



***Supervised Deep Learning for Detection and
Multi-Class Classification of Kidney Tumors
and Cancer Using CT scans***

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Chapter 1: Introduction and Overview

1.1 Overview

Kidney tumors are a major health issue of concern in the world and they comprise a large number of neoplasms which are either benign lesions or very aggressive malignancies. The majority of renal malignancy are represented by the renal cell carcinoma (RCC), the most prevalent malignant renal tumor in adults that occurs in about 90% of all cases. There are subtypes such as transitional cell carcinoma, Wilms tumor among children and benign entities such as the oncocytomas and angiomyolipoma. Kidney tumors have continued to grow steadily in the world and this has been due to the introduction of better diagnostic imaging, ageing populations, and increased prevalence of risk factors such as obesity, smoking and hypertension. Current epidemiological statistics indicate that in 2022, there were about 434,840 new cases of kidney cancer across the world, which is the 14th most widespread cancer in general, the 10th in men, and the 13th in women. There is also a high rate of mortality with approximately 155,953 deaths in the same year caused by kidney cancer which is very fatal unless it is detected and treated at an early age.

Kidney tumors are not uniformly distributed in geographical scenarios and socioeconomic levels. Income countries, especially those in North America and Europe, have higher rates of the disease as a result of access to diagnostic tools and screening, and the age-standardized incidence rate (ASIR) is as high as 15.60 per 100,000, in such countries as Argentina. Conversely, the burden of mortality in low income and middle-income nations is disproportionate and mostly because of late diagnosis and inadequate health facilities. An example is that estimates show the number of new cases and deaths could grow by 72 and 96 % by 2050, which explains why developing better detection measures is very urgently required. The stage of diagnosis is directly related to the survival rate; in the United States, the five-year relative survival rate is about 78.6 % on average, although it is higher, at above 90 %, with localized tumors, and much less, at less than 15 %, with metastatic disease. Such a difference highlights the importance of early diagnosis in enhancing the outcomes.

Computed Tomography (CT) scans have become the backbone of diagnosis of kidney tumors as they provide high resolution images that can be used to accurately visualize the tumor features in terms of size, shape, location and pattern of enhancement. Multidetector CT protocols, such as non-contrast, arterial, and venous phases, allow the accurate staging of the case through evaluating vascular involvement, lymph node metastasis, and distant spread with reported accuracies of over 99 % in detecting tumors. Conventional hand interpretation of CT images is however time consuming and liable to variance especially in identifying subtle differences among tumor subtypes.

The introduction of artificial intelligence (AI) and deep learning (DL) has transformed the medical imaging field by means of automatizing cumbersome processes, including tumor detection and classification. Under supervised DL, frameworks that utilize convolutional neural networks (CNNs) have been shown to be more effective in the analysis of CT scans of different types of cancers, and kidney tumor is one of them. These models acquire hierarchical characteristics with large scale datasets, allowing multiclass classification that distinguishes not only between benign and malignant tumors, but also between specific subtypes, which is the key to individual approach in the treatment planning. In the case of kidney tumors, multi-class classification is the most important since it determines whether to perform active surveillance on benign lesions or surgical treatment on malignancies, which would result in less unnecessary procedures and improve the quality of life of patients.

This thesis aims at the construction of a supervised DL system to detect and multi-classify kidney tumors and cancer with the help of CT scans. Its objective is to improve the quality of diagnosis by reducing inter-observer variability, time-saving, and consequently alleviate the rate of mortality due to kidney tumors by overcoming the shortcomings of manual diagnosis. The introduction of DL into the field of clinical practice can be viewed as a paradigm shift towards precision medicine, where the AI-based tools will supplement the knowledge of radiologists, resulting in more efficient and equitable healthcare provision.

1.2 Problem Definition

Although there has been an improvement in imaging technologies, kidney tumors diagnosis and classification are still fraught with challenges. Manual detection is more than dependent on the professional skills of radiologists to interpret CT scans, which is a subjective process likely to commit errors. Among subtypes, the similarity of appearances of the tumors, blurry limits, and overlapping imaging characteristics can be among the most perplexing issues, resulting in wrong classification. An example is benign tumor such as oncocytomas RCC can present in CT as mimic of malignant tumor, leading to unnecessary surgeries; as high as 14 % of presumed RCC tumors turn out to be benign after nephrectomy. Moreover, small renal masses (SRMs) are usually ambiguous to differentiate cystic, solid benign, and malignant maladies.

Incidental findings during routine imaging have risen all over the world leading to an increase in the workload of the radiologist which has added to the fatigue-based mistakes among radiologists. The inter-observer variability is experienced especially in multi-phase CT interpretations whereby the enhancement patterns should be carefully evaluated to determine the presence of vascular invasion or metastasis. The already scarce access to skilled radiologists in low-resource environments also further delays diagnoses, leading to increased death rates in the areas such as Asia and Africa, where the incidence has increased over the past several decades by more than 300 %.

Multi-class classification further complicates the picture since proper identification of subtype (e.g. clear cell RCC versus papillary or chromophobe) is essential to prognosis and treatment. The most aggressive subtype (clear cell RCC) needs immediate treatment, whereas the indolent subtypes might not need treatment and could just be monitored. This granularity is a challenge of manual techniques that may require biopsy which has dangers, such as bleeding or seeding. Additionally, staging systems such as TNM although standardized are based on accurate imaging determinations which may be missed by manual reviews particularly in venous or nodal involvement.

These issues necessitate the use of automated systems. Conventional machine learning methods involve manual extraction of features, thus restricting their flexibility to a wide range of CT datasets. Deep learning provides an answer in that it is able to automatically learn features but the current systems do not have the robustness over multi-center data or is not able to effectively

combine multi-phase information. This thesis fills these gaps with the suggestion of a supervised DL structure that will improve the sensitivity of the detection and the multiple-class accuracy, reduce the weaknesses of manual diagnosis and open the way to AI-integrated clinical practice.

1.3 Thesis Objectives

The overall aim of this thesis is to design and test a deep learning-based supervised system to identify and classify (in multi-class) kidney tumors on CT scans in an automated manner. This model will enable the enhancement of the diagnostic efficiency and accuracy of diagnosing, early intervention, and customized treatment.

The specific objectives are:

1. To discuss and examine the available DL applications to the medical imaging domain, paying particular attention to kidney tumor identification and classification, determining the advantages and shortcomings of the existing methodologies.
2. To develop a more powerful CNN-based architecture that incorporates the multi-phase CT data to extract more features and identify the location of the tumor.
3. In order to develop multi-class classification functionality, to be able to differentiate between benign (e.g., oncocytoma, angiomyolipoma) and malignant subtypes (e.g., clear cell, papillary, chromophobe RCC), to underline the clinical significance of subtype-specific prognosis.
4. In order to assess the performance of the framework based on various data, such as accuracy, sensitivity, specificity, and area under the ROC curve (AUC) in comparison to manual radiologist ratings and the state-of-the-art framework.
5. To determine the clinical applicability of the framework by validating it on actual CT scans, investigate ways to integrate it with current radiology procedures to minimize the time and errors in diagnoses.

Through the accomplishment of these aims, the thesis aims to make contributions to the domain of AI-driven oncology and eventually positively affect the patient outcomes in the management of kidney tumors.

1.4 Thesis Contribution

This thesis contributes to the field of medical imaging and AI in kidney tumor diagnosis in a number of important ways:

1. Another example is a new supervised DL model that integrates advanced CNN models (e.g., hybrid ResNet-CNN models) to detect and simultaneously classify objects into multiple classes with high rates of accuracy (up to 99%) on CT datasets, which is better than previous models.
2. Multi-phase CT analysis to identify dynamic enhancement patterns, enhance subtype differentiation and reduce false positive in the benign-malignant classification.
3. Focus on explainability by using methods such as Grad-CAM, which offers visual explanations on how the model makes decisions, which improves trust and adoption in clinical practices.
4. Multi-center validation, which is resistant to differences in imaging regimes and patient demographics, which is a common limitation in earlier studies.
5. Possible impact on the real world, providing a tool that could decrease the workload of radiologists, decrease the number of unnecessary interventions, and aid in precision medicine in the management of kidney cancer.

Such contributions facilitate the development of the field of integration of DL in the field of oncology, offering a universal solution to the global challenges encountered in healthcare.

1.5 Thesis Organization

The thesis is organized in the following way:

- Chapter 2 is a review of background literature about kidney tumors, imaging modalities, and applications of DL in medical imaging.
- Chapter 3 describes the suggested DL framework, its architecture, pre-processing of data, and training strategies.
- Chapter 4 is the results of the experiment, performance analysis, and the comparison with the benchmark.
- Chapter 5 ends with discussions, limitations and future directions of work.

This organization facilitates a rational flow of the initial ideas to the application and analysis of the ideas.

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