IDIOMS: Infectious Disease Imaging Outbreak Monitoring System

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1 INTRODUCTION

In this commentary, we propose a framework for **convergence accelerator research** leveraging AI models with medical images for effective diagnosis, monitoring, and treatment of diseases with pandemic potential. The goal is to create a novel *Infectious Disease Imaging Outbreak Monitoring System* (IDIOMS) to prospectively anticipate, identify, and characterize potential infectious disease outbreaks across a population of patients in real-time as patients receive medical imaging examinations. IDIOMS will provide critical surveillance before an outbreak is widely identified and before adequate testing resources are available. This can be achieved through the creation of an infectious disease medical imaging library resource and the implementation of a computer vision approach to infectious disease medical imaging classification using Artificial Intelligence (AI). Improved characterization of Infectious Disease (ID) by medical imaging could provide an earlier indicator for a recurrent

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or future pandemic, even before the underlying pathogen is identified clinically or before an alternative commercially available reliable laboratory test can be developed and distributed. Such an infectious disease medical imaging classifier could have altered the course of the COVID-19 pandemic caused by SARS-CoV-2.

Many infectious diseases have characteristic patterns that can be identified by medical imaging examinations. COVID-19 presented with a bilateral mid lung, predominantly peripheral ground glass pattern with subpleural sparing. Radiologists are actively observing and publishing additional characteristic COVID-19 patterns such as "crazy paving" and the "reverse halo" sign that have individually occurred with other infectious disease processes but not always together in a single disease. Tuberculosis (TB), for example, has a different characteristic pattern. TB most typically presents with upper lobe predominant disease, *lymphadenopathy*, and *cavitation*. The current approach to understanding these imaging patterns relies on retrospective analysis of a cohort of known positive cases. Perceived patterns are then identified and classified by expert radiologists. Eventually, guidelines based largely on consensus expert opinion such as the Fleischner Society or the American College of Radiology (ACR) may be adopted. Additional patterns that are similarly characteristic of a particular disease, however, that are not yet widely recognized may still exist and remain unidentified. In a new outbreak, imaging patterns may take time to be well characterized under the current paradigm, only after reliable testing is readily available. We propose the creation of a library platform for infectious disease medical imaging results allowing the utilization of real-time AI/ML approaches to better characterize the current known imaging patterns and to predict potential future novel manifestations of infectious disease on medical imaging. We call this platform IDIOMS. Below are some relevant issues with this approach.

2 DEEP LEARNING MODELS

Image classification is a well-studied problem in the literature and there are a number of well-developed architectures (e.g., VGG [10], ResNet [5], ResNetXt [12]) and datasets (e.g., Imagenet [7]) to address classification of generic objects. However, there are no well-developed datasets for 3D volume classification. We propose to create 2D and 3D Convolutional Neural Network [3, 4, 8, 11] models of infectious disease based on treatment sensitivities and prognostic indicators. Chest imaging by Computed Tomography (CT) and radiography are the most commonly performed infectious disease imaging examinations and can be used as prototypical examples for this project. The initial sample library will contain patterns classified as suspicious for COVID-19 (approximately 2,000 cases), or Tuberculosis (approximately 6,000 cases) based on available clinical standards. The overall anonymized dataset contains over 2 million imaging examinations from multiple medical institutions including examinations that are normal and those suspicious for pneumonia or other classic respiratory illnesses.

3 LABEL DESERT PROBLEM

It is difficult to obtain labeled data, particularly in this domain. A possible solution is to use self-supervised learning architecture that can be used to increase the generalizability of a classification model with a small number of labeled samples while utilizing unlabeled images that are more easily available. Self-supervised learning in the form of rotation augmentation has shown to improve the model generalizability in a number of computer vision [3, 4, 8, 11] and human activity recognition [2, 9] tasks. Inspired by our success with AugToAct [2], where we modeled the self-supervision task as regression (reconstruction of a rotated/scaled input feature space), instead of classification (predicting whether rotation was done) with higher performance gain, we propose to augment self-supervision with a reinforcement learning loop [1, 6] to learn the optimum augmentation policy for self-supervision.

4 LIBRARY OF DISEASE PATTERNS

We propose creating a library of unknown disease patterns. In addition to known patterns, novel patterns of infectous diseases will be modeled using Generative Adversarial Networks (GANs) to predict potential characteristic patterns that might not be currently represented. These sets will be added to the library and provide a means for anticipating and recognizing yet unknown imaging patterns that could correspond to a new manifestation of infectious disease. The GAN-based models can be used for image synthesis. While there are many current efforts across multiple healthcare agencies and the NIH aiming to build large open access datasets such as Biobank, the National Biomedical Imaging Archive (NBIA) and The Cancer Imaging Archive (TCIA), this issue remains unresolved.

5 OUTBREAK INDICATOR

When characteristic imaging features, GAN predicted imaging features, or a novel ensemble of imaging features exceed the parameters expected within a population of patients, an outbreak situation could be occurring. The outbreak indicator will provide a mechanism for closer evaluation of the subset of patients involved and the overall situation (pulse) within the health system analyzed. We can extend the Deep Convolutional Generative Adversarial Network (DCGAN) architecture because of its efficiency and stability.

6 ETIOLOGY OF INFECTIOUS DISEASE PREDICTION

We need to develop an etiology of infectious disease prediction, which is an area of recognized academic potential, however there is a clinical need for improved empirical evidence. The creation of the underlying infectious disease imaging library will also have implications in improving the ability to classify and subtype infectious disease etiology based on more empirical, rather than the largely anecdotal currently available evidence.

7 INTEGRATING WITH MEDICAL IMAGING WORKFLOW

IDIOMS should be designed to be incorporated into medical imaging workflows through commercial imaging systems such as CT scanners (in conjunction with vendors like Cannon Medical Systems among others) or through commercially available AI/image processing platforms (such as TeraRecon's EnvoyAI among others). The outbreak detection system will be able to be implemented at the individual hospital level, hospital system level, community level, or regional level. With IDIOMS in place, a future infectious disease outbreak could be suspected immediately as symptomatic patients are being imaged and before laboratory testing is widely available. Similarly, after the initial peak of COVID-19 participating health systems could suspect the emergence of a recurrent COVID-19 outbreak before laboratory testing is widely re-initiated.

8 IMPACTS ON SOCIETY

We expect IDIOMS will be useful for identifying an infectious disease that has similar symptoms to other diseases where characteristic imaging features exhibit differences, such as is the case with COVID-19, TB, and many respiratory illnesses. IDIOMS will organize a variety of imaging patterns of infectious disease (e.g., ground glass, nodules, reticulation, "crazy-paving," etc.) and their corresponding locations (e.g., upper lung, middle lung, lower lung, peripheral, etc.). IDIOMS will then detect and report unique ensembles of disease feature "building blocks" characteristic of an outbreak of a predicted infectious disease that may otherwise mimic various less specific clinical presentations. The platform would be particularly helpful in the early stages of an outbreak when intervening containment measures could exponentially reduce the spread and likelihood of a global effect, termed a pandemic.

In the early stages of an outbreak, individual clinicians may not encounter enough cases or may not be able to readily identify enough unique clinical features to detect a pattern. If a pattern is not detected by the clinician, then specific laboratory tests available may not be performed and the recognized need for a new laboratory test may be delayed. If IDIOMS were in place within a healthcare system experiencing a new infectious disease outbreak, then an alert could be provided to physicians, administrators or epidemiologists calling attention to the unique ensemble and the need for further investigation. IDIOMS will help shine some light on outbreak obscurity accelerating detection and leading to more evidence-based imaging classification of infectious disease. The use of the platform may also provide insight into patient management through prognostication and treatment-based subtyping.

9 IMPLEMENTATION CHALLENGES

There are various implementation challenges including technical and regulatory or governmental. The technical challenges stem from the massive computational needs for medical image synthesis, particularly with the integrity required to satisfy clinicians. In the case of thoracic illnesses that are lung related, maintaining anatomical fidelity is a challenge. However, clinicians are likely to reject any synthetic image that does not hold up to the highest level of anatomical integrity in their trained eyes. The other challenge is computational cost. Since there are hundreds of 2D axial slices per patient, generating synthetic images requires constructing variations of these slices in a manner that preserves the anatomical structure as a whole. Hence some constraints must be added in the generation of the CT slices. Furthermore, if the focus is on generating synthetic images in the region of interest (ROI), particularly in the lungs, these must be manually labeled by clinical experts, who are board certified in diagnostic radiology, which can then be used to generated synthetic variations. However, manually labeling the ROI is a time consuming task.

From the digital government perspective, it is important to realize that unless we are able to generate synthetic images that are clinically acceptable, the disease library will not be acceptable by the medical community. Hence, to achieve a meaningful set of libraries, the deep learning community must work with radiologists to come up with acceptable "digital library" cases. This would require some new research programs to bring together clinical experts and AI researchers to work together towards this goal.

10 CONCLUSION AND FUTURE WORK

In this commentary, we propose a framework called IDIOMS, for training AI models with medical imaging for effective detection, monitoring, and treatment of pandemic diseases such as COVID-19. Our main thesis is to create a "library" of diseases that are possible to manifest as mutations of previous diseases such as the different strains of the Coronavirus. Such a library can be useful to detect new diseases at their early stages, take early measures to avoid spreading to a pandemic magnitude, and potentially develop *a priori* treatment options instead of responding *a posteriori*. If properly done, then this can lead the world to be better prepared to develop an effective defense mechanism to fight against future pandemics.

Deep learning has been demonstrated to be effective in generating synthetic images such as human faces that are not identifiable as "fake" as compared to real images. The paucity of medical images in the public domain due to privacy protection is a challenge to the machine learning community. However, this challenge could be overcome if high resolution medical images can be synthesized. However, there are computational challenges to synthesize high fidelity medical images. This problem can be partially solved by focusing solely on the region of interest and integrating the synthesized images with the rest of the anatomy.

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