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Multi-Scale Temporal Imaging: From Micro- and Meso- to Macro-scale-time Nuclear Medicine

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Introduction

Living systems are in constant dynamism to keep the “internal milieu” stable despite the variation of external factors. This continuous change at the molecular and cellular levels aims at preventing a change at a large-scale (principle of homeostasis). In a medical context, there are two processes that can cause change at a large-scale: maladies and aging. Aging is a more gradual process that has been less studied.[1] Time provides a common frame of reference by which different processes of change can be related, and thus, time represents our understanding of change.

The human body is a system that is composed of structure on a range of scales from the nanometer size of amino acids, to the micrometer dimension of cells, to the milimeter length of tissues, to the centimeter proportion of organas. Properties of these structures can be measured using different imaging technologies. In the spatial domain, these imaging techniques provide characterization in the form of static or structural imaging. For instance electron density of the structure can be evaluated, and the mapping of this characteristics in the space-domain is achieved by CT images (X-Ray Computed Tomography). By comparing these structural snapshots with an expected norm, anatomical pathologies can be diagnosed and treated. In this way, structure can be captured and described as a multi-scale characterization of the spatial domain.

We capture the function and dynamism of an organ or organism via evaluation of the change in structures (like change in volume of left ventricle to measure function of heart as ejection fraction). Function, like structure, can be described as a multi-scale characterization. However, function could be characterized in the temporal rather than spatial domain:In clinical imaging, time ranges from the seconds of perfusion imaging, to the minutes of ^{18}F-Fluorodeoxyglucose (FDG) kinetics, to the days for ^{177}Lu-PSMA biodistribution, and to the months for tumor growth. If we have dynamic imaging then we can quantify the change to evaluate the function (like glucose metabolism by compartmental modeling in dynamic FDG-PET); however in clinical practice sometimes we only have the temporal snapshots of this dynamism (like static FDG-PET imaging). To interpret the meaning of these snapshots of the function, we have to compare them with the expected status of the dynamic systems at certain times to

identify functional pathologies (like 45 second post injection of iodine-based contrast to evaluate arterial perfusion in CT or 60 minutes post injection of 18F-FDG to evaluate metabolic activity in PET).

Change across different time points is a critical factor that is foundational for diagnostic imaging which is the basis of an aphorism in medical imaging community: “the best friend of a radiologist is prior images”. This wisdom emphasizes on the superiority of temporal dynamism over static appearance of structure. In this article, we discuss the interrelatedness of “change” and “time”, the similarities of “imaging of change” regardless of time-scale, and the scale-dependent difference of “temporal imaging”. We first describe the different time scales and the kinds of imaging that take place under those time scales. We then examine the current status of medical imaging literature focused on a macro time scale. We identify strengths and weaknesses of existing evaluations. Finally, we offer some observations and suggestions for future directions of medical imaging research.

Section snippets

Temporal imaging and various scales of time

The temporal domain can be described over several different time scales. Within the context of medical imaging, we describe three such time scales: micro-, meso-, and macro- time scales.[2] Micro-scale temporal imaging refers to a small temporal window that encompasses a single imaging or acquisition event (session). This can range from the narrow window of beam on-time in a system to repeated scans that occur between when a patient gets on and off the imaging table, including techniques such as…

Longitudinal data in medical imaging research

Thinking on the macro-scale is common in clinical care. When interpreting the images of a particular patient, clinicians often invoke earlier imaging studies or other tests. The specific medical history of that patient is then used to inform medical decision-making. When a specific diagnosis is then made, a clinician can also use the natural history and progression of disease to understand the status of that specific diagnosis. With the advent of personalized medicine, the long-term time focus…

Four challenges in quantifying time interval changes

Different studies of macroscale time in the medical imaging literature were described in the previous section. There are some challenges to expanding the scope and application of these types of studies in the near future. In this section, we identify four challenges, specifically related to (i) data collection, (ii) algorithmic developments, (iii) performance metrics, and (iv) ethical considerations and discuss the need for addressing the key concerns.

The first major challenge is the issue of…

Recommendations

Information derived from changes over time is central to our understanding of normal physiologic processes, such as development and aging and pathophysiology of diseases. Although medical imaging in both clinical use and research has been focused on localized change, by better understanding the relationship between change and time, we are able to expand our scope. Although most of the longitudinal imaging studies have observations with two or more time points to capture and characterize change…

Summary

In medicine, time plays an important role in how we understand the progression of disease and development. Imaging provides a method to characterize this change, and with a focus on different time scales, we are able to contextualize that change and understand the implications for better medical outcomes. The present work focuses on methods and applications beyond only micro- and meso-scales. We discussed strengths and limitations of existing macro-scale (longitudinal) imaging and made…

Clinics care points

- Ability to measure change across different time points is critical for diagnostic imaging…
- There has commonly been greater emphasis on the micro and meso-scale temporal imaging in both clinical practice and research, than macro-scale.…
- Techniques used for quantification of change in one temporal scale can be used in and integrated with other temporal scales (toward multi-scale temporal imaging).…
- Challenges associated with longitudinal studies include the need for improved data collection,…

…

…

Disclosure

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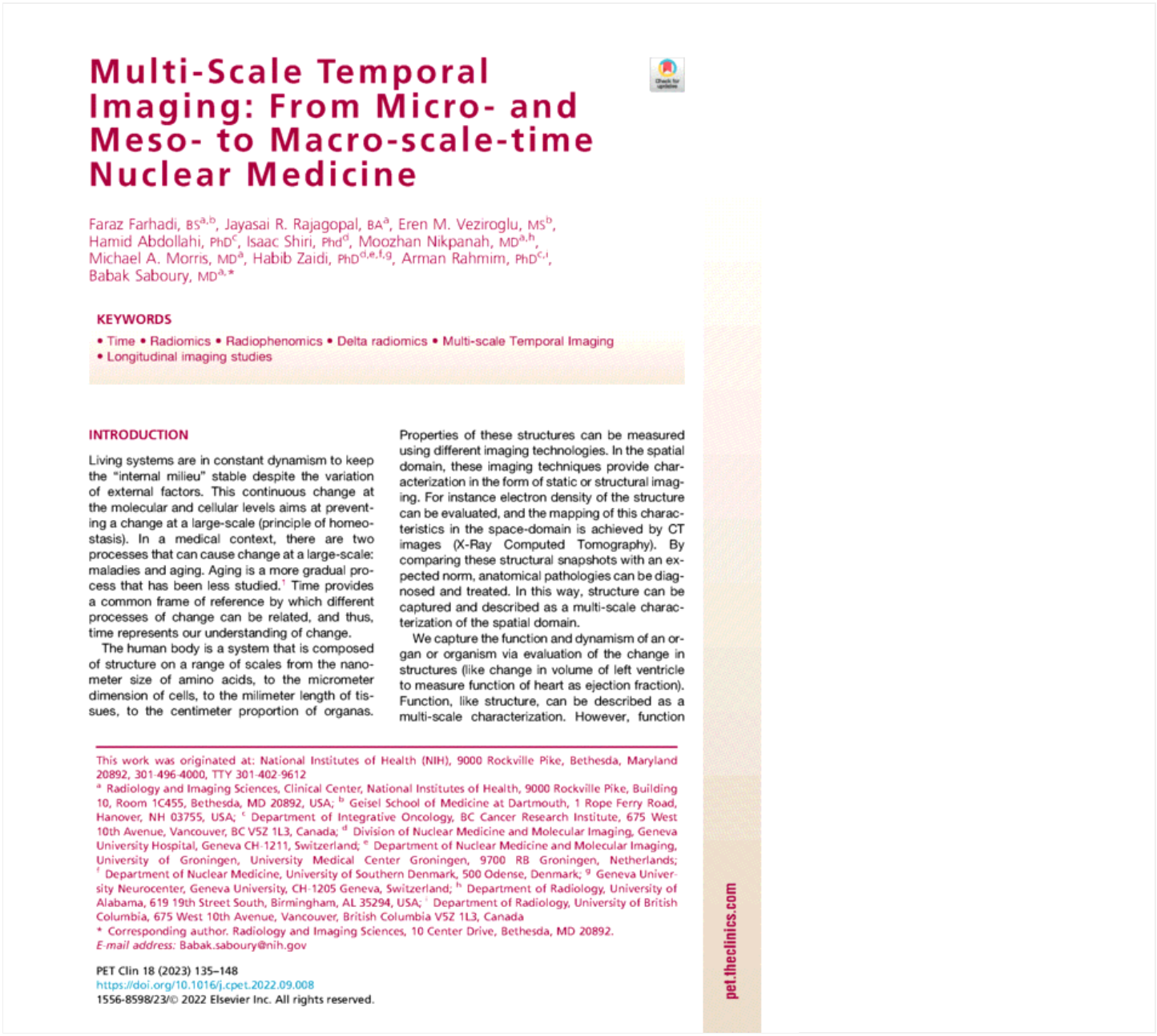

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KEYWORDS

• Time • Radiomics • Radiophenomics • Delta radiomics • Multi-scale Temporal Imaging • Longitudinal imaging studies

INTRODUCTION

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