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Opinion

Flow through Renal Tubules: An Application through Porous Walled Ducts

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The study of fluid flow through porous walled channels and ducts has many applications in biomechanics and in industry. In industry, processes such as desalination, reverse osmosis and flow through various tubular nanostructures (see, for example, [1]). However, such fluid flow studies have gained much popularity due to their applications in biology and biomechanics. For example, a few dozens of blood flows through capillaries and arterioles each day. The blood pressure in arterioles is much lower in comparison with that in the main arteries. Therefore, the pressure gradient gives rise to Poiseuille like flow in such structures. However, the Poiseuille like flow cannot be maintained in the renal tubules of a kidney. Kidneys are vital organs in an organism and perform the function of filtration of fluid through the body. Kidneys balance the amount of water in the body apart from getting rid of metabolic waste. Each day, about 200 liters of blood passes through human kidneys in order to filter out about 2 liters of excessive water containing waste products in the form of urine [2]. Blood enters a kidney through renal arteries for purification where the metabolic waste in the blood enters glomerular filtrate (urine). Kidney contains more than a million small filtration units called nephrons. The nephron can structurally be divided into two parts-the Bowman's capsule and the renal tubule. Absorption of useful substances like glucose, sodium, bicarbonate, potassium, phosphate, calcium and amino acids from the filtrate takes place in the nephron. This reabsorption takes place through small pores among the surface cells on the tube walls. The glomerular filtrate, after the reabsorption process is completed, enters the bladder through ureters for excretion. There have been several mathematical studies on the analysis of fluid flow through renal tubules, both in plane channel geometry and in cylindrical tube geometry. Researchers have assumed several variations in the type of variation that takes place through the tubule walls. Some discussions of renal tubule models were presented by Wesson [3] & Burgen [4]. These studies were theoretical in nature and the authors assumed a constant rate of reabsorption. There have also been studies on a purely mathematical basis that address the analysis of flow through porous walled channels and ducts. These works, however, by Berman [5-9] do not include the application of flow through renal tubules. The idea of these studies is to establish the nature of the flow as a two-dimensional flow. This is caused by a transverse velocity component that arises due to the suction/absorption that takes place at the surface of channel walls. Thus, the velocity pro les of such flows differs greatly from simple Poiseuille flow.

Macey [10] presented the rest formal mathematical treatment of the flow through renal tubules taking into account a constant or uniform reabsorption rate. Kelman [11] argued that the reabsorption function showed an exponential decay through the proximal renal tubule in his theoretical study. Macey [12] again incorporating the exponential decay assumption in his work. He presented explicit solutions for axially symmetric creeping flow as well as for the average pressure drop in the tubule. Kozinski [13] presented an extension of Macey's work for porous channels. Marshall [14] & Palatt et al. [15] presented their analyses of fractional reabsorption and leakage flux in the proximal renal tubules. Radhakrishnamacharya [16] also studied such flows in tubules of varying cross section. On similar lines, diverging and converging tubes as well as tubes with slowly varying cross-section were also studied [17].

Ahmad [18] additional considered periodic reabsorption velocity at tubule walls and obtained exact solutions for the flow. More recently, Siddiqui et al. [19-24] presented various mathematical analyses for creeping flow of Newtonian fluid through a porous slit or tube with various functions for reabsorption at the wall, with no-slip as well as slip effects taken into consideration. In another advancement of the studies under consideration, it is argued that disease in the renal tubule can make the tubule channel to act as a porous medium. Various diseases like interstitial nephritis or tubular proteinuria can cause excess amounts of fibers, proteins, fatty substances and cholesterol can enter the glomerular filtrate. These substances can then get suspended in tubule channels. These glomerular diseases can therefore affect the permeability of the tubular channel. Moreover, some fatty fibers may also cause full or partial blockage of the channel. In the latter case, some material passes through the blocked duct. This phenomenon can be modeled effectively with the equations for flow through porous media. These models take into account the supplementary drag forces exerted on the flow due to the presence of solid matrix fibers [25]. Two of the more recent studies incorporating porous medium for creeping flow through porous walled channels are by Siddiqui et al. [26,27]. Some of the studies mentioned here use the data for rat kidneys to study pressure differences and effects of reabsorption parameters on the flow. Most of the works discussed and cited here are limited to the study of Newtonian fluid flows. However, in recent years, there have been some advancements in the field of non-Newtonian fluids flowing through porous channels as well (See, for example, [28-30]). There is also consideration being given to study the flow of couple stress fluid [31] through porous channels. Couple stress fluid has also been known to model blood flow in various physiological situations [32]. In our opinion, the idea of using couple stress fluid model to study the flow through porous walls its very well in context of a diseased renal tubule. Since couple stress fluid model is a blending model, it incorporates the presence of particles in the fluids, and can also be useful for consideration of polar effects. Hence with non-Newtonian fluids, the possibilities of studying flow through renal tubules are endless.

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