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小動脈之微連體理論與形態分析

On the Analysis of Microcontinuum Theory and Morphology for Small Arteries

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摘　要

當小動脈的血液被視為傳統牛頓流體分析時，會得到一組拋物線的速度分布圖，然而諸多實驗的觀測顯示血液在小動脈流動時並不符合此結果。近年來，許多研究應用微連體理論(microcontinuum theory)來分析血液的流動，此乃因為這套理論可處理宏觀元素(macroelement)內紅血球的交互作用。

文獻指出當血液流入小血管時，血球會有集中現象，但是許多將血液視為微連體的研究中，並無考慮血球的分布。因此，在我們的血液模型中使用一個可以描述血球分布的函數，於是本模型隨後被化簡成一外層以及一內層的兩層流(two-layer flow)。當兩層都被視為微形流體(micromorphic fluid)時，我們找到其理論解。而後，基於一個用以計算稀釋流體的有效黏度公式，我們將內層視為微形流體而外層當作古典牛頓流體並且獲得理論解。為了使分析問題更具合理性，我們藉由文獻中的實驗結果與所求得之理論解，計算並建立在微形流體中的一個修正參數。

基於紅血球分布的數值結果，在小動脈的旋轉場與速度場皆與文獻的實驗結果相應。因此，紅血球在小動脈中的分布會影響血液的流動性質，相對於古典牛頓流體在小動脈中的解，其結果具有較高的速度分布，這表示流通量相較於傳統的分析是迥然不同。由於小動脈的形態學(morphology)與血液之流通量有關，因此我們修正 Murray 的定律以及小動脈的形態分析。對於分析血管半徑的最佳設計，目前的理論結果顯示應當比傳統理論來的大，而針對小動脈的最佳分叉角，目前的理論也建議應比傳統所算得之結果來得大。

關鍵字：微連體理論，微連續體理論，微形流體，Eringen 流體，血流，紅血球分布，形態學，血管分叉，Murray 定律

Abstract

On the analysis of the blood flow as the classical Newtonian fluid in small arteries yields a parabolic velocity profile. Experimental observation shows that the blood flow in small arteries does not obey the result. Recently, many studies apply the microcontinuum theory to analyze the blood flow since the theory take red blood cells' interaction into account in a macroelement.

Literatures denote that cells will be concentrated when the blood flowing into small arteries. But most of the microcontinuum approaches do not consider cells distribution. Hence, a function describing cells distribution is used in our blood model. Accordingly, the model is then reduced into a two-layer flow, a peripheral layer and a core layer. We find the theoretical solutions in the case of both two layers are micromorphic fluids. Later, the core layer is modeled as a micromorphic fluid, and the peripheral layer is made of classical Newtonian fluid based on an effective viscosity formula for dilute fluid then the theoretical solutions are obtained. We also use the solutions to calculate and to create a modified parameter in the micromorphic fluid by experimental results form literatures in order to analyze the problem reasonably.

Numerical results depending on red blood cells distribution, the rotation and velocity fields in small arteries compared with the experimental results from literature are correspondingly. Therefore, red blood cells distribution affects the blood flow properties in small arteries. The results yield higher velocity distribution than the classical Newtonian fluid approach in small arteries. This implies the flow flux is different from the classical analysis.

Since the morphology for small arteries is related to the blood flow flux, we modify the Murray's law and some morphological analysis for small arteries. The results show that the optimal design of arterial radius in present theory is larger than the classical approach, and the optimal bifurcation angle in small arteries is suggested to be also grater than the classical approximation.

Key words: microcontinuum theory, micromorphic fluid, Eringen fluid, blood flow, red blood cells distribution, morphology, vascular bifurcation, Murray's law.