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Measurement of glomerulus diameter and Bowman's space width of renal albino rats

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ABSTRACT

Glomerulus diameter and Bowman's space width in renal microscopic images indicate various diseases. Therefore, the detection of the renal corpuscle and related objects is a key step in histopathological evaluation of renal microscopic images. However, the task of automatic glomeruli detection is challenging due to their wide intensity variation, besides the inconsistency in terms of shape and size of the glomeruli in the renal corpuscle. Here, a novel solution is proposed which includes the Particles Analyzer technique based on median filter for morphological image processing to detect the renal corpuscle objects. Afterwards, the glomerulus diameter and Bowman's space width are measured. The solution was tested with a dataset of 21 rats' renal corpuscle images acquired using light microscope. The experimental results proved that the proposed solution can detect the renal corpuscle and its objects efficiently. As well as, the proposed solution has the ability to manage any input images assuring its robustness to the deformations of the glomeruli even with the glomerular hypertrophy cases. Also, the results reported significant difference between the control and affected (due to ingested additional daily dose (14.6 mg) of fructose) groups in terms of glomerulus diameter ($97.40 \pm 19.02\,\mu m$ and $177.03 \pm 54.48\,\mu m$, respectively).

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1. Introduction

Kidney is a significant organ which controls homeostasis, water volume and electrolytes in blood, blood pressure. The foremost function of the kidney is urine filtration. Histologically, the kidney is formed of peripherally situated cortex and a centrally located medulla. The cortex is very rich in nephrons that considered the main functional unit consisting of the renal corpuscle and renal tubules. On histological specimens, renal corpuscle looks like a small rounded structure that has a centrally located glomerulus surrounded peripherally with Bowman's capsule [1,2]. The glomerulus is a collection of capillaries lined united by a delicate mesangial matrix [3–5]; while, the Bowman's capsule consists of two epithelium layers: visceral (envelops glomerulus) and parietal.

Glomerular hypertrophy is indicated by the glomerular diameter. It is related to abundant human diseases and in tentative animal models such as rats. Such diseases are, namely: the Focal segmental glumerlosclerosis (FSGS), Extensive loss of renal mass, Diabetes, Oligomeganephronia, Reflux nephropathy, Obesity/sleep apnea, and Unilateral renal agenesis evoke glomerular hypertrophy, which increases the glomerulus diameter [6]. These diseases affect the glomerular morphometry that justifies the developing of accurate solutions for the assessment of the glomerular diameter.

In addition, obesity, advanced glycation and lacking of the tetraspan in CD151 can lead to Bowman's capsule expansion that is caused by either glomerular hyper filtration, which is indicated by Bowman's capsule dimensions, or tubular cast formation. For example, kidney undergoes numerous significant structural and metabolic changes with obesity, including glomerular hyper filtration, thickening of the glomerular basement membrane, and thickening of the mesangial matrix, proliferation of mesangial cells and the expansion of Bowman's capsule. In humans, micro albuminuria is the earliest clinical obesity manifestation related to the kidney damage and diabetic nephropathy, is characterized by glomerulosclrosis.

Furthermore, there are common factors that can affect the glomerular filtration and solute excretion on the kidney such as the aging and diet type. Thus, the pathological changes in the renal corpuscle of animal disease models supply significant information in screening composites to target such diseases.

Thus, various diseases can affect the renal corpuscle which is manifested by changing of corpuscles morphometric parameters such as glomerulus diameter and Bowman's capsule dimension. Accurate measuring of these parameters in experimental animal models assists the early diagnosis of such renal diseases and helps to prognosis kidney function changes. However, manual measurements consume time, increase the probability of miscalculations and are prone to errors. Furthermore, the common variations of the Bowman's capsule dimensions and glomerulus diameter, limit the measurements performed by the pathologist and lead to incorrect diagnosis.

Generally, object detection algorithms have two particular points of research in the case of renal corpuscle detection, namely: the non-rigid shapes of the objects in the microscopic images and high variety of the glomerulus intensity in the images under analysis. Typically, sliding window techniques have been used to detect the glomerulus at each location in the renal images [7–9]. While, standard parametric active contour algorithms are suitable for object tracking, they fail to track multiple objects particularly when the objects are close to each other.

Since, the detection of the objects' particle size in binary image is a very significant issue that can be performed using particles analysis algorithm for image analysis or image processing via the analysis of particles. This technique is employed for particle detection and measurements using digital imaging. Such measurements include particle shape (morphology or shape analysis), particle size, as well as particles distribution.

Therefore, the goal of this study is to achieve high accurate detection of the renal corpuscle and its objects in light microscopy images of control and affected rats' renal images. Therefore, it was focused on the automated detection and measurement of renal corpuscles objects employing a new solution based on the particles analyzer in binary images. Thus, the RGB original images are split into three channels from which the green channel is used as it contains the main information about the renal corpuscle. In order to test the ability of the proposed approach, a control and affected rats' model (fructose-induced glomerulus hypertrophy) is studied to obtain renal images.

The remaining manuscript is structured as follows. Next section presents the related work. Section 3 includes the proposed solution and describes the two phases used for the detection and measurement of the glomerulus diameter and the Bowman's capsule dimension. The results are discussed in Section 4, followed by the conclusions in Section 5.

2. Related work

In current time, one of the most important topic in the field of nephrology is the metabolic syndrome and chronic kidney disease (CKD). Fructose-induced nephropathy is serving as a model of CKD. Several studies discussed the significance of this model and refer to the glomerular hypertension and microvascular damage. Fructose-fed rat model was found to result in severe metabolic syndrome and kidney damage which suggested a relationship between the amount of fructose consumed and the development of deleterious effects [10]. In addition, recent studies revealed that excessive intake of fructose may induce fatty liver, insulin resistance, dyslipidemia, hypertension, and kidney disease [11].

Thus, analysis of renal microscopic sample images is an imperative tool for several disease diagnoses. Although quantitative analysis of the renal capsule objects is crucial in pathologist studies, only inadequate numbers of consistent techniques have been proposed. Existing solutions for glomerulus aided automatic analysis in microscopy renal images were discussed in [12]. Earlier, Osawa et al. [13] developed solutions using combined manual methods that can be applied to limited image datasets; however, they are very time consuming and prune to visual errors. Few image processing methods have been proposed to detect and analyze the glomerular basement membrane (GBM). Ong et al. [14] suggested a method that measured the smoothness, intensity