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Deep learning applications in lung cancer imaging

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Societal Impact and Valorizations

This thesis explored deep learning applications in lung cancer imaging. Chapters of the thesis involved the study and development of computational image analysis and machine learning methods to extract meaningful information from routine imaging data beyond that currently captured by trained experts. This section will discuss the potential impact of the research on related fields of study as well as society at large.

The global cancer burden is constantly on the rise. This thesis focused on improving the utilization of a routine and standard of care data type pertaining to cancer patients i.e. medical imaging data. Applications discussed in the thesis focused on lung cancer as the leading cause of cancer-related mortalities worldwide - larger than the next five cancer types combined. The computational approaches described here, however, are broadly applicable to other cancer types that come in the form of solid tumors. For instance, another disease candidate for similar studies would be breast cancer. Breast cancer is a major disease affecting women worldwide, and similar to lung cancer, relies on imaging data for patient management. Finally, it is also worth noting that this thesis may have a translational impact beyond oncology. Other diseases that rely on standard of care imaging techniques e.g. neurodegenerative and cardiovascular diseases, may greatly benefit from some of the methods described herein.

The work presented here broadly falls under precision medicine. This emerging approach allows for early diagnosis and customized patient-specific treatments thus delivering the appropriate medical care to the right patient at the right time. Extracting insights from imaging data represents a single facet of such an approach. Similar methodologies to those described in this thesis are actively being applied to other cancer patient data types including genomics, pathology, and electronic health records among others. As such, this work must be considered within the larger context of a growing body of multi-dimensional cancer data, with AI applications deducing patterns and predicting outcomes to improve decision-making. Finally, it is noteworthy that such decision-making applies to both the clinician and the patient alike: the former to advise on the best treatment pathway, and the latter to choose their desired quality of life.

Much hype surrounds AI applications and their utility in healthcare and other domains. Currently, most scientific literature that studies the clinical impact of these technologies tend to be at the proof-of-concept stage i.e. confined to *in silico* validation in small internal data cohorts, and lacking data on real-world clinical utility. Experiments in this thesis aimed at moving studies beyond this preliminary stage by validating models in large external data cohorts, as well as performing clinical validation through human subject experiments wherever possible. As such, this thesis attempts to close the translational gap between early *in silico* validation and larger scale prospective clinical trials. Closing this gap may provide the high levels of confidence needed to pursue AI clinical trials in medicine, uncover model weaknesses that would have been otherwise overlooked, generate preliminary data on human factors given our incomplete understanding of this area, as well as help quantify the time and effort needed to bring AI outputs to clinically acceptable levels.

To translate the research outputs described herein into clinical tools with direct impact on patients, further validation must be performed. To this end, maintaining the transparency and reproducibility of datasets and methods is crucial. Multiple datasets utilized in this thesis come from open-access online repositories, one of which is The Cancer Imaging Archive[3]. This allows for future improvements on the same data together with developing performance benchmarks. Virtually all computational methods used in this thesis were based on widely available open-source tools, a testament to the great value brought along by open-source software. This ranged from computational languages e.g. R[4] and Python[5], to deep learning libraries e.g. Tensorflow[6], as well as medical imaging software e.g. 3DSlicer[7]. Additionally, multiple trained AI models as a result of work described in chapter 5 have been shared publicly in well-documented and reproducible formats[8].

This research was made possible in large part due to an existing scientific infrastructure, relative abundance of research funding, as well as a network of experts and collaborators - all traits of high-income countries. As a result, most AI developments in healthcare cater to the needs of these countries where the majority of research is conducted. Conversely, little is discussed about what AI can bring to medical practice in low- and middle-income countries, where workforce shortages and limited resources constrain the access to and quality of care. It is therefore crucial to view the work presented here from a global health perspective. Health conditions between these two contexts are rapidly converging, as indicated by the recent shift of the global disease burden from infectious diseases to chronic noncommunicable diseases including cancer. Some of the methods described here may have global oncology applications through allowing non-specialized primary care physicians to perform specialized tasks including interpreting imaging data. Other methods may provide specialists with expert knowledge across multiple subspecialties. This is particularly important in oncology where lack of subspecialists may force an oncologist to manage tumors across multiple anatomical sites, and thus deliver care of inferior quality owing to the constantly varying scope of services.

Uneven distribution of the access to technologies has created a digital divide between the rich and poor, while contributing to existing global inequities. AI could emerge as a socially responsible technology with inherent equity.

3 https://www.cancerimagingarchive.net/
4 https://www.r-project.org/
5 https://www.python.org/
6 https://www.tensorflow.org/
7 https://www.slicer.org/
8 https://github.com/modelhub-ai/deep-prognosis

Some awards and media coverage include:

- Chapter 3 “Artificial Intelligence in Radiology” was featured on the cover of Nature Reviews Cancer journal in August 2018[9], and was discussed in popular media outlets including Wired[10] and The New York Times[11].
- Chapter 5 “Deep Learning for Lung Cancer Prognostication: A Retrospective Multi-Cohort Radiomics Study” was selected by the International Medical Informatics Association (IMIA) as one of the best articles published in 2018 in the ‘Cancer Informatics’ subfield[12].
- Chapter 7 “Deep Learning Predicts Lung Cancer Treatment Response from Serial Medical Imaging” was discussed in an Auntminnie article[13].
- Chapter 11 “The Importance of Transparency and Reproducibility in Artificial Intelligence Research” was discussed in popular media outlets including MIT Technology review[14] and Scientific American[15].

9 https://www.nature.com/nrc/volumes/18/issues/8
10 https://www.wired.co.uk/article/artificial-intelligence-2019-predictions
11 https://www.nytimes.com/2019/05/22/opinion/health-care-privacy-hipaa.html
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14 https://www.technologyreview.com/2020/11/12/1011944/artificial-intelligence-replication-crisis-science-big-tech-google-deepmind-facebook-openai/
15 https://www.scientificamerican.com/article/will-artificial-intelligence-ever-live-up-to-its-hype/