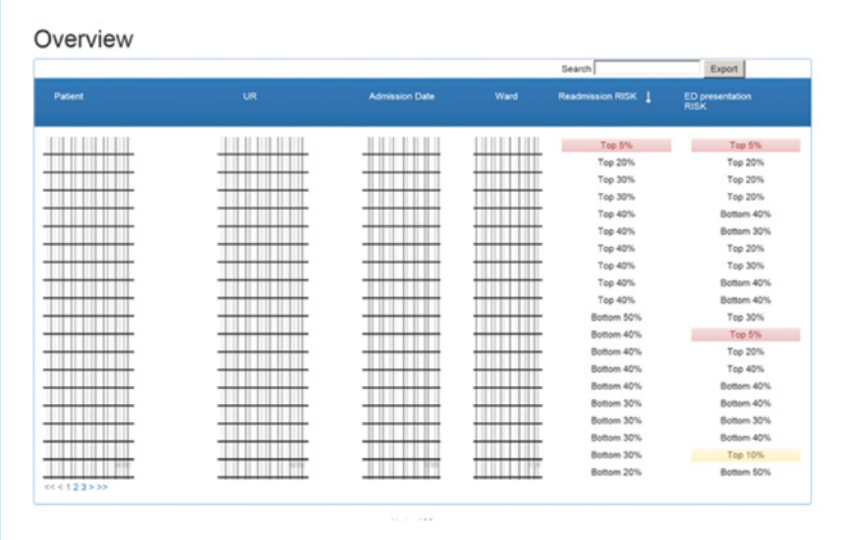


Figure 1: Risk of readmission and representation to ED are provided via a dashboard for all patients staying overnight in hospital.

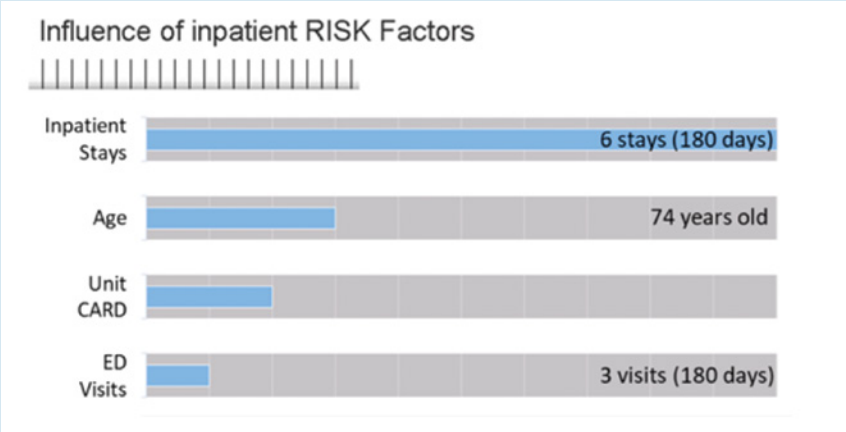


Figure 2: Patient-specific factors contributing to risk of readmission are provided for each inpatient via a dashboard.

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.

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

There is a need to deliver healthcare in a manner that maximises outcomes for patients. In 2017/2018, the team completed a large state-wide study 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 2017/18, the team commenced an engagement with Queensland Health's Healthcare Improvement Unit to undertake additional statistical modelling of surgical and inpatient data for the major public hospitals across Queensland. The modelling builds on previous analysis by the team aimed at maximising the utilisation of operating theatres as one of the highest resource costs of hospitals. The additional analysis explores whether the day of the week that elective surgery is undertaken affects post-operative length of stay, whether sessions comprising the same medical specialty are more highly utilised than sessions with a mix of specialties, and whether more frail patients lead to longer procedure times and turnover times between operations. 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, co-ordinated 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 co-ordinated model of care that integrates hospital, ambulatory and community-based services. 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 (termed "flexible 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.

In 2017/18, additional focus group surveys and interviews were conducted with three participating health services to understand healthcare professionals' perceptions of how HealthLinks has been implemented at their health services and their perceived potential impact of HealthLinks. Quantitative analysis compared key outcome measures (e.g. 30-day readmission to hospital and representation to ED) for patients who were either enrolled at a flexible funding site and/or who were streamed into a particular intervention/model of care to those patients who were enrolled at a complimentary control site. Preliminary results show no significant change in outcomes measured as a result of flexible funding. At this stage there is limited data to make any further inferences on the impact of flexible funding.

HEALTH DATA ANALYTICS *(continued)*

Predicting unexpected patient deterioration in a digital hospital setting

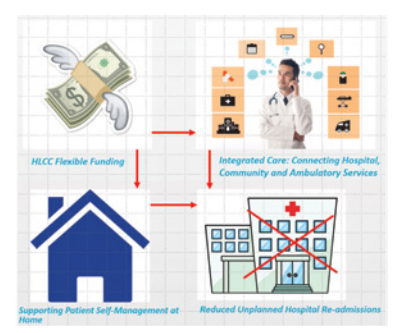
In 2017/18, planning commenced for a new project aimed at reducing the incidence of unplanned adverse patient outcomes within hospital using new applied predictive tools developed specifically for a digital hospital setting. Such a system is the future of hospital health care. The specific outcomes of focus are to:

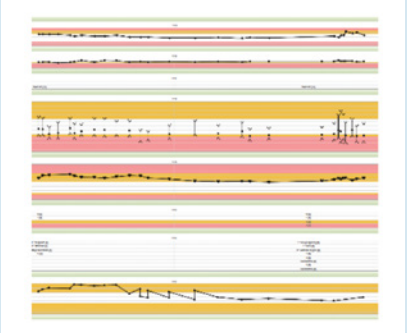
1. Reduce unplanned Intensive Care Unit admissions from a general ward
2. Reduce Rapid Response Calls arising from a non-deteriorating patient, and
3. Reduce the rate of serious injury/ disability or death due to an adverse outcome while in hospital.

Additionally this research will seek to:

1. Customise vital signs thresholds programmed into a digital hospitals' Electronic Medical Record that suit individual patients using historic data.
2. Predict the likelihood of a patient deteriorating significantly before they become a candidate for critical or intensive care using a range of data sources.

Two digital hospitals will be participating in this study: the Princess Alexandra as the training site and the Townsville Hospital as the test site. A project proposal has been submitted to the Clinical Excellence Division at HITEC for potential funding and the project has employed a post-doc to work on the project.





Source: Clinical Informatics, Metro South Health

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
- Telstra Health.

Project Highlights for 2017/18:

- Patient risk stratification model was developed, validated and accepted by the Department of Health for to be used by GPs in the National Health Care Homes trial
- Web based risk stratification algorithm for predicting rehospitalisation developed and trial started at Logan Hospital
- Report provided to Queensland Health on patient outcomes around after-hours hospital care
- First interim HealthLinks evaluation report delivered to DHHS for this 3.5 year project.

Project Aims for 2018/19:

- HealthLinks Chronic Care evaluation: completion of annual report for year 1 and year 2
- Evaluation of the web-based risk stratification algorithm at Logan Hospital
- Start of a new collaboration with Victorian Agency for Health Information (VAHI) which has oversight of all Victorian hospital data
- Start of a new collaboration with WA Health with a project at Fiona Stanley Hospital to gain better insight into theatre efficiency
- Continued support, validation and extension of the Patient Admission Prediction Tool within Queensland Health.

HEALTH DATA ENGINEERING

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

Over the past 12 months the team has 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 continues 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. Our team manages a common framework known as the MoTER platform to deliver these projects, attempting to maximise reuse while not hindering innovation. The platform consists of iOS and Android native applications and a web portal for clinicians to review the collected data.

AEHRC on FHIR

Activities include:

- 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
- investigating 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
- an extended version of the HAPI FHIR Server, Sapphire, that delegates to Ontoserver for its terminology subsystem to take advantage of its advanced SNOMED capabilities.

A SMART on FHIR reference implementation has been developed incorporating OAUTH against third-party systems (such as Google) and the AEHRC FHIR server. The first application to use this reference implementation will be a genomic test ordering system.

Delivery of technology into the health system

Our team provides the bridge between research outcomes and deployment of technology into the health system by productising, system integration, deployment and support. As an example, PAPT has been made into a product and is deployed into Queensland Health and licensed to Telstra Health, greatly increasing its impact. The Readmission RISK Stratification system is deployed at Logan and being used daily for decision support.

Clinical trial support

We provide support for clinical trial data management systems like REDCap and OpenClinica as well as custom data collection solutions. REDCap has been extended to support using an external FHIR-based terminology server for coded data fields.

BIOMEDICAL INFORMATICS

2017/2018 Science and impact highlights

- The Biostatistics team was involved in the Nature (IF40) publication that described the first blood test for Alzheimer's disease with greater than 90% accuracy to detect disease pathology in individuals older than 60 years.
- Our cloud computing platform for image analysis 3x automated image analysis pipelines has processed more than 3000 MRI and PET scans, including the PET scans used to evaluate the blood test.
- Our cloud computing genomics applications around clustering and genome editing have received broad coverage including iAwards recognition.
- The first clinical trial using MRI to guide prostate radiotherapy has been progressing well and relies on several important technologies developed by the Biomedical Informatics Group.
- A suite of machine and deep learning techniques have been deployed in numerous tools.
- Multiple NHMRC clinical studies and clinical trials, including very large multi-year studies on Alzheimer's. The recognition of our capabilities in clinical study data management is increasing with multiple studies relying on our support and expertise.

Biomedical Informatics Group Leader: Jurgen Fripp

The Biomedical Informatics research group develops innovative medical technologies to quantify genotyping and phenotyping. By developing software and imaging techniques, we aimed to create 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.

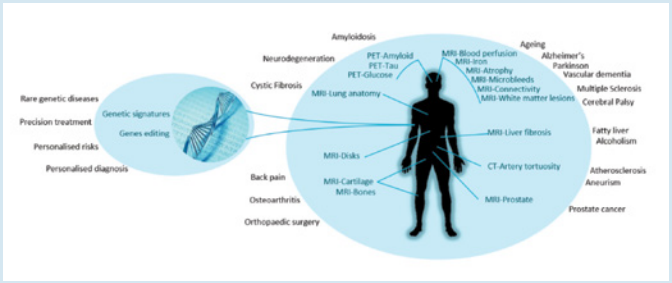


Figure 1: Our portfolio of technologies covers (blue) a vast areas of disorders (white)

Medical Image Analysis Team Leader: Jason Dowling

The Medical Image Analysis team is leading a paradigm shift in radiology from qualitative to (semi-) quantitative imaging and the development of a new generation of 'imaging biomarkers'. The technology developed turns images into information that is used for earlier detection of diseases and improved the diagnostic accuracy. These technologies are used in trials across a number of clinical areas including, prostate radiotherapy planning, cartilage health assessment, characterising cerebral palsy risk in infants, surgical planning and paediatric MR-based lung assessment.

Neuroimaging Team Leader: Sam Burnham

The Neuroimaging team uses their deep knowledge of medical instrumentation, image processing and machine learning algorithms to automatically extract and present pertinent information from medical image data both at the scale of populations and individuals. The team contributes to image-based biomarker analysis for a number of large studies and supports a range of large Alzheimer's disease trials around Australia, including the recently funded Alzheimer Dementia Network (ADNeT). ADNeT is part of Australia's quest to find cures and prevent and better manage dementia, involving a registry of clinical trial volunteers to fast-track research and translation. The team have recently partnered with Maxwell Plus in a CRC-P project to translate CSIRO's CapAIBL software which uses artificial intelligence to assess the Amyloid burden in the brain from PET scans. This will involve EC approval of the software tool so that it will be available for clinical use in nuclear medicine and radiology.

Transformational Bioinformatics Team Leader: Denis Bauer

Our Transformational Bioinformatics team 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 is well placed to analyse biomedical data with the view to interpret some of the world's most important medical research questions.

PROJECTS

MEDICAL IMAGE ANALYSIS

Medical imaging is critical in achieving further improvements in outcomes for patients and in driving efficiencies across the health system. The medical image analysis team combines expertise in 3D image processing, machine learning and medical physics with nationwide clinical collaborations to automatically extract and present information for clinicians and researchers, enabling optimal clinical decision making and treatment delivery. Projects within the team range across the lifespan (pre-term infants to diseases of old age) and from head (brain pathways) to toe (musculoskeletal analysis).

Cerebral palsy and paediatric neuroimaging

Paediatric neuroimaging of children with cerebral palsy

Cerebral palsy (CP) remains the world's most common childhood physical disability secondary to an insult to the developing brain. Approximately 700 babies born each year in Australia are later diagnosed with CP. Understanding the relationship between brain structure and clinical function is crucially important for diagnosis and prognosis.

Using brain MRI, we are developing methods to quantify the degree of brain injury and brain developmental status of children with CP relative to neurotypical children. Together with our collaborators at The University of Queensland and the Cerebral Palsy Alliance, our team is using these methods to predict clinical function and to assess neuroplasticity in response to intervention. One observational study of children aged 8-10 years is currently underway (Predict-CP), with the aim to determine the relationship between brain development and clinical function, as well as two randomised controlled trials of early intervention for infants aged three months to two years at high risk of CP (GAME and REACH). Together with collaborators at The University of Queensland, funding has been secured for a new randomised controlled intervention trial for children with CP aged 6 to 18 years (HABIT-ILE). Additional funding has been secured with collaborators at Melbourne University for an observational study of the early natural history of CP.

This research will enable major advances in the management of children with CP by providing a means to identify those therapies that will provide the greatest benefit to the individual child.

Neurodevelopment of preterm-born infants

Very preterm infants (born before 31 weeks gestation) have a high risk of an adverse neurodevelopmental outcome. Approximately 5% of these infants will be diagnosed with cerebral palsy, and half of them have later learning and behavioural difficulties. Diagnosis of cerebral palsy is currently made on average at 19 months corrected age, diagnosis of learning and behavioural difficulties even later. During the first two years of life, there is substantial scope to reduce later difficulties, because at this age the brain has a large capacity for repair. Earlier diagnosis and prognosis are crucial to identifying infants at high risk so that tailored therapy can be provided at an early age when it is most effective.

We are developing approaches to model normal neurodevelopment of the infant brain using MRI, and identify abnormal development. These approaches include methods to improve image quality, automatically delineate brain structures of interest to observe their growth and changes in their microstructure, and the extent to which different parts of the brain communicate. Together with our collaborators at The University of Queensland and the Royal Brisbane and Women's Hospital, our internationally recognised team is using these methods to predict the potential for adverse neurodevelopment earlier, and to more accurately identify those in need of therapy.

This 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.

Neurosurgical planning system: CONSULT

CONSULT aims to reduce rates of adverse events in neurosurgery through utilisation of cutting-edge brain mapping techniques, including advanced functional MRI and diffusion MRI tractography. The software produces a 3D model of a patient's brain and its wiring patterns. Neurosurgeons can then interact with this 3D model to plan the safest angle and depth to "cut" to cure patients without inducing critical injuries. The model and plans integrate with surgical-guidance technology, providing surgical teams with real-time feedback on progress and potentially imminent safety issues during surgery itself. CONSULT aims to make brain surgery safer, more effective, and allow surgeons to treat patients who would previously have been considered too high risk. This work is performed in conjunction with clinical partners, including radiologists and neurosurgeons at prominent Australian hospitals. The research is funded through grants from Advance Queensland (Research Fellowship), the Royal Australian and New Zealand College of Radiologists, and RBWH Foundation (Diamond Care Grant).

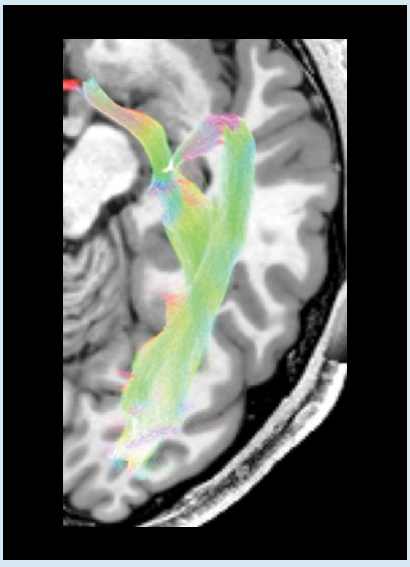


Figure 2: CONSULT: Automated delineation of the optic pathway, including Meyer's Loop, which is commonly severed during temporal lobectomy and usually considered extremely difficult to identify with MRI.

MEDICAL IMAGE ANALYSIS *(continued)*

Musculoskeletal image analysis: ChondralHealth

Osteoarthritis (OA) is a joint disease that characterised 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.

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 in clinical (e.g. European Journal of Radiology) and technical (e.g. Medical Physics) international journals. The developed software, ChondralHealth, has been shared with our industrial partner (Siemens Healthcare, Germany) who are 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. In addition we are using the multi-tissue 3D imaging capabilities of magnetic resonance (MR) for non-invasive objective assessments of hip joint biomechanics, morphology and biochemistry in patients.

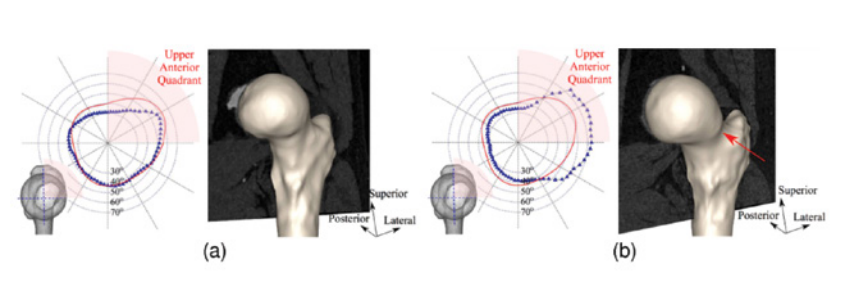


Figure 1: Femoroacetabular Impingement in the Hip: An automated MR-based method was developed for quantitative assessment of the hip joint that evaluates 3D bone morphology and provides 360° calculation of alpha angles around its femoral head-neck (FHN) junction. Analysis of the upper anterior quadrant of the FHN junction enable to distinguish bone lesions characterised by elevated alpha angles as shown in the figure (red arrow): hip joints having (a) smaller and (b) larger anterosuperior and anterior alpha angles (left: polar plots of alpha angles around the FHN junction, right: 3D bone models of the proximal femur surfaces automatically segmented from the MR scan).

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 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 lifespan 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.

MRI-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, we have developed the first atlas-based method to map realistic 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. After two successful retrospective trials involving 80 men, this work has grown into a Phase II multi-centre prospective trial for MRI-alone localised prostate cancer external beam radiation therapy (ANZCTR trial: ACTRN12616001653459). As at 30 June 2018, 15 men have completed treatment for localised prostate cancer with this technology.

Improving radiotherapy treatment clinical trial quality assurance

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 four large clinical trial datasets with the aim of changing practice for future studies and enabling consistent assessment in the clinic.

Collaborators:

- Royal Melbourne Hospital
- Queensland Institute of Medical Research
- McCusker Foundation
- Queensland Cerebral Palsy and Rehabilitation Research Centre
- Siemens Healthcare
- Steadman Philippon Research Institute
- Lady Cilento Children's Hospital
- Royal Brisbane and Women's Hospital
- Queensland Cerebral Palsy and Rehabilitation Research Centre
- Stella Maris Institute, Pisa
- Ingham Institute for Applied Medical Research
- Calvary Mater Newcastle Hospital
- Sir Charles Gairdner Hospital
- Liverpool and Macarthur Cancer Services
- Universities of Queensland, Newcastle, New South Wales, Western Australia, Melbourne, Sydney, South Australia and Wollongong
- University of Barcelona, Spain
- Brisbrain and Spine.

Project Highlights for 2017/18:

- ChondralHealth software delivered to Siemens for internal evaluation
- Alex M. Pagnozzi, et al. Best Scientific Poster Award, American Academy for Cerebral Palsy and Developmental Medicine 71st Annual Meeting, September 13-16, 2017, Montreal
- Lee Reid: People's Choice Award and CSIRO Accelerator Award at Impact 7, Melbourne
- International multi-centre prospective clinical trial for MRI-alone, external beam radiation therapy for localised prostate cancer
- Initiation of a new project aimed at MRI-based non-invasive lung structure assessment for children with cystic fibrosis
- 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
- Development of a method for automated delineation of the optic radiation using MRI
- Journal papers in top rated medical imaging and clinical journals
- Successful grant funding, including NHMRC, RANZCR, RBWH Foundation.

Project Aims for 2018/19:

- Clinical validation of the CONSULT platform for neurosurgical planning
- Evaluation of ChondralHealth software in a multicentre study
- Development of automatic quantitative MRI reports for children with cerebral palsy and infants at risk of cerebral palsy
- 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
- Start development of motion correction methods to improve the analysis of dynamic image data
- Validation of methods for contrast synthesis and segmentation based on deep learning
- Segmentation tools for retrospective mining of radiation oncology imaging data.

MEDICAL IMAGE ANALYSIS *(continued)*

PhD Student

Miles Seidel
University of Queensland

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.

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 three and 12 months of age in a large cohort of neonates born very preterm.

Ashley Gillman
University of Queensland

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 artifacts can have an 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 utilise 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 re-scans where motion corruption rendered the original scan unusable. Researchers may be able to run previously unachievable tests, such as dynamic modelling of deformable regions like the abdomen and pelvis. The software developed is also intended to foster and accelerate PET/MR motion correction efforts by the research community.

NEUROIMAGING

Healthy ageing and Alzheimer's disease research

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 recognised as a critical component to developing effective treatment for various forms of neurodegenerative diseases, including Alzheimer's disease, as it allows interventions prior to widespread and irreversible tissue loss. The primary pathway for early detection is through identification of neuropathology biomarkers derived from neuroimaging.

The Clinical Imaging team combines knowledge obtained from collaborating physicians with a deep knowledge of medical instrumentation, image processing and machine learning algorithms to automatically extract and present pertinent information from medical image data both at the scale of populations and individuals. We provide automated quantification of such biomarkers to collaborators at Austin Health, the Florey Institute of Neuroscience, McCusker Alzheimer's Research Foundation, Edith Cowan University, Macquarie University for the Australian Imaging and Biomarker and Lifestyle (AIBL) study, KARVIAH and PISA studies. Within these collaborations we have provided strong evidence that AĐ-amyloid (AĐ) plaque accumulation commences 10-20 years before clinical symptoms, highlighting a significant window for pre-clinical treatment.

AIBL and the Alzheimer's disease network (ADNet)

As expectations increase for data-driven knowledge and understanding, it will be necessary to consider data streams in combination with each other, not as silos, to provide improved classification, categorisation of comorbidity burden, diagnosis and prognosis at the individual level. This will require harmonisation of imaging biomarkers to give the best overall picture.

An example where we are currently working on harmonisation is the centiloid scale. Amyloid imaging with positron emission tomography (PET), has produced remarkably consistent qualitative findings across a large number of centres, however there has been considerable variability in the exact numbers reported as quantitative outcome measures of tracer retention. The centiloid scale was developed by an international working group to alleviate some of these issues and provide a framework to standardise measures of AĐ burden from PET images. The centiloid framework was applied to the calibration of CapAIBL; we showed that reliable centiloid estimates could be obtained with our CSIRO pipeline. There is still a need to validate the centiloid scale with longitudinal dataset.

Prospective Imaging Study of Ageing (PISA): genes, brain and behaviour

PISA studies the interplay between genetic, epigenetic and environmental factors for dementia, and also aims to identify risk factors that could be modified through intervention – such as lifestyle choices. The study is a unique international research resource, providing new links to studies into the causes of dementia, assisting clinical trials in dementia prevention, and bringing about new possibilities for translational research into this important public health issue.

PISA uses cutting edge imaging technologies to examine the neurobiological features associated with high risk for dementia, and identify the changes that lead to a patient's transition from high risk to cognitive impairment. The combined use of genetic risk scores and neurobiological markers creates a potential prognostic marker for dementia development. Outcomes of the study will inform and establish a platform for future intervention programs that target preventing and treating dementia. So far, 93 subjects have been recruited in PISA.

NEUROIMAGING *(continued)*

Figure 1: Example quantitative reports for PET analysis (CapAIBL), MR morphometry (CurAIBL) and FLAIR white matter hyperintensity segmentation (HIST)

BIOMEDICAL INFORMATICS

Sterling's Dream

Cholinesterase inhibitors (ChEIs) are a major class of cognitive enhancing drugs designed to target the symptomatic treatment of Alzheimer's disease. This is based on the knowledge that cholinergic degeneration of the basal forebrain is a hallmark pathological feature of Alzheimer's with specific vulnerability to amyloid-beta (AÐ). Despite widespread use in clinical practice, in reality only 30-35% of patients respond to treatment. The ability to identify patients who will respond to ChEI using biomarkers would significantly impact treatment and policy guidelines for the use of these cognitive enhancing drugs. In terms of brain scans, Positron Emission Tomography (PET) and Magnetic Resonance Imaging (MRI) will be acquired and from the findings we will better understand if there are differences in the characteristics of healthy brains compared with those with early stages of Alzheimer's disease.

UK Biobank

With the current data revolution and its application to the medical and health fields, there will be an increasing pull for more and more personalised health data across populations. This increase in demand will be equally applied to imaging markers requiring high throughput technologies for image processing. We will implement new strategies using deep learning to tackle this demand. This includes processing of over 50,000 images as part of our successful proposal to UK Biobank this financial year.

Collaborators:

- ADNeT team
- Australian Imaging Biomarkers and Lifestyle (AIBL) study
- QIMR Berghofer Medical Research Institute
- Florey Institute of Neuroscience and Mental Health
- Nuclear Medicine and Centre for PET, Austin Health
- University of Melbourne
- Edith Cowan University
- University of Wollongong
- University of Sydney
- Macquarie University
- University of Western Australia.

Project Highlights for 2017/18:

- Successful CRC-P proposal with partners Maxwell Plus to commercialise our IP on automated PET and MRI image analysis
- Co-authored paper in the journal Nature (IF40) describing the first blood test for Alzheimer's disease with greater than 90% accuracy to detect disease pathology in individuals older than 60 years
- Deployment of the HIST white matter hyperintensity segmentation tool on MilxCloud
- 17 published journal articles and 31 conference papers.

Project Aims for 2018/19:

- Evaluation of Centiloid calibration in longitudinal PET Amyloid study
- Translation of CapAIBL and CurAIBL to Maxwell Plus
- Development of novel deep learning methods for image quantification
- Harmonisation of imaging biomarkers across sites for ADNet
- Validation of CapAIBL for use with Tau and FEOBV tracers
- Interpretation of imaging and other data to provide clinically meaningful staging criteria for progressive diseases such as Alzheimer's disease.

PhD Student

Biting Yu
University of Queensland

Magnetic resonance imaging (MRI) is a widely used medical imaging modality that can be configured to provide different contrast between tissues in the human body. By setting different scanning parameters, each MR imaging modality reflects the unique visual characteristic of the scanned body part, which benefits medical image analysis from different perspectives. To utilise the complementary information from different imaging modalities, cross-modality MR image synthesis has been sought after and attracted increasing research interest recently. This project aims to develop novel techniques in deep learning applied to medical image synthesis for the purpose of improving current image analysis workflows.

Cathryn McKenzie
University of Western Australia

Cognitive reserve is the hypothesised capacity for adapting to physiological changes in the brain, such as those caused by ageing or disease pathology, in order to maintain normal cognitive functioning. Cognitive reserve can be assessed as the difference between an individual's observed test performance, and the performance predicted based on structural brain health (such as volume of brain matter). Cognitive reserve, as indexed by this residual approach, has been found to be related to factors thought to build reserve such as education, cognitive decline and future dementia diagnosis, independently of brain health, and increased efficiency of brain networks as measured by functional magnetic resonance imaging. While this approach has shown initial promise, some aspects that might improve our understanding of the cognitive reserve construct remain unexplored. This project will address these gaps in the current research.

TRANSFORMATIONAL BIOINFORMATICS

The Transformational Bioinformatics team develops novel bioinformatics solutions for research and industry using the latest in cloud and big data 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 harness 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 the Dementia Team Grant led by Prof Ian Blair at Macquarie University, which aims to uncover the molecular mechanisms of Amyotrophic Lateral Sclerosis (ALS), the disease Stephen Hawking suffered 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 five-year project. These samples will form the Australian contribution to the international Project MinE consortium. CSIRO is also engaged in this wider initiative by analysing this 22,000 strong case-control cohort.

Outcomes

- Publication in Cell Neuron (IF=14.024, cited 4).
- The work will be presented by CSIRO as a keynote at the International Conference on Frontotemporal Dementias in Sydney.
- CSIRO is developing a relatedness tool that improves upon existing approaches for detecting distantly related individuals and accurately assigning the degree of relatedness.

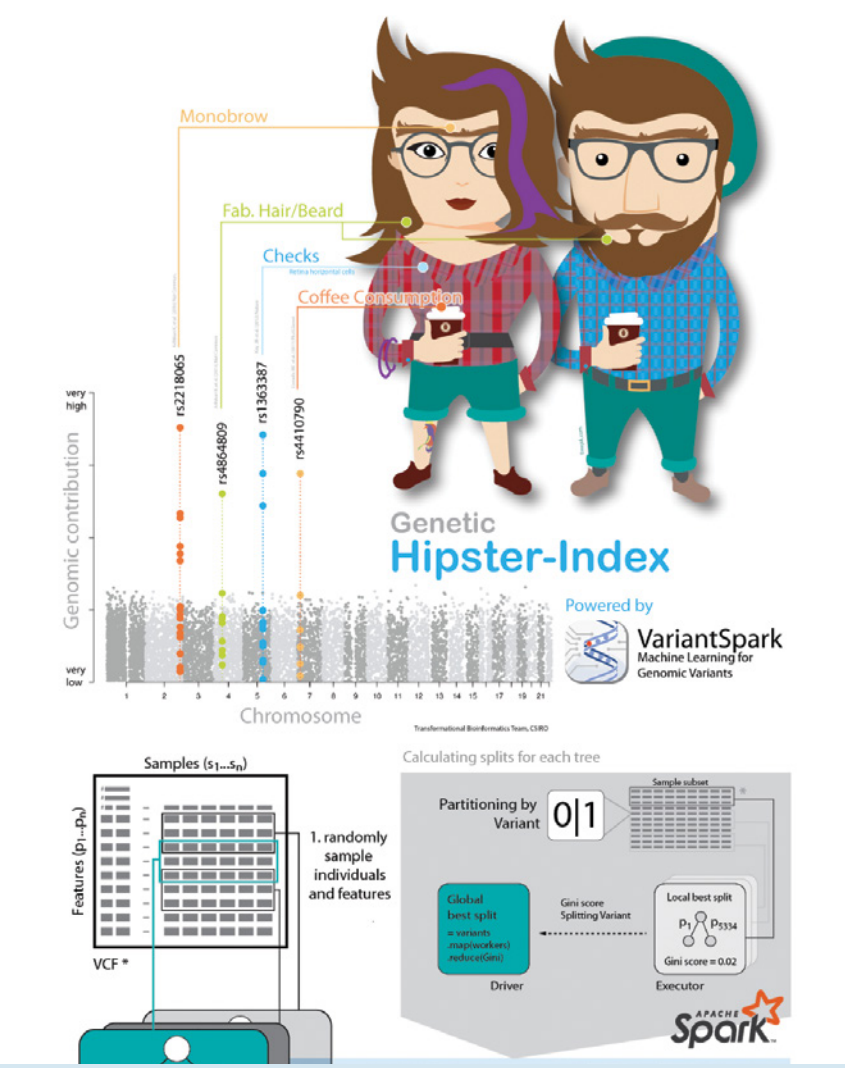


Figure 1. Novel machine learning methods for disease association (here synthetic phenotype hipster-index)

Cloud-based genome analysis tools

This project develops novel approaches for analysing genomic data from population-scale cohorts (i.e. common and rare variants). Our software platform VariantSpark has been demonstrated to save companies 80% of cost by requiring fewer samples for standard case-control studies (GWAS) to reach significance. It achieves this by using Apache Spark technology for building machine learning models capable of analysing the full genome simultaneously. This allows the tool to identify genomic locations that jointly contribute to disease as oppose to being limited to detecting only the strong individually contributing genes (GWAS).

Outcomes

- Featured as one of ComputerWeekly's Top-10 IT stories of 2017 and in an interview on Future-proofing Companies.
- Machine Learning Algorithm submitted for publication.
- CSIRO presented VariantSpark as keynote presentation at international IT conferences (AgileIndia, AIDevDays) and will present at the AWS Public Sector Summit, Canberra.

Computational genome editing services

This project develops computational solutions 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. The task of finding a suitable genome editing spot is comparable to finding the right grain of sand on the beach, i.e. it needs to have the right shape and colour (properties for CRISPR to bind) and also be unique compared to all other grains on the beach (for CRISPR not to accidentally bind to another gene). This is a very expensive task computationally. We reduced the overall runtime for this task from weeks to seconds by massively parallelising the individual search tasks using a revolutionary new compute approach called Functions-as-a-Service.

We also improved accuracy by 30% by tapping into CSIRO's 25-year experience in the science of how the 3D organisation of the genome affects the accessibility of the genomic address. Finally the machine learning models are built to more precisely fit experimental use cases (e.g. SNP-aware prediction for wild populations) thereby being able to personalise results to individual patients.

Outcomes

- Publications in The CRISPR Journal and Frontiers in Pharmacology (IF=4.4).
- CSIRO presented GT-Scan on 'This is my architecture', a youTube channel by Amazon Web Services featuring international clients with the most outstanding software architecture.
- CSIRO will present the GT-Scan setup on Alicloud at Alibaba Cloud Summit in Singapore.

Figure 2. Genome Engineering Symposium in Canberra.

Collaborators:

- Macquarie University
- Children's Medical Research Institute (CMRI) Westmead
- Guangzhou Medical University
- National Measurement Institute
- University of Newcastle
- Queensland University of Technology
- Australian National University
- Australian Genomics Health Alliance
- Melbourne Genomics Health Alliance
- Graven Institute for Medical research
- ProjectMine (Europa)

Project Highlights for 2017/18:

- The team has published six journal papers (three senior author, and two in IF>10) and over 20 conference papers (seven keynotes at major national and international conferences with up to 800 attendees, 14 oral presentations, all presenter or senior author).
- Our work was featured in international media articles (AWS, ComputerWeekly) and we won the H&B "Outstanding Collaboration Award" and FreshScience Award.
- The team has secured $800K in competitive funding and has engaged 14 companies in customer discovery conversations (e.g. Illumina, Sonic Health, Samsung, Sanford Health).

Project Aims for 2018/19:

- Establish VariantSpark internationally as the technology of choice for large cohort analysis to capture part of the $19.99 billion (2020) genomics market (Markets and Markets)
- Develop technology for ImmunoEngineering in collaboration with CMRI Westmead and Guangzhou Medical University to capture part of USD $7.5 billion (2024) genome editing market (Global Market Insights, Inc.)
- Publish a high impact journal publication featuring original research using our technology.

TRANSFORMATIONAL BIOINFORMATICS *(continued)*

Figure 3. Marc Horlacher (Masters student), Amnon Bleich (Masters student) and Aidan O'Brien (PhD student).

Student Profile

Aidan O'Brien, PhD student co-supervised with ANU.

Topic: Genome editing is a new molecular discipline with transformative impact on human health, environmental and agricultural applications. Of particular promise is the ability to insert synthetic DNA into the genome at precise locations as enabled through CRISPR-Cas9 and homology-directed-repair. Being able to do this with the precision and efficiency requires extensive computational optimisation processes. This project builds sophisticated machine learning models that enable researchers to identify the optimal genomic location for an intervention. Working together with Australia's premier research organisation and CRISPR facility, the computational tools will be validated on novel datasets and enable new application areas.

Amnon Bleich, Masters student in the Bioinformatics Student Exchange Program.

Topic: Genome-wide association studies (GWAS) have contributed towards finding disease genes over recent decades. The traditional GWAS approaches use odds-ratio and defined distributions, like chi-square tests, to compute p-values for associating SNPs with traits. While this is appropriate and efficient for simple genotype-phenotype patterns, they are not capable of identifying interacting SNPs for multi-genic diseases (e.g. diabetes, ALS). Machine learning methods, such as Random Forest, can overcome these limitations. This project investigates how to improve upon standard Random Forest algorithms to be applicable to genomic data analysis.

Marc Horlacher, Masters student in the Bioinformatics Student Exchange Program.

Topic: Genome editing with CRISPR-Cas9 is opening up new avenues in almost all facets of research. While CRISPR-Cas9 normally induces random mutations, some control can be exerted by leveraging specific repair pathways within the cell. One such pathway is Microhomology Mediated End Joining (MMEJ), which results in a controlled deletion of a very specific portion of the DNA. What drives a target to be repaired via this mechanism is still unknown, making its use unreliable. This project uses machine learning approaches to identify features that predict MMEJ repair, helping researchers design CRISPR-Cas9 applications that take advantage of this pathway and providing greater control over the results.

BIOSTATISTICS

Australian Dementia Network (ADNeT)

Our Biostatistics team combines data from multiple modalities to answer 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 process in Alzheimer's disease.

Our team are key members in the Australian Imaging Biomarkers and Lifestyle (AIBL) study. The core mandate for AIBL 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, researchers in the AIBL study aim to develop and commercialise our research findings in order to deliver changes to treatment in medical and health care practices. Recently, key researchers from AIBL were awarded a $20 million grant to start the Australian Dementia Network. This research project will kick off in 2019, and will involve recruiting about 4000 participants over the next five years from around Australia, hosting data from imaging, biomarkers and lifestyle similar to the AIBL study.

This year our 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.

Neuropsychology and its disorders

Members of the team play 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 disease. This research has led to six journal publications in high-ranking journals.

Instrumental relationship with pharmaceutical companies

Our team is working closely with international pharmaceutical companies Roche and Biogen to assess the cognitive trajectory of Alzheimer's disease from its very early stages (prodromal and pre-clinical) through to late stage clinical AD. Research is focused around changes in cognition, blood and CSF-based biomarkers and pathological proteins via PET imaging. Along with collaborators from world-leading laboratories, our 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.

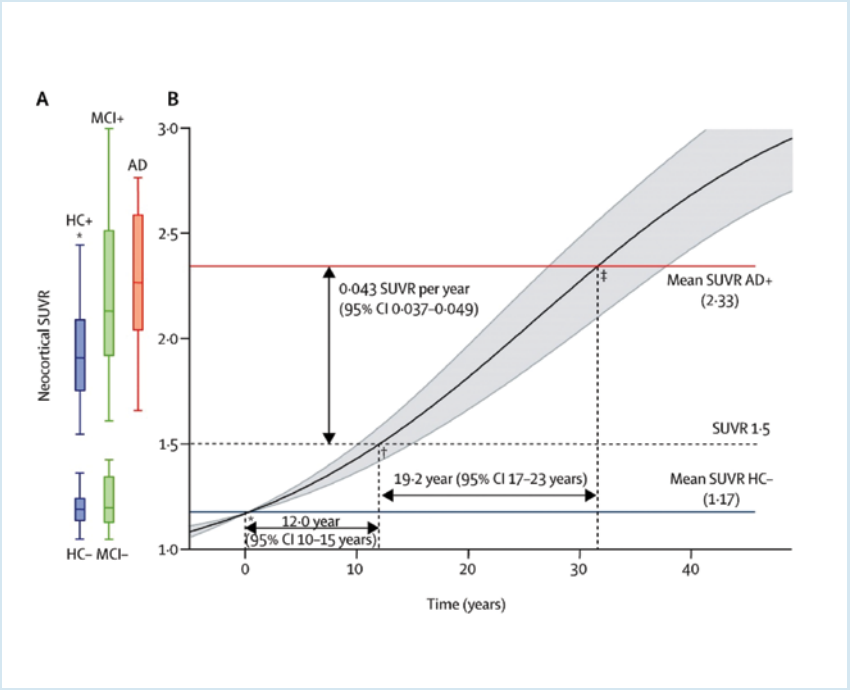


Figure 1: Alzheimer's disease progression model.

BIOSTATISTICS *(continued)*

Figure 2: Genome Engineering for Cancer Treatment conference.

Genome Engineering for Cancer Treatment conference

Team members are part of the organising team for the CSIRO-funded Cutting Edge Biosciences conference. Last 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 was held in November 2017 at the ANU in Canberra and attracted 120 participants.

Collaborators:

- ADNeT team
- 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 2017/18:

- Real bench-to-bedside research with biomarker studies leading to changes in clinical practice
- Co-author paper in the journal Nature (IF40) describing the first blood test for Alzheimer's disease with greater than 90% accuracy to detect disease pathology in individuals older than 60 years
- 20 published journal articles, including first author papers in Lancet Neurology (IF22) and Neurology (IF8)
- 12 conference presentations.

Project Aims for 2018/19:

- 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.

HEALTH SERVICES

2017/2018 Science and impact highlights

- Research initiatives were made to innovations to address Autism Spectrum Disorder using chatbots and robotics.
- Smarter Safer Homes project was kicked off to validate the platform with four service providers, and a testbed project was initiated to evaluating new features for the platform.
- Feasibility study for mobile health delivery of gestational diabetes (M♥THer) completed.
- Remote-I was commercialised to TelemedC.
- Health services projects were highly recognised for their innovation, with five Queensland iAwards (including the Premier's award) for mobile health projects (kidney disease and pulmonary rehabilitation management); one Victoria iAward for CALD Assist; and two Western Australia iAwards and one National iAward for Remote-i in the detection of diabetic retinopathy.

Health Services Group Leader: Mohan Karunanithi

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

Mobile Health Systems Team Leader: Marlien Varnfield

With the wide uptake of smartphone, internet and health monitoring technologies in people's everyday lifestyles, the Mobile Health Systems team is translating the delivery of health care from acute care setting into the community to relieve the undue pressures hospitals face in managing chronic diseases and illnesses. Our team has demonstrated capabilities as a world leader in providing scientific evidence supporting mobile 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 clinical trials for evidence base.

Health Internet of Things Team Leader: Qing Zhang

With the advent of wireless sensors, mobile, and health technologies pervasive in everyday use, new and rich sources of data are now accessible to determine people's lifestyles and their influences in their health and well-being. The Health Internet of Things (HIoT) team is 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 or internet devices. We have been developing and exploring smart data analytics (through machine learning and artificial intelligence) on aggregated data sets to better support the older community and people with disabilities to live longer in their homes, and also to support their carers and service providers.

Digital Health Engagement Team Leader: Dana Bradford/Jill Freyne

For effective adoption of new health intervention delivery, particularly using technology, consumer/provider driven design is paramount. Our Digital Health Engagement team aims 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 and 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 the health services group, the e-Health program and other CSIRO business units to contribute to the delivery of consumer design prototypes for testing in clinical trials.

Australian Tele-health Research and Development Group Lead: 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.

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, and burns and wound care management. The team were recognised for WA Information Technology and Telecommunications Alliance (WAiTTA) Incite Awards 2018 – Winner of Most Innovative Enabler in Health Care, and Achiever of the Year.

PROJECTS

MOBILE HEALTH SYSTEMS

Smart mobile devices and wearable technologies have created a new communication channel between healthcare service providers and patients. The adoption of mobile health systems is on the rise, with indications they have the potential to alter the way health services operate to enable better patient care. Benefits of mobile health include direct individualised patient management, enhanced physician efficiency, convenience, improved multidisciplinary care, enhanced team co-ordination and increased information access and communication.

In recent years, the Mobile Health Systems team has designed, developed and evaluated patient online portals and mobile applications to improve coordinated care in a variety of chronic conditions including heart disease, diabetes, lung disease and kidney disease. Furthermore, the team has developed a solution for activity pacing (in pain management) and is also involved in a project for early detection of cerebral palsy, using a wearable sensor system for monitoring body movements of neonates. Selected projects are presented below.

Pain ROADMAP: pilot study in chronic pain management

Chronic pain is estimated to effect 20% of Australia's population; arthritis and back problems account for 40% of forced retirements, and the total economic cost of chronic pain is estimated at $34 billion. In collaboration with Metro North HHS, we started a pilot study in mid-2017 testing a digital intervention for people with chronic pain. Study participants (n=20) were provided with a mobile application that tracked daily actives, medications and pain levels while streaming accelerometer data from a wearable device.

The data collected by the user is sent to a online data integration and analysis portal which generates daily graphs, where periods of over-activity can be identified as well as daily and weekly summaries of:

- Pain intensity and variation
- Mean objective activity and variation
- Dosage and frequency of medication intake
- Percentage of time spent on rest, productive tasks and leisure/social activities.

Examples of the visualisation of the data are given in figure 2. This data allows the collaborating occupational therapist to provide a patient-centric intervention program to lower medication intake and pain levels and ultimately increase wellbeing.

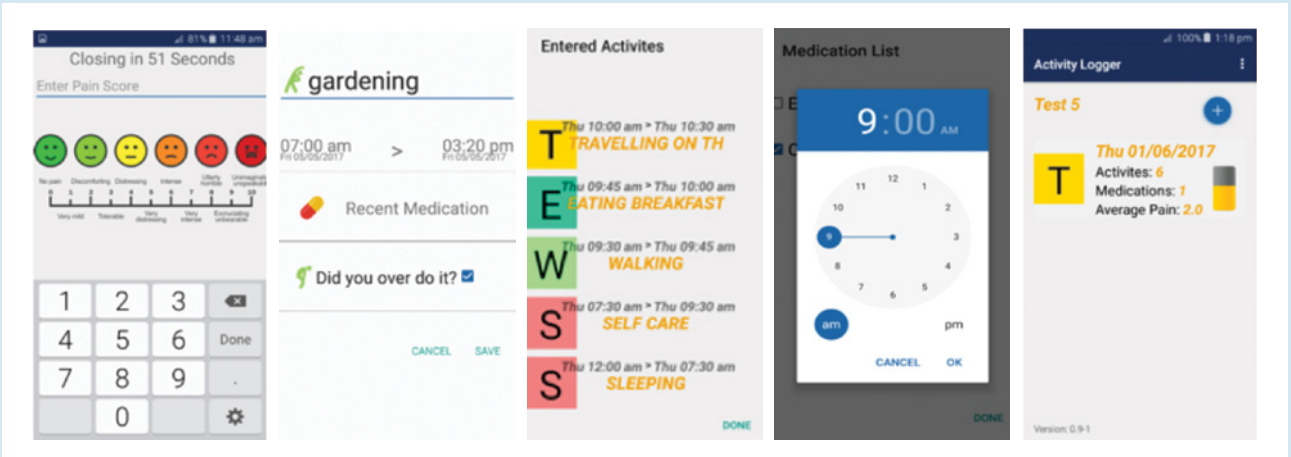


Figure 1. Screenshots of the mobile application. The app alerts individuals to enter their pain score every waking hour. Individuals also enter their daily activities and opioid medication in an electronic diary.

MOBILE HEALTH SYSTEMS *(continued)*

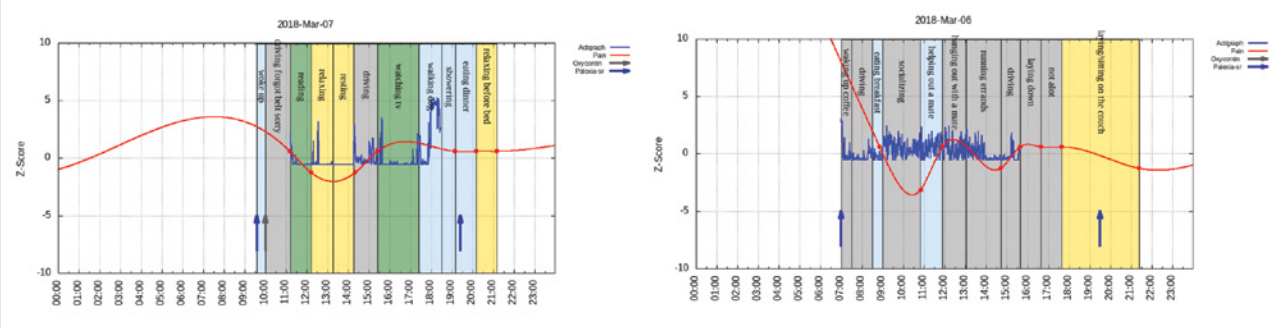


Figure 2. Examples of the visualisation of the Pain ROADMAP portal that show a user's day of activities, levels of pain and times of medication intake. Activities are colour coded to indicate the type of activity.

The results of this pilot study have been extremely encouraging. After the third monitoring period, participants reported less pain, stress and anxiety, with increases in physical activity. Most importantly, there was a general reduction in the amount of pain medication taken. 100% of participants indicated that specific feedback provided by the clinician was worth going through the monitoring procedures. All participants said that they would recommend Pain ROADMAP to others.

Early detection of cerebral palsy

Babies at risk of developmental disorders can benefit from early medical interventions, but methods for early diagnosis are nascent, limited, and often case-specific.

About 27,000 Australian infants born preterm every year have a heightened risk of developmental delay or difficulties, including cerebral palsy, minor motor and behavioural difficulties, and cognitive impairment. Many have subtle brain abnormalities that are not easily seen on cranial ultrasound or conventional magnetic resonance imaging (MRI). Infants with clinically observable abnormalities in movement, speech, vision or cognition typically undergo physical therapy, which relies on the brain's innate plasticity to help them achieve substantial improvements in clinical performance. These therapies can significantly increase their quality of life and lower their lifetime healthcare costs but can only be undertaken once a positive diagnosis has been made.

The aim of this project is to enable major advances in the management of babies at risk of cerebral palsy, reduce the financial burden of the condition on the health system, and increase societal integration and quality of life for children born with this difficult-to-diagnose disease.

We are developing methods to detect even subtle brain abnormalities at an earlier age, allowing earlier intervention which will lead to better outcomes for patients. The ability to track development over time is allowing us to predict the extent of improvement for patients using different therapies, and for the first time we can examine the association between therapy, physical changes within the brain, and clinical outcomes. This knowledge will allow us to develop the next generation of therapies and tailor them to the individuals.

One of the methods under development is the use of wearable sensors to augment existing clinical assessments towards higher sensitivity to the presence of disease at an earlier age. The infant wearable sensors under development can be used to measure and quantify extremity motor characteristics, indicative of normal or abnormal development. Under normal developmental trajectories, infant movements will be fluent and varied, representative of a healthy and developing brain. In cases where an injury or insult may be present in the brain, the movements are more patterned, repetitive, and monotonous. Using unobtrusive sensors placed at the hands, feet, and head, we can measure the motor characteristics and identify infants at risk of cerebral palsy for follow-up testing. In contrast to existing screening methods, this measurement tool can also be used in rural clinical and home environments, expanding the reach of early screening methods beyond specialist centres. At-risk infants can theoretically be identified at an earlier age than previously possible and referred for additional radiological testing and intervention therapies.

Innovative mobile health program for COPD

Chronic obstructive pulmonary disease (COPD) is the fourth leading cause of death globally. Resources to help patients self-manage COPD have long been available, however, patient adherence to these remains suboptimal. We are studying whether an innovative mobile health-enabled care program (MH-COPD) will improve the patient self-management and relevant health outcomes.

A prospective open randomised controlled trial has been designed. In the trial, patients with COPD will be recruited from The Prince Charles Hospital, Brisbane, Australia. They will then be randomised to participate in either the MH-COPD intervention group (n=50 patients), or usual care control group (UC-COPD) (n=50 patients) for six months. The MH-COPD program has been designed to integrate a mobile health system within a clinical COPD care service. In the program, participants will use a mobile health application at home to review educational videos, monitor COPD symptoms, use an electronic action plan, modify the risk factors of cigarette smoking and regular physical activity, and learn to use inhalers optimally. All participants will be assessed at baseline, three months, and six months. The primary outcomes will be COPD symptoms and quality of life; the secondary outcomes will be patient adherence, physical activity, smoking cessation, use of COPD medicines, frequency of COPD exacerbations and hospital readmissions, and user experience of the mobile app.

The study has integrated an innovative mobile system with a clinical COPD service and will evaluate this approach through a randomised control trial. The evaluation will provide a unique opportunity to improve COPD care in the community through mobile health innovations.

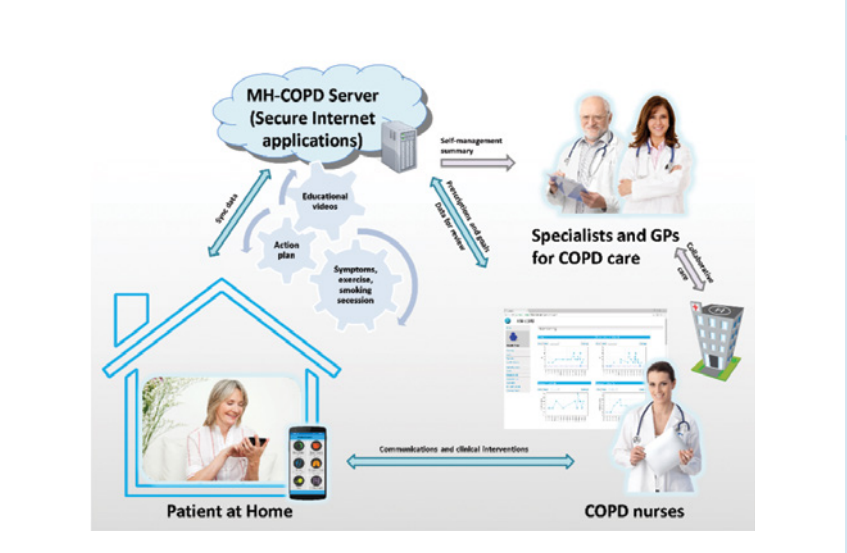


Figure 3. The care model of the MH-COPD program includes the components of health education, electronic COPD action plan, symptom monitoring, physical activity, smoking cessation, and inhaler technique.

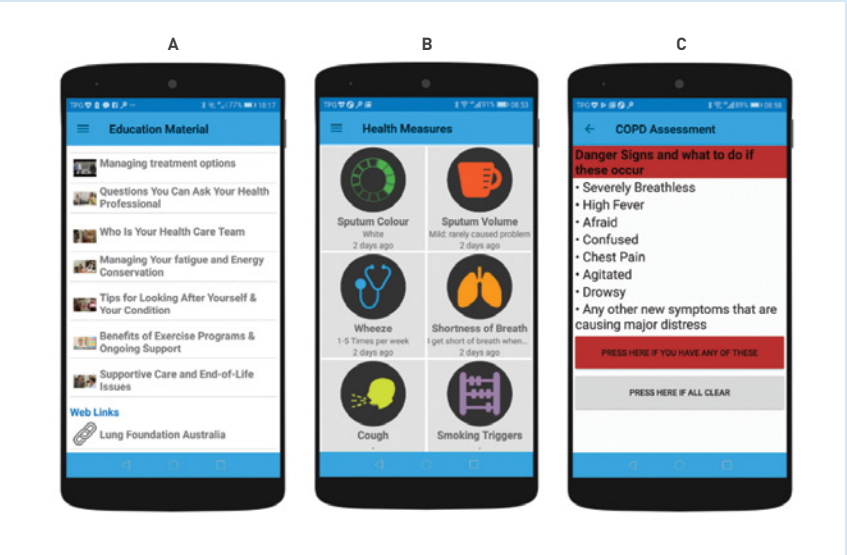


Figure 4. Selected screenshots showing the user interface of the mobile application.

A: Scheduled educational videos preloaded in the app
B: User interface to record symptoms and risk factors
C: User interface showing an assessment of symptoms in the COPD action plan.

MOBILE HEALTH SYSTEMS *(continued)*

Mobile Pulmonary rehabilitation Platform (m-PR)

Pulmonary rehabilitation (PR) is an evidence-based and effective treatment but only 5-10% of eligible patients are currently attending PR services. PR services are delivered in highly specialised hospitals and this service model is inefficient and unsustainable. Lack of motivation, transport issues and clinical patient's liability have been signalled as causes for low uptake and adherence to the current PR programs, leading to poorer clinical outcomes and misuse of resources. The mobile Pulmonary Rehabilitation (m-PR) platform is a novel smartphone and Internet-based interactive solution to support patients with chronic lung conditions during their Pulmonary Rehabilitation (PR). m-PR is a collaborative study with clinicians from Metro North HHS and New South Wales health services partnering to improve health outcomes and quality of life for these patients by developing and implementing m-PR to improve the access to PR services, potentially enhancing the effectiveness of the model of care and the satisfaction level from the users. The m-PR system integrates mobile health technologies including a smartphone app, the Internet, health measure devices and multimedia content to support patients on PR. These technologies enable a productive interaction between patients and the PR teams, which may also contribute to improving quality and cost-effectiveness to the current model of care.

For this project, the platform will be pilot trialled in two sites (one in QLD and one in NSW). The m-PR platform has recently won 3 awards at the 2018 QLD iAwards held in Brisbane in June 2018: QLD Premier's Award for Public sector innovation, Award for Public and Sector Government and Merit Research & Development project of the year.

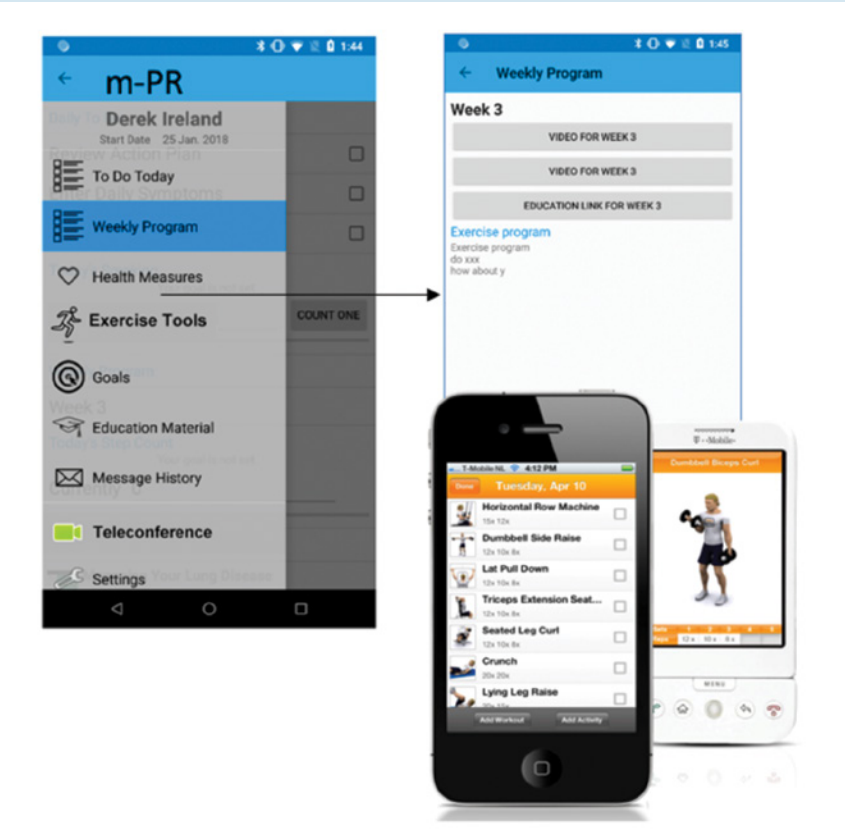


Figure 5. The "mPR" platform: individualised exercise and education.

PD-BUDDy: app changing lives of renal patients at Metro South Health

PD-BUDDy is a smartphone and internet-based interactive system that accompanies and guides peritoneal dialysis (PD) patients through every step of their dialysis treatment by monitoring health measures (including fluid exchanges tracking), providing educational multimedia, and assisting in their appointment scheduling and medication management. It also supports multidisciplinary care delivery by providing shared access to the multidisciplinary care team. The platform was developed in collaboration with Logan Hospital (Metro South Health). A smartphone app allows patients to enter health parameters (e.g. dialysis fluid intake, weight and blood pressure), medications, exercise, symptoms and exit site photos, which automatically upload to a password-protected clinician portal. The aim of the PD-BUDDy platform is to assist 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 healthcare system by saving time. PD-BUDDy leverages from CSIRO's existing clinically validated mobile health digital platform for cardiac rehabilitation, and through the close relationship with stakeholders, features have been incorporated to PD-BUDDy that are unique to PD patients such as ultra-filtration volume quantification, clinician-driven communication and ability to share photos of catheter exit sites for potential infection. PD-BUDDy has extended functionality to connect to wireless physiological monitors and fits perfectly for new remote health care delivery models extended to community and home care.

PD-BUDDy is in the final stages of being tested in a feasibility study at Logan Hospital, Queensland. The study had finished recruitment (n=30) patients, mean age 51± 8 years, by the end of February 2018 and the last participant is due to finish the six-month follow-up period in September 2018. Preliminary results indicate a slight decrease in exit site infections and peritonitis infections since the introduction of the platform. Patient feedback from initial surveys are extremely positive, with one patient calling the app 'life saving' with others reporting back regularly to staff that the app is extremely valuable and convenient. Use of the portal by staff has become routine, with clinicians commenting on the beneficial impact this platform has had on the service. PD-BUDDy has the potential to provide access to healthcare in remote communities that currently lack access to these services and we believe that the PD-system will significantly benefit the patients, the staff caring for these patients and ultimately the healthcare system. With minimal modifications, PD-BUDDy has already been identified to be a suitable solution not only to persons undergoing haemodialysis, but it has also been deemed suitable by nephrologists to manage their kidney transplant patients. This signifies utilisation in national and international markets.

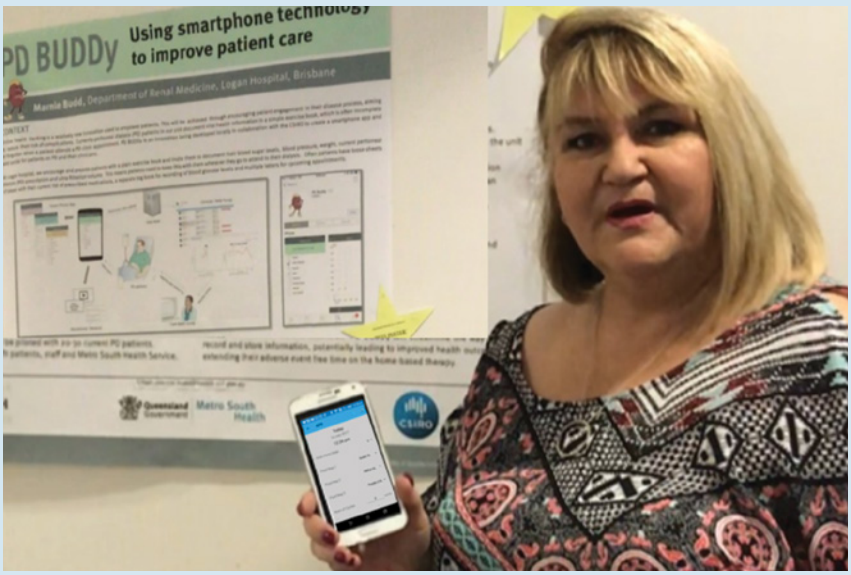


Figure 1. A patient from Logan Hospital relating her PD-BUDDy experience.

MOBILE HEALTH SYSTEMS *(continued)*

M♥THer: gestational diabetes app helps health workers monitor pregnant women

Gestational diabetes mellitus (GDM) is an increasing problem among pregnant women worldwide with a prevalence of up to 20% depending on diagnosis criteria and population. The increasing number of pregnant women being diagnosed with GDM is leading to snowballing healthcare costs. M♥THer is an interactive system designed to support women throughout diagnosis of GDM to childbirth. It also improves multidisciplinary care co-ordination by providing shared access to the women's clinical information.

M♥THer was recently tested in a feasibility study at a hospital in Queensland, Australia. The study recruited 40 women (mean age 30 years old by the end of Jan 2018). The app was well received by the women as an alternative to the paper-based blood glucose level (BGL) recordings. All respondents agreed that the app was user friendly, convenient and helpful in managing their GDM, making them feel confident in the management of their condition. Treating clinicians reported improved communication with the women in their care and experienced an increase in multidisciplinary co-ordination amongst themselves. The platform enabled early intervention for a number of women identified with elevated BGL readings in the first week of using the app, and due to elevated fasting BGLs, a number of women were timeously commenced on Metformin or insulin treatment.

Data input received from the M♥THer app include physiological measuring outputs and supports decisions on patient management that can impact clinical outcomes and patient care. M♥THer expands access and can improve the quality of healthcare for women in regional and rural areas. It reduces burdens for these women, such as travel to receive specialist care, and improve monitoring, timeliness, and communications within their care teams.

Figure 1. Redland Hospital Chronic Disease Team CNC Roisine Warwick

Diversity

In 2014, we validated a mobile health home-care model for cardiac rehabilitation (CR), which used smartphones and the internet to deliver rehabilitation in the patient's home setting to align with their lifestyle. This platform was tested in a randomised clinical trial, becoming the first clinically validated mobile health delivery of CR, improving uptake, adherence, completion rates of participants and with similar health outcomes as that of the traditional centre-based CR programme. Now, in 2018, we want to develop this concept internationally and test how our technology can be validated irrespective of the intrinsic characteristics of the health structure and the culture and language of the users.

To address the objective of this study, we have engaged with four different countries in Europe starting a pilot study in different CR centres of Sweden, Belgium, Netherlands and Poland. Following the results of this study, a randomised clinical trial with the participant sites will be proposed. For this study we are utilising Cardihab as commercial partner for delivering of the cardiac rehab platform, which has been translated into Swedish, Dutch and Polish.

Collaborators:

- Queensland Cerebral Palsy Rehabilitation and Research Centre
- University of Queensland
- CSIRO's Data61
- Metro North Hospital and Health Service (The Prince Charles Hospital; Royal Brisbane and Women's Hospital)
- Metro South Hospital and Health Service (Redland Hospital; Logan Hospital)

Highlights for 2017/18:

- Queensland iAwards 2018
- Mobile-Pulmonary Rehabilitation Platform (m-PR) won three awards: QLD Premier's iAward for Public Sector Innovation; iAward: Public Sector & Government; Merit Award: Research & Development Project of the Year.
- PD-BUDDy: Support for Peritoneal Dialysis Patients won two Merit Awards: Research & Development Project of the Year; Community Service Markets.
- David Ireland was interviewed on ABC Radio discussing AI, mental health and autism spectrum disorder.
- The M♥THer platform was shortlisted as finalist in the International Hospital Federation Awards, with final judging based on a pitch to be delivered on 10 October 2018 during the World Hospital Congress in Brisbane.
- Dr David Ireland and Dr Christian Redd were successful in obtaining funding for early stage projects through Acorn Awards. These projects are 'Bots, Bullies and Autism', and 'A Universal Smart Toy Sensor System for Monitoring Child Development', respectively.
- The Mobile Health Systems team has this year been very engaged in community programs such as the CSIRO's Assets Work Placement for Indigenous students, work experience, and Indigenous cadets.

Project Aims for 2018/19:

- To extend the mobile health platform to incorporate gamification features, to support patients in adhering to goals.
- Secure extensive external funding such as NHMRC; Cerebral Palsy Foundation; Advance Queensland; CRC Northern Australia.
- Complete IGMS study 1 on healthy term infants.
- Infant smart toy development and feasibility study.
- International recognition and collaboration e.g. PD-BUDDy feasibility study in Czech Republic, extending diversity study to Kuwait and China, entering the US market.

MOBILE HEALTH SYSTEMS *(continued)*

PhD Student

Nazli Ghafouryan

Project title: A mobile based multidisciplinary virtual clinic for patients with Acute Coronary Syndromes: A Randomised Controlled Trial, MoTER-ACS project

The aim of this research is to develop a mobile based multidisciplinary virtual clinic based on the existing platform (MoTER) and to investigate the impact of such a clinic on health outcomes and clinical management of patients with Acute Coronary Syndrome (ACS). MoTER is a platform designed for home based monitoring in cardiac rehabilitation using smartphone application and the internet. We customised the MoTER platform for delivering care in patients with ACS as a comprehensive virtual clinic. This study consists of a pre-study survey and a pilot testing and randomised controlled trial. The objective of the pre-study survey was to conduct short structured interviews with small groups of patients (N=30), one session of focus group (N=10) with healthcare professionals and a survey with cardiologists (N=30). The results of the pre-study survey were used to develop a model of care for post-discharge management of ACS patients using the mobile-based application and its web portal.

The post-discharge virtual clinic will be offered to patients as an alternative program to a hospital-based follow-up. The mobile phones are used for providing education and personalised feedback, monitoring physiological data as well as recording patients' self-observations on their health-related behaviour and virtual consultation via audio or video. All the data is synchronised daily to a portal on a remote server. Following testing of the feasibility of the mobile-based intervention in the pilot study (N=54), a randomised control trial will be conducted to evaluate its effectiveness. We hypothesise that the use of mobile-based clinics offer effective post-discharge management tools for both patients and healthcare professionals.

Collaborators: Metro North Hospital and Health Service.

Figure 1. MoTER-ACS platform.

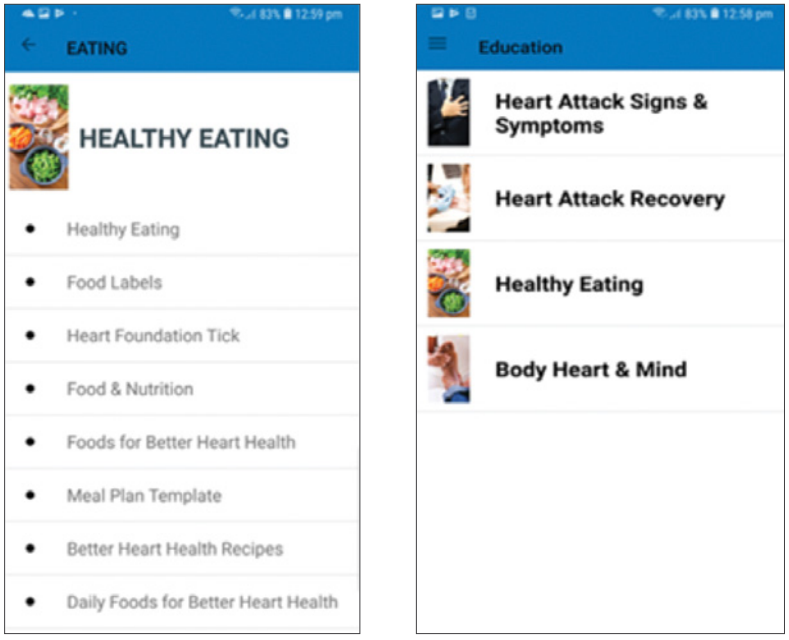


Figure 2. Selected screenshots showing educational materials.

Publications:

- Bashi N., Fatehi F., Fallah M., Walters D., Karunanithi M. Self-management education via mobile health (mHealth): A review of strategies and structures. JMIR Mhealth Uhealth. 2018 Jun 26. doi: 10.2196/10771. [In print]
- Bashi, N., Karunanithi, M., Fatehi, F., Hang Ding, H., Walters, D. Remote Monitoring of Patients with Heart Failure: An Overview of Systematic Reviews. J Med Internet Res; 2017;19(1): e18, doi:10.2196/jmir.6571

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

CSIRO's Smarter Safer Homes (SSH) is a lifestyle-based technology platform developed to enable older people to live longer in their own homes. The platform was designed with consumers to enable self-management, and engage assistance from informal and family carers and clinical services. The platform uniquely features an individualised measure of functional independence, together with health measurements and social isolation, from an unobtrusive, sensor-enabled home.

The SSH platform project is led by the Australian e-Health Research Centre with multidisciplinary collaboration including universities, aged care service providers and local clinicians. It 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.

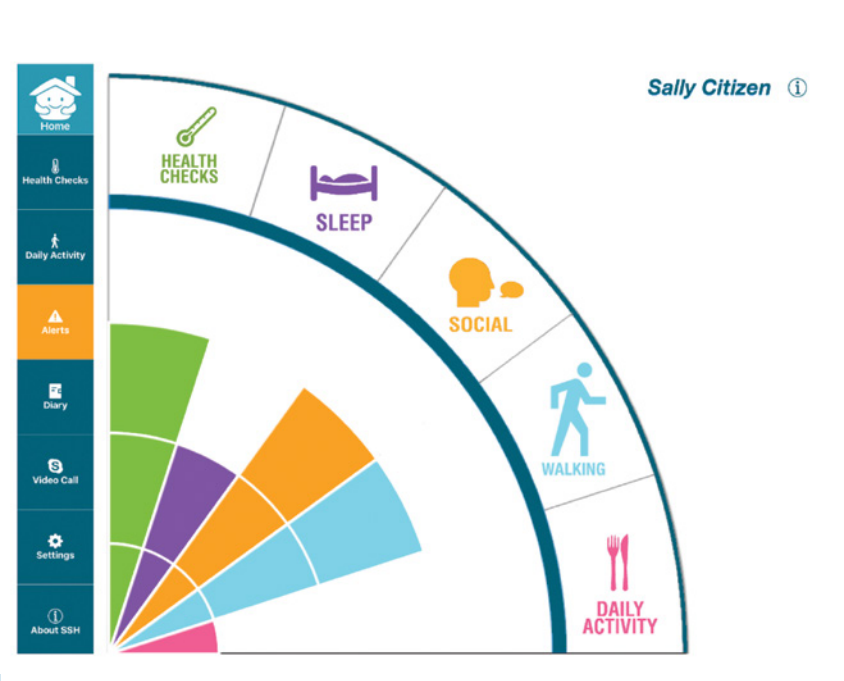


Figure 1. SSH iPad application allows residents to view data derived from the sensors and medical devices.

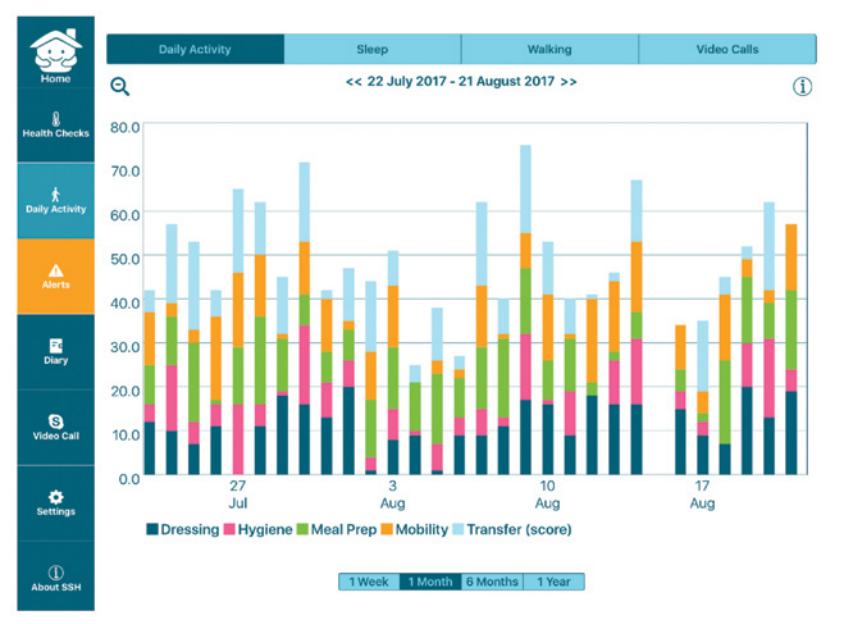


Figure 2. Objective-Activity of Daily Living (OADL) scores of the SSH app to represent everyday health and wellbeing status.

HEALTH INTERNET OF THINGS *(continued)*

Dementia and aged care services: Sustainable, cost effective, smart assisted independent living – Smarter Safer Homes

This project's objective is to use the Smarter Safer Homes platform to revolutionise aged care services delivered to people in their homes, in alignment with consumer directed care, through:

- developing innovative service models appropriate across a range of service and geographical settings which is effective, client-driven and focused.
- enabling a platform that not only tailors to individuals, including those with dementia, basic functional and health needs, but also supports carers' needs.

To achieve this, our Smarter Safer Homes platform will be implemented in metro, regional and rural service settings in four sites that present different geographical challenges and work force issues. This implementation will be facilitated by national, metro, regional, and rural service providers as partners of the consortium. The evaluation will be conducted among 200 participants, aged 65 years and over living at home and supported by home care service providers, through a pragmatic randomised controlled trial which translates evidence into real practice and policy. The outcomes of the trial include changes in quality of life, functional, psychological and cognitive health, carer burden, and cost-effectiveness.

Collaborators:

- Service providers: Anglicare Australia, integratedliving Australia Ltd, All About Living.

Highlights for 2017/18:

- Project initiation meeting with partners and service providers
- Research protocol developed
- Ethics application submitted to CSIRO ethics.
- Work Placement for Indigenous students, work experience, and Indigenous cadets.

Project Aims for 2018/19:

- Ethics approval granted
- Recruit and randomise participants from three to four geographical sites specific to the service providers
- Deployment of 100 homes for intervention group
- Commence randomised controlled trial among 200 participants.

Smarter Safer Homes 100 testbed

This project's objective is to deploy 100 Smarter Safer Homes platforms within Australia to provide an ongoing testbed for AERHC research. Its aims are:

- To collect longitudinal sensor and activity data from real residential homes and construct a database to continuously develop, evaluate and extend the Smarter Safer Homes platform (installation of inconspicuous sensors and devices to monitor the activities of daily living of seniors).
- To foster collaborations with service providers on a well-developed research platform with continuous inputs of large quantity of real data to help shape an economic and sustainable care delivery system that can affect policy-makers and eventually benefit all Australians.

Collaborators:

- integratedliving Australia Ltd.

Highlights for 2017/18:

- Initial 25 homes installed to kick off the project.

Project Aims for 2018/19:

- Research protocol developed
- Ethics approval granted
- Deployment of Smarter Safer Homes platform to trial participants' homes
- Commence the longitudinal pilot study.

Smart home multi-resident activity recognition

The multi-resident activity recognition system (MARS) is designed to support multiple occupants in a smart home with minimum impact on their lifestyles. The system uses Google Home and natural language processing to annotate and label activities, then adopts deep learning techniques to capture and predict activities. We evaluated the system in the house of a family of three, receiving the best state-of-the-art results in activity recognition accuracy.

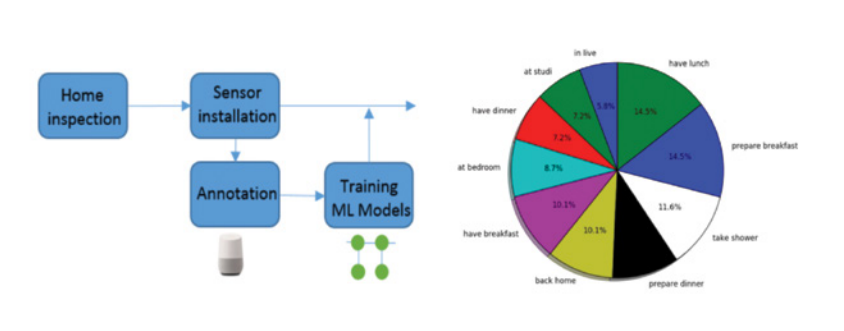


Figure 3. The MARS system and most labelled activities through voice recognition and natural language processing (these are real inputs from residents).

Fall detection in smart home using non-wearable radar sensor

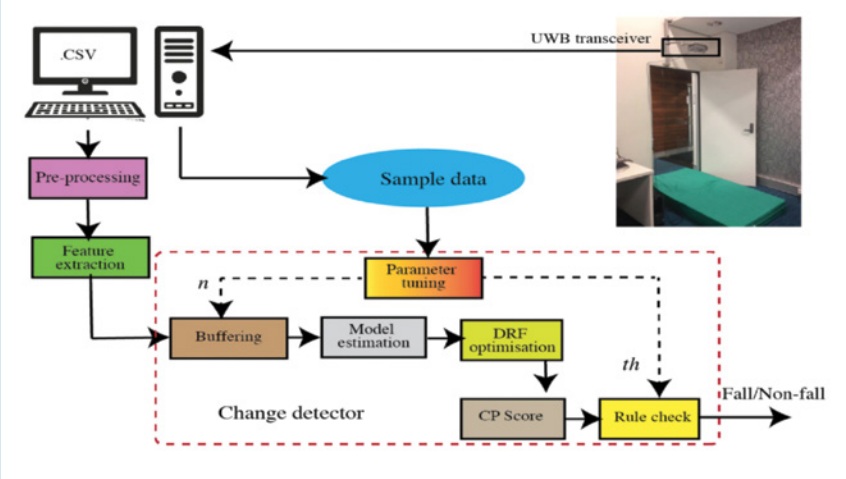


Figure 4. The unsupervised fall detection system.

Falls are one of the major issues which can endanger the lives of older adults. Numerous research studies investigate the use of wearable technologies to detect falls in everyday environments. Although wearable sensor solutions provide good accuracy and sensitivity for fall detection, it may not always be convenient or desirable for older adults to wear a tag or sensor in home environments. This project discusses using non-wearable ultra-wideband (UWB) radar sensors as a practical, environmental fall detection solution in home settings.

ID sensor for human identification

This project achieves the goal of human identification through properly processing and analysing the received signals from the UWB radar installed in indoor environments. We employ unsupervised feature learning techniques to automatically learn local, discriminative features that can incorporate intra-class variations of the same identity, and yet reflect differences in distinguishing different human identities.

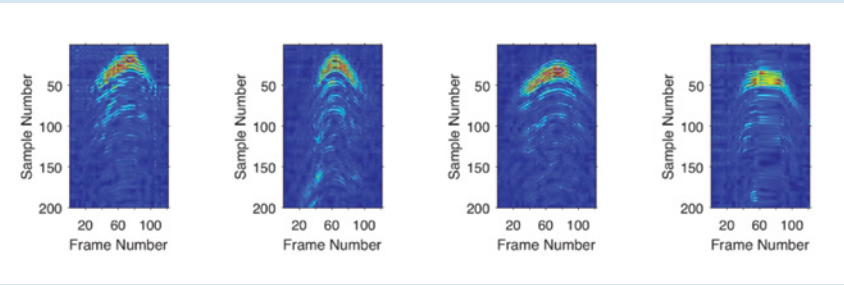


Figure 5. Scattered UWB signals of various people with individual walking styles.

HEALTH INTERNET OF THINGS *(continued)*

Immersive augmented reality: remote clinical consultation

Using emerging augmented reality (AR) technologies on mobile devices, this project developed an AR clinical consultation system through an iPad and a Kinect sensor. This low-cost and highly portable AR consultation system can be easily deployed in a patient's home and clinician's office with minimum footprints on their normal daily activities. It not only provides a great and immersive telehealth consultation experience for patients, but also can help clinicians to easily explain complex medical conditions to patients through visualisation and simulation.

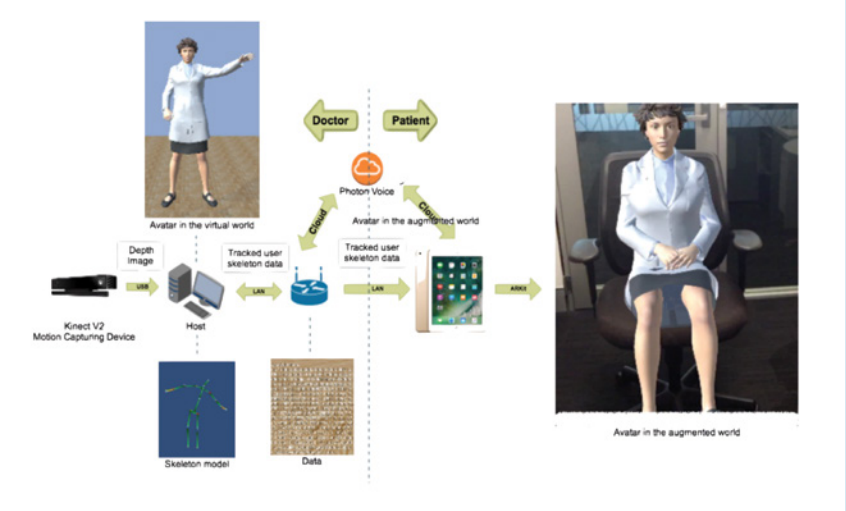


Figure 6. AR Doctor system structure.

HEALTH SERVICES

Collaborators:

- Data 61/Energy Flagship, CSIRO
- Aged care service providers
- QIMR Berghofer Medical Research Institute
- Washing State University, USA
- City University, UK
- University of Twente, Netherlands
- Shanxi University, China
- Academy of Science, China

Team highlights for 2017/18:

- A large randomised control trial supported by Department of Health is about to start in Queensland.
- Two smart home trials supported by CSIRO and the local community are about to start in Brisbane and Geelong.
- A novel ID sensor prototype is being developed at CSIRO.
- CSIRO signed a Memorandum of Understanding (MOU) with China Telecom Shanghai on research collaboration of aged care and smart homes.

Team aims for 2018/19:

- Conduct a large randomised control trial evaluating how information provided by SSH can improve quality of care.
- Conduct two smart home trials in Brisbane and Geelong to investigate how seniors can use information provided by SSH to improve their quality of life.
- Conduct a smart sensor trial in the PISA study to investigate correlations between sleep patterns and early symptoms of dementia.
- Submit patent application of the novel ID sensor.
- Extend SSH in the Hong Kong market.

Figure 7. The MOU signing ceremony of CSIRO and China Telecom.

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 2017/18 the team engaged primarily with industry partners to deliver excellence in science.

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, and so they often fail to implement an effective rehabilitation plan.

The Australian eHealth Research Centre, 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 gaps that exist between clinicians and patients. We have designed and developed Activate TKR, an orthopaedic support technology platform, comprised of a mobile 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 their 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 an 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 randomised control trial began in November 2016 to evaluate the technology platform. It is being conducted at multiple sites in a number of states in Australia, with about 150 patients undergoing TKR surgery. Participants are randomised to either a control group or the intervention group, with both receiving usual care as provided by their surgeon or hospital. The intervention group receives the app and wearable activity tracker in addition to usual care. This trial is investigating the clinical and behavioural efficacy of the app, and the impact of the technology platform components in terms of service satisfaction, acceptance, and economic benefits of the provision of digital services. The trial is running for a period of 13 months for each patient.

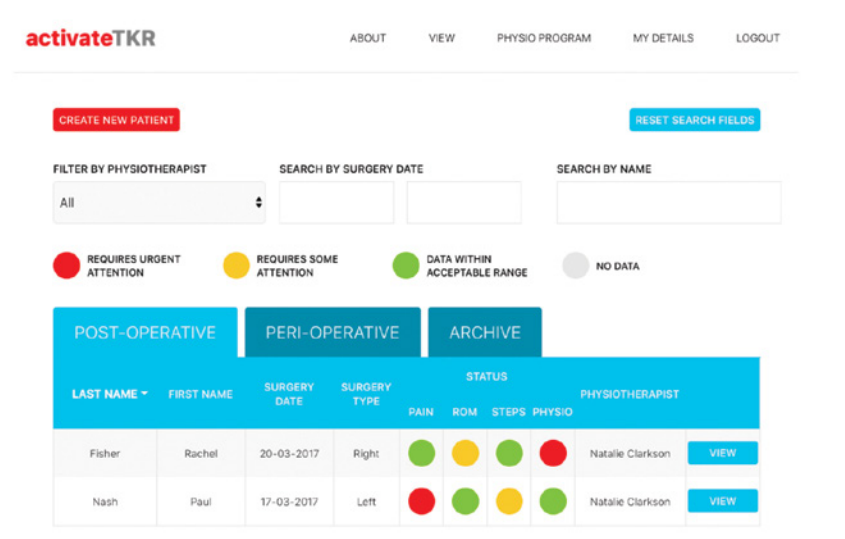


Figure 1. Activate TKR clinical portal. The web portal allows clinicians (e.g. surgeons, physiotherapists) to view patient data and configure exercise programs for individual patients.

DIGITAL HEALTH ENGAGEMENT *(continued)*

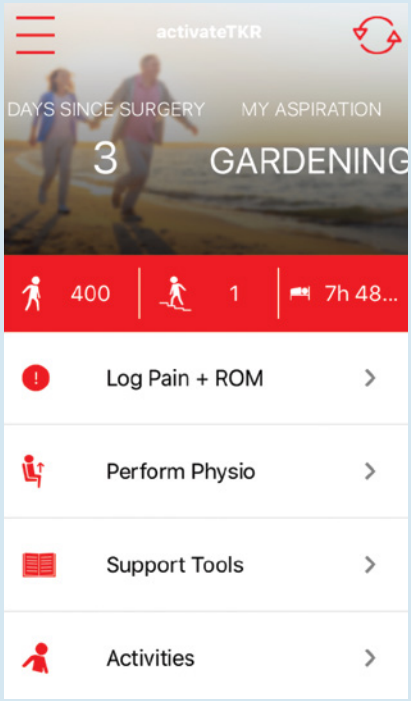


Figure 2. Activate TKR app: Home screen.

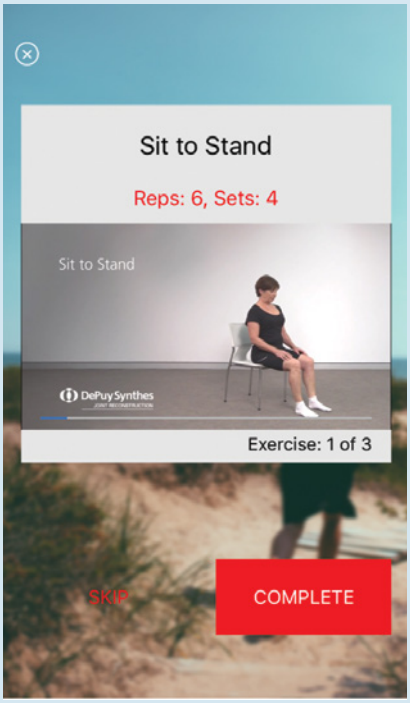


Figure 3. Activate TKR app: Physio Coach screen. Exercise programs are configured by physiotherapists from a library of videos typically used for TKR rehabilitation.

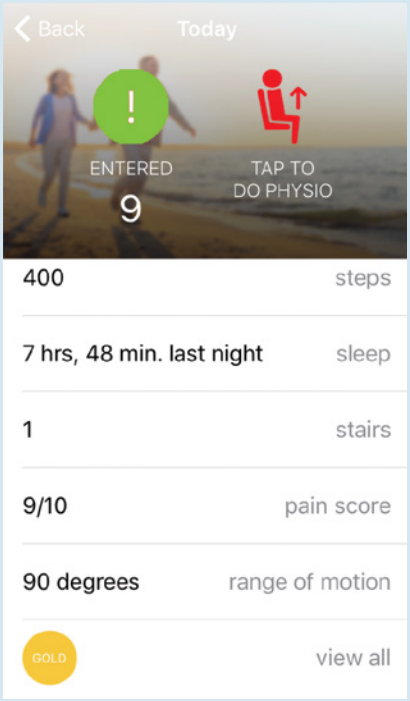


Figure 4. Activate TKR app: Today screen. Shows data from the activity tracker (daily step, stairs, and sleep) and self-reports (pain and knee ROM).

HEALTH SERVICES

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, with the potential to achieve the same clinical outcomes as normal business-as-usual care.

Impact

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

Outputs to date

- Development of the technology platform (patient app and clinical portal)
- Randomised control trial launched in November 2016; kicked-off with four trial sites in NSW and SA
- First media release in March 2017
- Showcased project together with Johnson & Johnson Medical Devices at the Bennelong Innovation Summit at Parliament House in 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
- TKR user needs paper published in JMIR: van Kasteren Y, Freyne J, Hussain MS Total Knee Replacement and the Effect of Technology on Cocreation for Improved Outcomes and Delivery: Qualitative Multi-Stakeholder Study J Med Internet Res 2018;20(3):e95.

Outputs expected in 2018/19

- Data extraction and preliminary data analysis (quantitative)
- Qualitative research findings
- Interim outcomes workshop with Johnson & Johnson.

Supporting men's health

For many older men, there's a defining code around being a man. It's about being in control of any given situation, of not being seen as weak or emotional, about having a healthy sexual appetite. Prostate cancer erodes the very core of this code, through incontinence, fear and depression, and erectile dysfunction. In Australia, it accounts for almost a quarter (23.1%) of all new cancer diagnoses, is the second leading cause of all male cancer deaths and carries the highest suicide risk of all cancers with the greatest risk in the first year post diagnosis. As there is a relatively high five-year survival rate for localised prostate cancer (94%), the number of men living with the psychosocial ramifications of the disease is correspondingly high.

The prevalence of prostate cancer, the impact of symptoms on mental wellbeing and the increase in suicide ideation indicate an urgent need for a greater understanding of how psychological services can support men on their prostate cancer journey. Movember Foundation has established and funded the TrueNTH network, a prostate cancer survivorship initiative which is a collaborative effort among various global organisations, of which CSIRO is a member. Through the TrueNTH program, Movember Foundation aims to develop and implement an agreed set of interventions supported by an innovative online technology platform targeted at improving the lives of men living with prostate cancer in Australia, UK, Canada, the USA and New Zealand. The implementation of this online platform is facilitated by a care co-ordinator working with the healthcare team, the individual and the Movember Foundation team, to ensure men receive a high level of integrated care and enhanced health outcomes. In addition, the Movember Foundation provides support and counselling services to men with prostate cancer and their significant others. This study was undertaken to determine what needs could be met with psychological support services over the course of the prostate cancer journey, and how they could be delivered to facilitate the greatest uptake.

Outcomes

- Focus groups were conducted with men who had participated in Movember's TrueNth Prostate cancer program
- Men spoke candidly about the psychological ramifications of their prostate cancer journey
- A number of potential strategies were identified to enhance the provision of psychological services.

Impact

- Understanding the trigger points for men allows Movember to provide enhanced services when they are most required.

Outputs to date

- Bradford, Dana. But I'm Healthy: psychological stressors of prostate cancer and potential strategies for support services. CSIRO: 2018. EP18233
- Bradford, Dana. Improving care for men with prostate cancer. CSIRO: 2017. EP176237. https://doi.org/10.4225/08/59b6dd593f5ea
- Bradford, Dana. Sunshine Coast TrueNTH Focus Groups: Improving engagement and care experience of men living with prostate cancer. CSIRO: 2017. EP175572.

CALD Assist: translation support expanded for nursing workforce

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 (CALD) backgrounds 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 2017, CALD Assist was expanded to meet the specific needs of the nursing workforce. The inclusion of nursing-specific material enables nursing staff to better meet the daily care needs of their CALD patients, reducing variance in practice, and providing a timely and positive patient experience.

DIGITAL HEALTH ENGAGEMENT *(continued)*

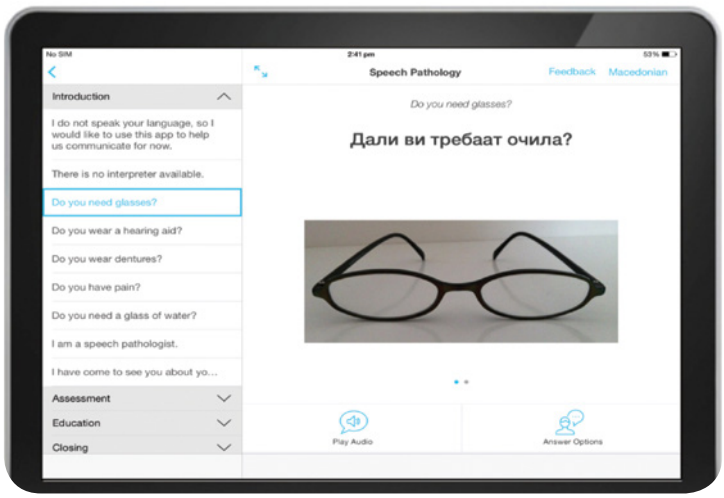


Figure 5. CALD Assist app: upon selection of an individual phrase, translated text and appropriate image is displayed on the screen.

HEALTH SERVICES

Outcomes

- A new app was developed that includes nursing-specific content
- An 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 4 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'
- 2018 iAwards Victoria Merit Certificate (Public Sector & Government)
- 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. JMIR Formative Research, 2 (1), 2018.
- D. Silvera-Tawil, C. Pocock, D. Bradford, K. Harap, S. Brinkmann. CALD Assist – Nursing: Improving Patient Communication in the Absence of Interpreters. Journal of Clinical Nursing, 2018.

Working with the Autism community

Working with Autism Spectrum Australia (ASPECT), the Autism Hub, Autism Academy for Software Quality Assurance and the Autism CRC, we have developed a body of work with and for the wider autism community. The work builds on previous work in social robotics and conversation agents. Over the next year we will harness the knowledge gained from these projects to implement robotics and conversation agents developed with and for people with autism and their wider community to improve social interaction and verbal participation in early school-aged children and facilitate participation in tertiary education in young adults.

Increasingly technology is being incorporated into the curricula with mobile devices in almost all classrooms across Australia. The implementation of these technologies facilitates skill acquisition across a range of learning styles and will have far reaching benefits for students in their future careers. Students on the autism spectrum tend to show a keen interest in, and respond positively to, technology including chat-bots, tablet-based communication devices, and robots. These technologies open the door towards new approaches to education and learning. We are working with the wider autism community to understand the roles that innovative technology can play during successive stages of childhood development in the home, in the classroom, and during extracurricular activities, with a focus on social participation. In collaboration with the Autism Hub, we conducted a think tank to explore the directions for the future of technology-supported education to create better outcomes for students on the spectrum and the wider autism community.

Outputs to date

- Bradford, Dana; Ireland, David; Silvera, David; Farr-Wharton, Geremy; Xiao, Yi; Cooper, Anabelle. Teachnology: Tech reshaping the face of education in the Autism community. A report of the Autism Technology Think Tank. CSIRO: 2018. EP183925.

Socially assistive robots to support children on the autism spectrum

For children on the autism spectrum, social interaction and communication can be significant challenges. With about 83 per cent of the 164,000 Australians living with autism spectrum disorder under 25 years old, additional support is often needed to help these children gain the skills necessary to navigate the world independently. Digital technology is often used as a supplement to traditional education, as it provides an environment that allows for self-paced learning and immediate feedback. While considered generally safe and effective, there are concerns that a child who is taught to communicate using interactive technology may become dependent on the virtual world and its rewards, while interpersonal skills are sacrificed or not generalised to real world settings.

We have developed interactive modules to support therapy and education for children with autism and intellectual disability. We are trialling four different social robots: NAO, KASPAR (from the University of Hertfordshire), PARO and ROBOTIS OP3, including trials in partnership with the University of New South Wales, Autism Spectrum Australia (ASPECT) and Murray Bridge High School in South Australia. Social robots are novel, animated and appear to be autonomous, setting themselves apart from other technology, and their physical, 3D presence provides a compromise between the virtual world and the real world. Robots can provide complex behaviour patterns, while appearing much less intimidating than humans. They can also deliver predictable behaviours and repetitive feedback, and they don't get angry, tired or stressed. More than anything, robots provide a new environment where it is fun to learn. To support our trials, we have developed an app and compatible platform that can be used as a user interface to control the social robots used during our trials.

Outcomes

- Our trials are ongoing, but results so far suggest that social robots are effective tools to assist during therapy and education of children on the spectrum
- Participants are particularly enthusiastic about humanoid robots.
- Developed Max, an Android-based user interface to facilitate the use of robots in therapy and education.

Impact

- Observed improvements in social interaction, communication, participation and self esteem
- Benefits observed in students when they interacted with robots in the classroom are transferring to interpersonal interactions.

Outputs to date from our robotics work

- Bruck, S., Silvera-Tawil, D., Bradford, D. 'NAO Robot's new role - teaching in the classroom, Autism in Education.
- Silvera-Tawil D., and C. Roberts-Yates, "Socially-assistive robots to enhance learning for secondary students with intellectual disabilities and autism," in *IEEE Robots Man Systems Interactions Conference*, 2018.
- Silvera-Tawil, D., C. Roberts-Yates and D. Bradford, "Talk to me: The role of human-robot interaction in improving verbal communication skills in students with Autism or Intellectual Disability," in *IEEE Robots Man Systems Interactions Conference*, 2018.

Figure 6. The humanoid robot NAO and the robot seal PARO at the Murray Bridge High School Disability Unit.

DIGITAL HEALTH ENGAGEMENT *(continued)*

Chat-bots to support people on the autism spectrum

For several years the development of an artificially intelligent, chat-bot technology has been underway. Similar to Apple's Siri and Amazon's Alexa, the chat-bot technology Harlie is being developed to support people with difficulties in speech, language and social interaction that are often seen in autism spectrum disorder, dementia and Parkinson's disease.

Figure 7. An example of a conversation to identify if a child perceives they are being bullied.

ON LaunchCamp: commercially testing chat-bots with the autism community

In a two-day ON LaunchCamp program, we had the opportunity to understand the commercial prospects for our chat-bot. We interviewed seven experts who engage with children on the autism spectrum, and their insights were captured within two key problem statements, (I) *for clinicians and teachers, monitoring development is challenging, particularly outside of a clinical or classroom setting and* (II) *parents and carers need tools tailored to their child's context that encourage quality family time and inclusion.* These findings have helped us align the strategic direction for the chat-bot work, enabling direct benefits for those who need this technology the most: individuals on the spectrum, and their families and carers.

'Hear' to help: striving for greater participation and wellbeing through tailored chat-bot technology

In collaboration with Curtin University, Autism Academy for Software Quality Assurance (AASQA), the Queensland Department of Education and Training, and Autism Spectrum Australia, this project will work with people on the autism spectrum, support service providers and peer mentoring services to determine how chat-bot technology can support education participation and education-related health and wellbeing (study-related stress, looking after yourself on campus). The ultimate aim of the project is to create a chat-bot 'brain' that can deliver useful multi-modal resources to support greater participation and wellbeing of people on the autism spectrum in higher education.

Figure 8. A sample dialogue between Harlie and a person with autism. Green rectangles designate dialog generated from Harlie, blue rectangles designate responses from the user, grey rectangles indicate pauses in the timeline.

Bots, bullies and autism

Bullying is a prevalent societal problem which disproportionately impacts special needs children, particularly those with autism spectrum disorder (ASD). Children with ASD can find social interaction challenging and frustrating, which can lead to social disengagement and result in social isolation. Identifying bullying in children with ASD is hampered by the fact that children with ASD may have limited speech and struggle to communicate their experiences. In these cases, being bullied can compound social interaction difficulties and impede communication development. Sadly, many children on the autism spectrum who wish to make new friends have an even higher chance of being bullied. It can be strongly argued there needs to be an ongoing and early implementation of programs to build lifelong resilience against bullying behaviour.

In light of this, seed funding from CSIRO's Health and Biosecurity business unit was provided to develop a specific bullying module for the Harlie chat-bot. Harlie's bullying module is under development and will be co-designed by the autism community. A number of key stakeholders have expressed interest in being involved in the evolution of this module for children, young adults in tertiary education and young employed adults with autism. Early content includes an example interaction of the beginning of a conversation involving identifying whether the user is being bullied. Images are embedded into the responses to help guide the meaning of the conversation.

Chat-bots for people on the autism spectrum who may be non-verbal

A significant portion of individuals on the autism spectrum are at some point categorised non-verbal. An individual may later become verbal, however, many remain non-verbal for life. This does not mean they cannot communicate, but rather require other means. With the ubiquitous use of mobile technologies, software-based assistive technologies have become increasingly available. In the case of augmentative and alternative communication (AAC) systems, the introduction of tablets was revolutionary due to their relatively low cost, portability, and resulting increase in social acceptance of AAC.

We have been developing a AAC app with an embedded chat-bot, herein referred to as Alex. Alex is designed for use by people on the autism spectrum. Programming Alex does not need any specialist skills and is designed for speech therapists, parents and other key stakeholders to contribute what they deem relevant. The user is able to practice spontaneous conversation with Alex in a safe, non-judgemental environment. The long-term aim of this research is to examine the validity of intervention based on artificial intelligence that augments conventional therapy.

Outputs to date

- Farr-Wharton, Geremy; Ireland, David; Bradford, Dana. Social Fringe Dwellers: Designing Chat Bots as Bridges for Children with ASD. In: OzCHI 2017; November 28th to December 1st; Brisbane, Australia. SIGCHI; 2017.
- Bradford, Dana; Ireland, David; Wiles, Janet. Talk to me: The Chat-bot as a speech pathology monitoring tool. In: Health by Tech; 1 June 2018; University of Twente. University of Twente; 2018.
- Ireland, D. Farr-Wharton, G and Bradford, D. Social Fringe Dwellers: Can chat-bots combat bullies to improve participation for children with autism? Journal of Community Informatics, Special Issue (In press).
- A. Cooper and D. Ireland, 'Designing a Chat-Bot for Non-Verbal Children on the Autism Spectrum', Studies in health technology and informatics. Volume 252 pp. 63-68, Health Informatics Conference (HIC), 2018

Collaborators:

- Johnson and Johnson Medical AU
- The Project Factory
- Movember Foundation
- Melbourne Genomics Health Alliance
- Western Health
- Autism Spectrum Australia
- Autism Hub
- Autism CRC
- Curtin University
- University of New South Wales
- Murray Bridge High School.

Project Aims for 2018/19:

- Finalise clinical trial for Activate TKR program
- Roll out evidence-based implementation of robots into Queensland schools
- Develop and deploy chat-bot technology to facilitate participation in tertiary education and offer bullying strategies for children on the autism spectrum.

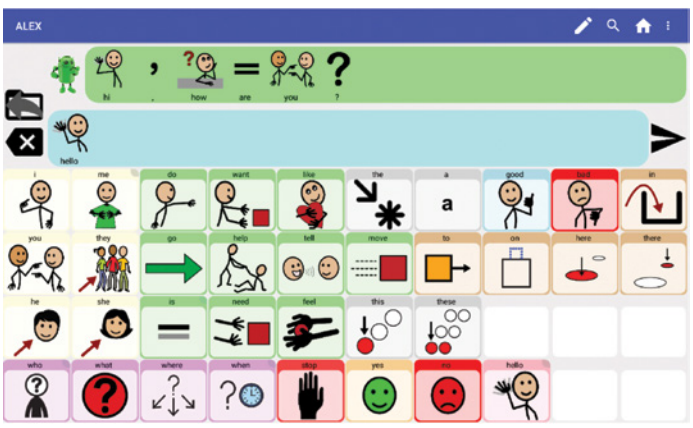


Figure 9. Example of conversation using AAC. The blue box holds the user input, and the green box shows Alex's response.

Student or postdoc highlight

Yi Xiao initially joined CSIRO as a Vacation Student from the University of New South Wales. During this time, she developed an Android-based user interface to facilitate the use of robots in therapy and education. She has a strong technical background in computer science with a focus in robotics, artificial intelligence and machine learning. She is now doing her Bachelor of Honours research project with the Digital Health Engagement team around the application of social robotics for autism and intellectual disability.

AUSTRALIAN TELE-HEALTH RESEARCH AND DEVELOPMENT GROUP

Director: Yogi Kanagasingam

The Australian Telehealth Research and Development Group (ATRDG) was established by CSIRO in conjunction with the Department of Health Western Australia (DoH) in June 2012.

Its purpose was to develop a strong digital health and telehealth research and development program 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 ATRDG aims to align and work with service providers and other stakeholders and assist them in developing systems and technologies that result in better service delivery solutions and preventative health applications.

The ATRDG strives to be a world-leading telehealth research and development group, and aims to transform the way health services are delivered. 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 the state.

The group has three key research areas:

Remote delivery of clinical services

This stream will focus on the development and evaluation of remote delivery of clinical services to metro, rural and isolated populations. Using the Remote-I system or Android-based technology, patient images will be forwarded through existing internet services to specialist clinicians at major centres for evaluation. Applications in this stream include ophthalmology eye screening for aged care facilities and dentistry (a rural pilot study using an Android-based imaging system), burns (using advanced imaging techniques to grade wounds) and emergency medicine (development of an emergency telehealth service in collaboration with WACHS), amongst others.

Chronic disease management

This stream will include research on how telehealth can be used to assist in the management of complex and chronic conditions in the home. An existing trial of automated data collection and alerts for chronic obstructive pulmonary disease patients will be expanded. Clinical decision support and management of patients with chronic health conditions in their homes using mobile technology will be evaluated, mainly those living in rural and remote locations.

Disease diagnosis and screening technologies

This stream will pursue research around Alzheimer's disease, hypertension, H.Pylori and stroke. The Alzheimer's disease study is designed to evaluate the use of curcumin (derived from turmeric) as a diagnostic marker which can be detected using high-resolution retinal imaging. In the stroke study, data from patients after they experience a first stroke are interrogated with the aim of identifying markers that are predictive of a second stroke, thereby providing a window for preventive interventions.

Highlights:

1. First to deploy artificial intelligence-based grading system for diabetic retinopathy and other eye diseases into a real-world clinical setup (Midland GP Superclinic)
2. Developed a automated retinal imaging platform called VASP to measure ocular biomarkers
3. Developed and validated a mobile app called MICE, Medical Image Communication and Exchange, at the Burns Unit at Fiona Stanley Hospital. This is expected to be rolled out into hospitals in South Metro Health Service
4. Tele-dentistry system has been developed using mobile phones for imaging and evaluated in WA. One PhD (Mohamed Estai who received Dean's Award for his PhD on tele-dentistry) has published over 10 papers around this study
5. Attracted major funding from NeuroVision Imaging to conduct further clinical trials around Alzheimer's disease and eye imaging.

PROJECTS

Artificial intelligence-based grading and diagnosis of diabetic retinopathy at GP clinics

The Australian Tele-Health Research and Development Group has obtained a Diabetes Research WA grant to validate our smart eye-screening system for early detection of the sight-threatening condition, diabetic retinopathy (DR). The aim of the project is to build and validate a novel artificial intelligence-based disease grading and clinical decision support system for screening and telemedicine-based diagnosis of DR. The proposed system will be integrated with fundus cameras, with real-time image quality control software for colour fundus images to produce sensitivity and specificity over 90% for DR grading.

In the past year, we have completed the DR screening model training process and improved the performance of the Quality Assessment model and DR grading model. We have developed a telemedicine system for the DR screening and built all components into one integrated system, which is suitable for GP clinics. Our research team worked closely with clinicians from the Midland GP Superclinic, and integrated the AI and telemedicine system with GPs' patient management system. We screened over 200 patients and two of them were graded as having severe disease and referred to ophthalmologists.

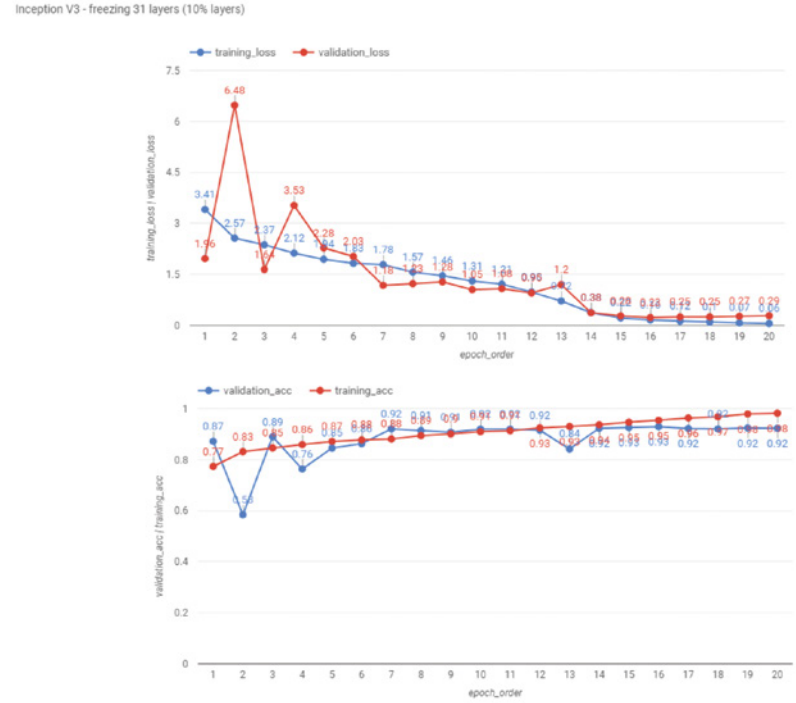
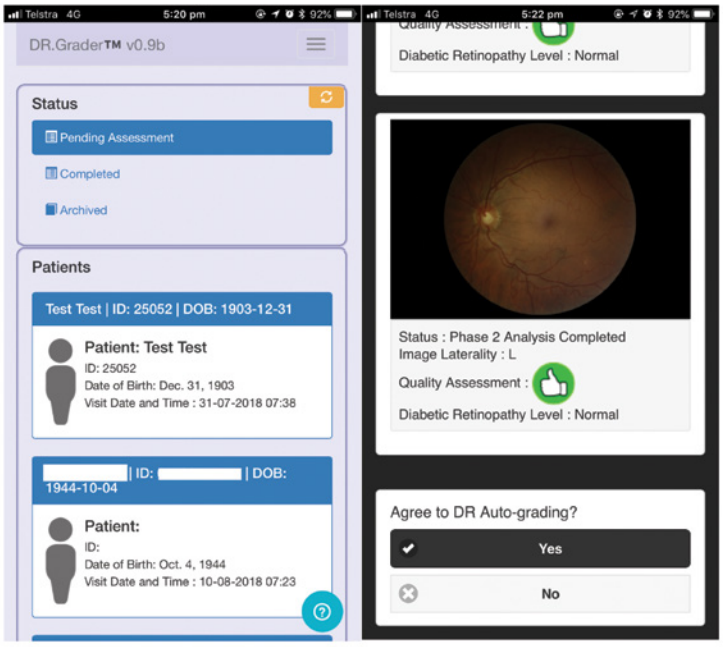


Figure 1: One example of DR grading performance on training and validation datasets.



REMOTE DELIVERY OF CLINICAL SERVICES *(continued)*

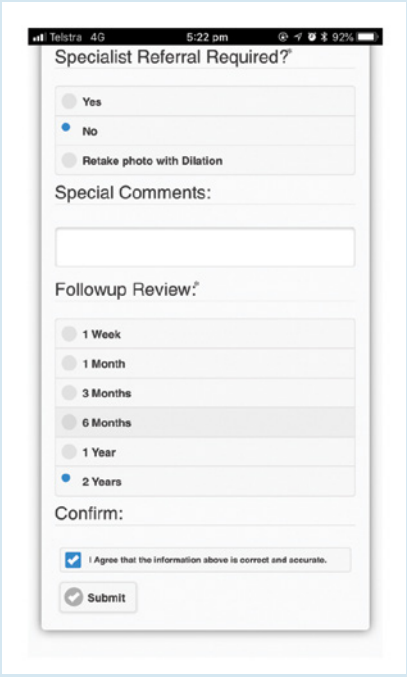


Figure 2: Smart phone application of the DR screening system.

Collaborators:

- GP Superclinic, Midland
- TeleMedC LLC.

Project highlights for 2017/18:

- Completed the system development
- Participated in "Explore Diabetes" Expo event organised by Diabetes Research WA and showcased the technology to audiences
- Licensed the system to TeleMedC, and through the company rolled out the system in Singapore by collaborating with National University Hospital Singapore
- WAiTTA Incite Awards 2018 - Winner of "Most Innovative Enabler in Health Care".

Project aims for 2018/19:

- Complete clinical trial at GP Superclinic, Midland
- Target screening at least 200 more patients
- Data analysis on clinical data
- Implement the system at Royal Perth Hospital and REACH Clinic.

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 a mobile device to a burns specialist. By 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 users.

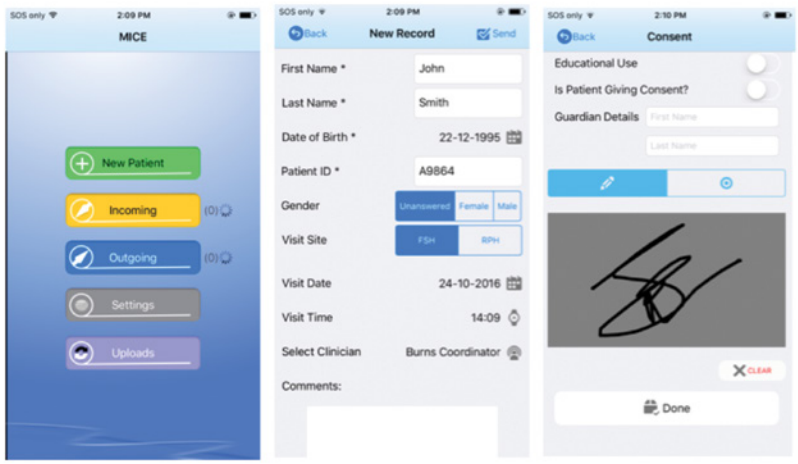


Figure 3: MICE app screenshots.

Highlights of MICE Trial (Apr 2017-June 2017)

- 30 users, ranging from iPhone 5 to 7
- Four 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 identify the pictured body part, to assist in searchable clinical images
- Engagement: Engaged with many other hospital departments (such as plastics, orthopedics, business intelligent unit, security, IT)

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 2017/18:

- 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 completed by the specialists and junior doctors at Fiona Stanley Hospital and the hospital executive committee is supporting the project for statewide rollout.

Project aims for 2018/19:

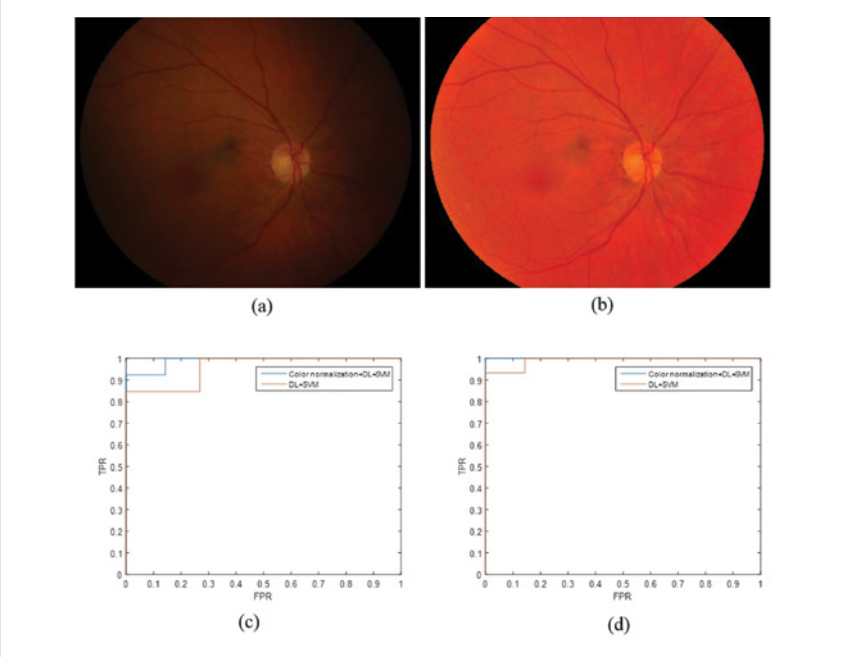
- Roll out the diabetic retinopathy grading system to other clinics
- Publish trial outcomes in high impact journals
- Apply for funding to expand MICE app to other medical applications (e.g. wounds, dermatology)
- License MICE to WA Health for use at different hospitals
- Further develop MICE on other mobile platforms and disease conditions
- Evaluate data from various clinical trials using VASP (hypertension, stroke, Alzheimer's disease).

Age-related macular degeneration (AMD) grading

Age-related macular degeneration (AMD) is the leading cause of vision loss in people over the age of 50 years in developed countries, and this number is expected to increase by 12- to 20-fold over 10 years due to ageing populations. Therefore, identifying people with early signs of the disease and then determining their risk based upon their fundus characteristics is important when considering both the social and economic impacts of AMD. Existing AMD grading systems require a human grader's subjective manual interaction, which is time consuming and can difficult to maintain intra- or inter-rater agreement. Aiming to achieve population-based disease screening, ATRDG aimed to develop a clinical decision system which can automatically perform AMD "disease/no disease" grading.

We have developed an automated method for the "disease/no-disease" grading of AMD by applying deep learning techniques. The method includes two major steps: 1) image illumination correction; 2) deep learning-based disease classification. Two publicly available AMD datasets (ARIA and STARE) were used for the experiment along with a private dataset. In the preliminary validation, the proposed system achieved an overall accuracy of 99.4% on the test dataset. The proposed colour normalisation improves the overall accuracy of the deep learning framework by 16%.

REMOTE DELIVERY OF CLINICAL SERVICES



a) Colour fundus photograph prior to normalisation; **b)** colour-normalised photograph; **c)** ROC curves for disease/no-disease grading when deep features are learnt at the last convolutional layer; **d)** ROC curves for disease/no-disease grading when deep features are learnt at the first fully connected layer.

Figure 4: Performance of deep learning model for AMD disease grading.

Postdoctoral fellow

Sajib Saha, PhD

Dr Sajib Kumar Saha is a postdoctoral fellow at the CSIRO Australian e-Health Research Centre 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-based 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 colour normalisation method to eliminate intersubjective colour 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), 'Biomedical Signal Processing and Control' (IF: 2.7).

Dr Saha has led 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. Presently, Dr Saha is working at UCLA for six months on applying deep learning methods for detecting early AMD pathologies from OCT images.

Dr Saha acts as a reviewer for many journals, 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 the Journal of Cultural Heritage. He is an editorial member of the journal titled EC Ophthalmology.

CHRONIC DISEASE MANAGEMENT

The Australian Tele-Health Research Development Group (ATRDG) is also interested in delivering management of complex and chronic conditions in the home using telehealth, particularly in Western Australia. This is undertaken in collaboration with the Mobile Health team to extend mobile health trials currently underway to Western Australian arms. One of the initiatives 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). We are exploring additional funding to continue a large scale multi-centre study.

We have also explored using the cardiac rehab system in remote and rural WA in collaboration with the West Australian Centre for Rural Health of the University of Western Australia, and have applied for NHMRC partnership funding for this project.

Collaborators:

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

Project aims for 2018/19:

- 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 plan to submit a grant proposal for a multi-centre study to NHMRC.

DISEASE DIAGNOSIS AND SCREENING TECHNOLOGIES

In this stream of work we are exploring ways to develop biomarkers to screen and diagnose diseases early, so appropriate treatment and surgery can be provided in a timely manner. Our focus has been studying the changes related to vascular parameters from the retina and the anterior segment in relation to various disease development such as stroke, hypertension, Alzheimer's disease, heart disease and mental disorders. All data collection has been carried out in partnership with various Perth clinics.

Ocular biomarkers for Alzheimer's disease

We have 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 the disease.

The trial involves two visits by volunteers to the Australian Alzheimer's Research Foundation, where they have their eyes tested using retinal image fluorescence photography. Between appointments, volunteers take a curcumin supplement, which is a natural ingredient used in cooking and 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, we will have the makings of a screening tool for Alzheimer's. It may enable us to identify early 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
- N=250 New Eidon/Retia device.

Preliminary results have been presented at the Alzheimer's Association International Conference, the International Conference on Alzheimer's and Parkinson's diseases, and the Association for Research in Vision and Ophthalmology Annual Meeting. 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 used 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=250 completed).

We have also recently published papers in the Journal of Ophthalmology and Current Alzheimer Research reporting on changes in the way the pupil responds to light and the optical properties of retinal vessels in Alzheimer's disease. These ocular changes are 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.

Our new Cloud Based Multi-modality Intelligent Retinal Vessel AnalysiS Platform (VASP) has been patented and utilised to search for further retinal markers of Alzheimer's.

Retinal imaging in resistant hypertension

This is a collaborative research project between Royal Perth Hospital Hypertension Clinic and the ATRDG. The major aim of the project is to identify novel retinal imaging markers that may closely correlate with best practice blood pressure measurements and other signs of hypertensive organ damage in these high risk patients. Such a retinal marker or set of markers may serve as an integral summation of the blood pressure burden a patient has been exposed to at any given time and provide a simple, non-invasive and inexpensive test for accurate prediction of cardiovascular risk in these patients. Furthermore, longitudinal assessment and the corresponding changes in retinal markers may serve as an indicator of adequate/inadequate anti-hypertensive treatment.

Data collection has been completed for N=150 participants.

Additionally, another trial on the effects of Tropicamide pupil dilating eye drops on the retinal vasculature has been completed (N=41). Preliminary analysis reveals some changes and a publication is in preparation.

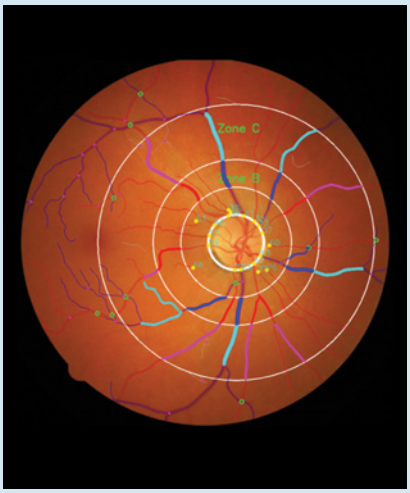


Figure 1: Retinal image analysis software interface - VASP.

Retinal biomarkers 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. 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 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.

With the RPH Stroke ward closing, the ATRDG is now pursuing contacts at Sir Charles Gairdner Hospital and the Perron Institute for Neurodegenerative Diseases to develop a new stroke research program.

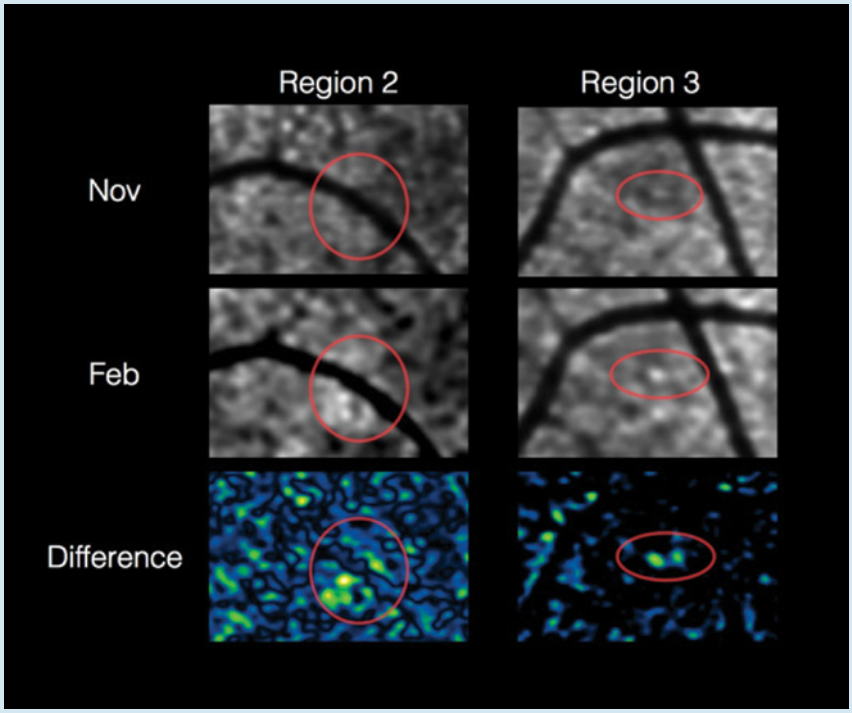


Figure 2: Retinal fluorescence image - identifying AD plaques in retina and how they increase over time.

Retinal imaging and nutrition

This is a collaborative research project between CSIRO Food and Nutrition and ATRDG. Retinal imaging is being conducted in the Adelaide SAHMRI centre. Recent findings include lower retinal AVR, previously reported to be predictive of future stroke or CVD, is also associated with lower plasma carotenoid concentration. Simple, non-invasive retinal photography may have utility both in assessing stroke/CVD risk and monitoring the vascular impact of dietary intervention to increase blood carotenoids. Additionally, in malnourished populations, this technique offers potential to track carotenoid status as part of interventions aimed to reduce vitamin A deficiency. A publication is in preparation.

Retinal imaging to detect H.Pylori related inflammation

This is a collaborative research project between Hollywood Private Hospital (HPH) Nobel prize winner Professor Barry Marshall and ATRDG. Retinal and anterior eye image collection has begun at HPH investigating ocular signs of inflammation co-morbid with H.Pylori infection, which results in increased incidence of glaucoma. This is a pilot study, with five patients so far, and it will continue until we reach 20 patients.

DISEASE DIAGNOSIS AND SCREENING TECHNOLOGIES *(continued)*

VASP: Vessel Analysis Software Program

VASP is a cloud-based Vessel Analysis Software Program developed in 2016/17. VASP was developed to fill the gap of disease risk analysis from the eye, can measure more than 80 vascular parameters and enables retinal biomarker research. The findings from research using VASP enables disease diagnosis and preventative management. There is a provisional patent filled for VAS, and it was awarded at the WAITTA iAwards (a Merit award under the &D category).

VASP is supported by the state-of-the-art performance algorithms, and has user-intuitive web visualisation and user interactions. Data is stored in a central database, and novel graph-based vessel topology structures are implemented. VASP is the first system deployed into real-world clinics to assist disease risk analysis. Some of the research techniques include deep learning, machine learning, image processing, computer vision and graph theory. VASP generates more than 80 retinal parameters from each retinal image, including central retinal equivalent calibers, A/V width ratio, fractal dimension, lacunarity, tortuosity, central reflex and branching parameters. VASP is unique in that it is the first cloud-based retinal vessel analysis platform. The intelligent algorithms in VASP provide hints for user interaction. VASP can also process multiple modality images, in less than three minutes including user interaction.

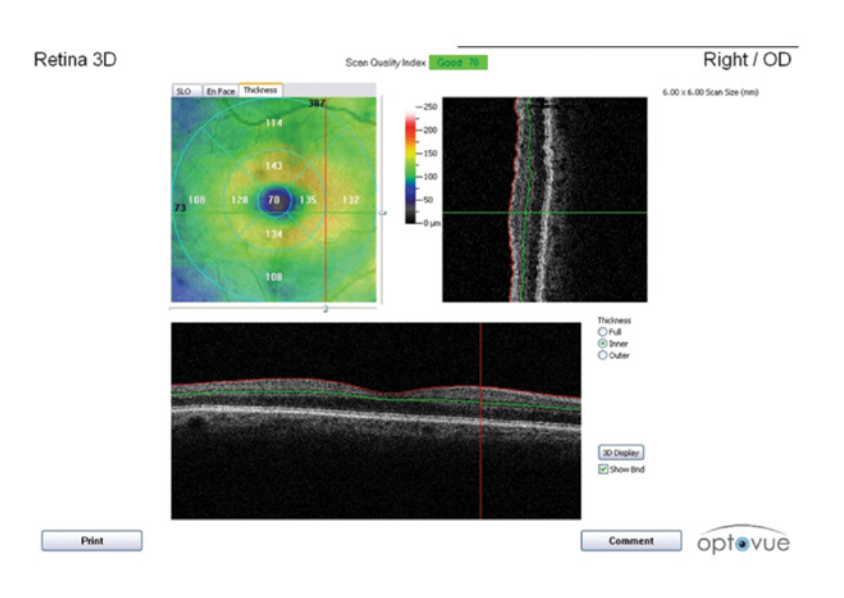


Figure 3: Retinal optical coherence tomography (OCT) identifying inflammation and subsequent atrophy in retinal layer thickness.

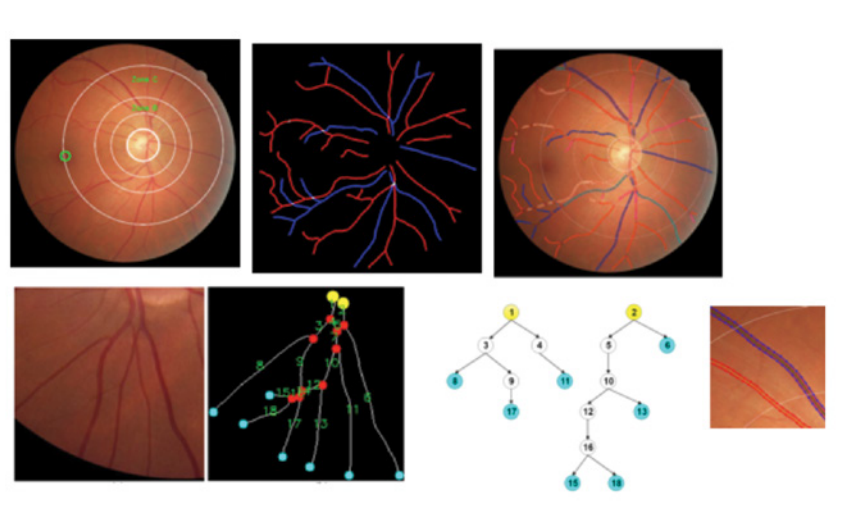


Figure 4: VASP image processing modules detect vessel tree structures, classify artery/vein, and measure vessel thickness at various regions.

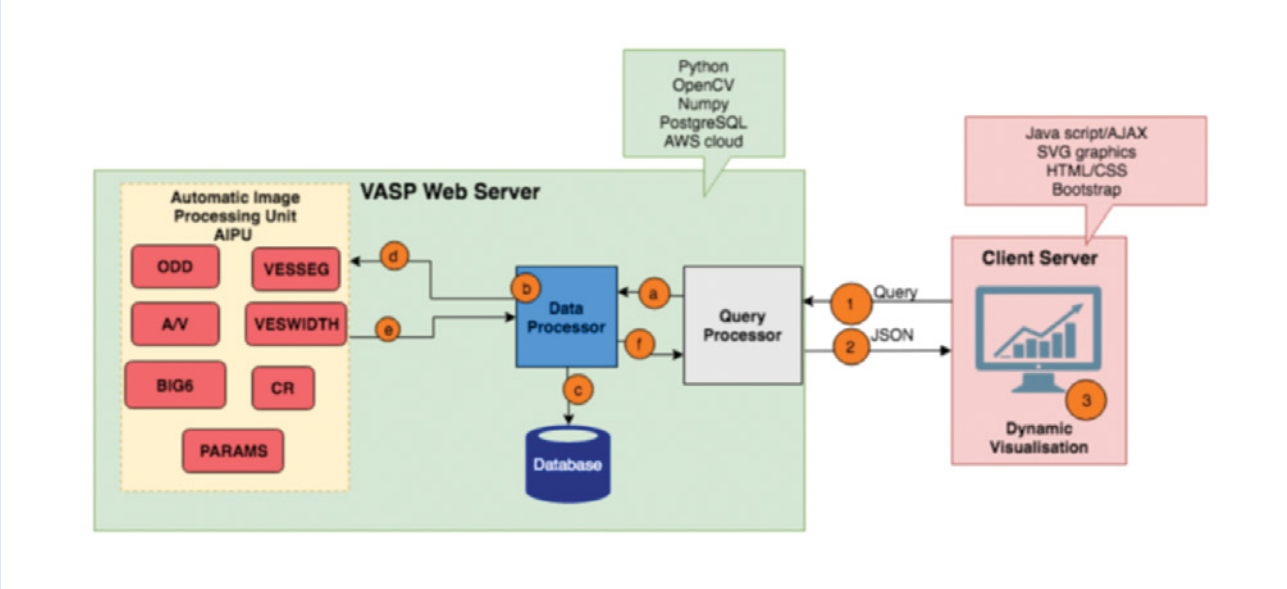


Figure 5: VASP system architecture is based on client-server web framework. The dynamic data representations and user interactions are translated into data, saved at central database, and communicated to the Automatic Image Processing Unit.

Collaborators:

- Neurovision Imaging, Sacramento, California
- Hollywood Private Hospital (Ramsay Health Care)
- Royal Perth Hospital
- University of Western Australia

Project highlights for 2017/18:

- Clinical trial nearing completion - external funding from Janssen, next-generation retinal fluorescence imaging in AD
- VASP software patented - Cloud Based Multi-modality Intelligent Retinal Vessel Analysis Platform for stroke, hypertension and H.Pylori studies
- Tropicamide study completed - manuscript under preparation.

Project aims for 2018/19:

- Complete new AD trial with new imaging technology and protocols
- Publish AD, tropicamide and SAHMRI study results
- Develop RPH studies into additional clinical areas
- Complete HPH trial on H.Pylori infection and retinal inflammatory markers
- 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.

Postdoc highlight

Shuang Yu, PhD

As a Postdoctoral Research Fellow at CSIRO, Dr Shuang Yu joined the Australian e-Health Research Centre in September 2015. Her research focussed on the automatic analysis of retinal vascular structures with graph theory and machine learning algorithms. This year her work led to a software patent and numerous improvements to the way retinal image analysis is conducted. Dr Yu's work was presented at ARVO 2017 and EMBC 2017.

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

SPECIAL PURPOSE FINANCIAL REPORT

30 JUNE 2018

Detailed financial information from pages 84-91 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 2018 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

Brisbane
Date: 21/8/18

Director

Brisbane
Date: 27/8/2018

Director

Brisbane
Date: 27/8/18

Director

Brisbane
Date: 27/8/2018.

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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 2018, 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 2018 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.

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- 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 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: 14 September 2018

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THE AUSTRALIAN E-HEALTH RESEARCH CENTRE