Research Statement
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Executive Summary

My research at McGill University has three axes within two broad research programs. The first two axes are in health informatics, focusing on the development of patient-centered data-sharing software and exploitation of radiotherapy data. The third is in biophysics and aims to use single-cell DNA sequencing to improve our understanding of the mechanism(s) underlying radiation-induced carcinogenesis. All three axes are underpinned by strong connections I have established with clinicians, patients, other researchers, industry partners, and nuclear regulators. All are well-funded and productive. They involve students, software developers and multi-disciplinary collaborations, and are bearing fruit in terms of output and impact.

Academic Background

My interest in working with data stems from my research background in astrophysics. As an astrophysics postdoc at McGill University (2003-2006) and at the Harvard-Smithsonian Center for Astrophysics (2006-2008), I worked with copious amounts of data. I acquired useful programming skills and I developed database software tools for the VERITAS telescope array in Arizona that are still in use. When I entered the field of Medical Physics in 2008, I learned that the oncology world is similarly data-rich. The various informatics research projects that I have led since have been driven by the experience and connections I fostered while working as a clinical physicist (2010-2017), where I was able to identify the clinical need and innovate with the support of clinical colleagues and, importantly, patients. Now, as an academic researcher (since 2017), I am building on my clinical expertise and incorporating it into my vision for patient-centered digital transformation.

Research Axis 1: Patient-Centered Health Informatics

My patient-centered health informatics research is mainly driven by my leadership of the Opal Health Informatics Group (O-HIG). The O-HIG is a unique patient-centered research collaboration at the Research Insitute of the McGill University Health Centre (RI-MUHC) that I co-founded in 2014 with the late Prof. Laurie Hendren, who was both a cancer patient and a professor of Computer Science at McGill University, and Dr. Tarek Hijal, chief of Radiation Oncology in our department. From the get-go, our collaboration's guiding principle has been the full participation of all stakeholders (including, patients, clinicians, and informatics experts) and students (i.e. future stakeholders) in healthcare informatics research so as to ensure that the necessary elements of person-centeredness, clinician/patient acceptability, and informatics feasibility are achieved. Our research aims to improve the healthcare experiences and health outcomes of patients that are identified by patients as important to patients. In the five years of its existence, the O-HIG has worked on a number of research projects centered around Opal, our award-winning flagship project.

Opal (opalmedapps.com) is a patient portal mobile phone app that we built and released to patients at our cancer centre. It provides patients with access to their electronic medical records (appointment schedules, lab results, clinical notes, etc) and automatically-personalized educational material tailored to their disease and phase of treatment. Opal also allows patients to check-in for appointments and be called in for examinations or treatments from their phones without needing to wait in the waiting room. This aspect, in particular, has proven extremely useful during the COVID pandemic as our cancer patients can socially distance in the hospital or in their cars while waiting to be called into appointments using the app. Crucially for clinical care and research, Opal is also a tool to collect patient-reported outcomes. It can tailor questionnaires based on a patient's disease and phase of treatment. Clinicians can access patient responses via a virtual clinic dashboard and data can be used for research studies under appropriate consenting frameworks. Presently, we are expanding the use of Opal beyond radiotherapy at our academic hospital and into five other hospitals in Montreal.

Through my leadership of the O-HIG and the development of Opal (I designed the underlying architecture, data flow, and security features) I have learned the power of patient involvement in healthcare research. I am committed to the notion of "patient-centered data" where data-sharing infrastructure fundamentally includes the patient as a hub, ensuring that the patient is informed and empowered and that the data are connected, benefiting not just clinical care but also research. To this end, I am leading a real-world evidence research project called PARTAGE to facilitate data donation by patients in Quebec using Opal. PARTAGE means "to share" in French and it stands for Patients And Researchers Team-up And Generate Evidence. In essence, the project is building a patient-centered blockchain-based data-sharing infrastructure for clinical care and real-world evidence research. The PARTAGE project was awarded the inaugural Trottier-Webster Award for Innovation at the Research Institute of the McGill University Health Centre in November 2019.

Research Axis 2: Radiotherapy Informatics

In my radiotherapy informatics research, I aim to collect, share and learn from the knowledge and experience that is encapsulated in radiation treatment data. My three most important current projects include: (1) a study to improve prostate cancer radiotherapy by searching for a correlation between the actual dose delivered during radiotherapy and patient-reported outcomes (as opposed to planned dose and physician-reported outcomes); (2) a study to combine radiomics applied to CT images and and natural language processing applied to clinical notes to develop a model to predict pain in patients with bone metastasis; and (3) development of incident reporting software for radiotherapy incorporating semi-automated classification using natural language processing. Each of these projects is funded and involves graduate and undergraduate students that I supervise.

Going forward, I am leading two related artificial intelligence (AI) projects in cancer care. In the first project, called OncoBuddy, we will develop a "dating algorithm" to match consenting cancer patients for peer support. New patients will be able to gain insight into their upcoming treatments through the hindsight of previous patients who are willing to share their experience. Individuals will be matched by the data in their medical record and additional data they provide via questionnaires in the Opal app. In the second project, we will take the dating algorithm one

step further and construct digital twins for each of our radiotherapy patients. Essentially, we will take new patients and match them with their digitally-created twins generated from the data of previously-treated similar patients. As such, we will aim to treat the twin in the digital world in order to predict the likely outcome of the patient in the real world. I am quite excited by this innovative concept and aim to demonstrate its power.

Research Axis 3: Neutron-Induced Carcinogenesis Effects

My neutron-induced carcinogenic effects (NICE) research axis aims to improve our understanding of the biophysical etiology of radiation-induced DNA damage, and subsequent carcinogenesis, using neutrons and single-cell sequencing. Recent innovative genomic research by Behjati et al. (2016) and others in the UK has shown that the genomes of radiotherapy-associated second malignancies contain radiation-specific mutational signatures. Having worked on various neutron dosimetry research projects for several years, I was excited to read the Behjati et al. paper. I was acutely aware that neutrons and photons differ in the biological damage they cause, which immediately suggested that perhaps they may induce different genomic signatures also.

In 2019, I began a research program to search for a possible mutational difference between photons and neutrons using single-cell sequencing. For this, I received initial funding from the Canadian Space Agency, which has an interest in the biological effects of ionizing radiation in space. I quickly realized that single-cell DNA sequencing is necessary since ionizing radiation is an indiscriminate stochastic process that affects each cell individually. Standard bulk-cell sequencing cannot work as it smears out the unique mutations from each individual cell in the bulk population. Thankfully, single-cell sequencing techniques have come of age and are inexpensive enough to be feasible. I formed a collaboration with a local single-cell sequencing expert (Dr. Ioannis Ragoussis) and hired a bioinformatics research associate and several graduate students. We obtained initial bioinformatics results before the COVID pandemic hit and were able to show in our preliminary data that the number of mutations in individual cells increases as a function of radiation dose. Due to pandemic restrictions, we have not yet been able to repeat the experiment but we are able to continue Monte Carlo modelling to better understand the biophysics at play. This intersection of bioinformatics and biophysics is a highly interesting avenue of research that I wish to continue to explore.

Summary

I am an experienced researcher with an academic background in astrophysics and a clinical background in medical physics. My current research includes contributions in clinical health informatics and biophysics. I believe strongly in the role of patients in sharing their own medical data and I am keenly interested in using novel genomic techniques to explore the biophysical etiology of radiation-induced cancer.