Modeling Blood Flow in Macrocirculatory System

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Notes pertaining to mathematical models of blood flow in the macrocirculatory system.

Contents

1 Introduction

The circulatory system consits of a human's humans heart, vascular network, lungs and organs. The heart is the source, transporting Oxygen-rich blood to the organs and deoxygenated (and carbon dioxide enriched) blood back to the lungs; to discharge $CO2$ and enrich blood with Oxygen. We refer to these respective processes as the *pulmonary circulation* and the *systemic circulation* (resp.). The *macrocirculatory system*, consists of the heart and the large vessels in the systemic circulation. Particularly, the arteries and large vessels of the macrocirculatory system transport oxygenated blood from the heart, driving the return of deoxygenated blood back to the heart. Hemodynamics refers to the study of blood flow in the circulatory system.

Cardiovascular disease (CVD) is the leading cause of death in developed nations. According to the World Health Organization (WHO), CVD accounts for approximately 31% of all global deaths, making it a significant public health concern. Understanding the hemodynamics of the macrocirculatory system is crucial for diagnosing, treating, and preventing CVD. We aim to develop mathematical models that accurately describe blood flow in the macrocirculatory system. Our motivation is to use these models to simulate and analyze various cardiovascular conditions, such as arterial stenosis, aneurysms, and heart valve disorders.

A single beat of the heart propels blood through the macrocirculatory system, and the cardiac cycle refers to the events between two successive heartbeats. The cardiac cycle consists of two main phases: systole and diastole, during which the heart chamber is accumulating blood and releasing blood (resp.). The beat can be recognized as a pulse wave in large vessels.

We assume a normal resting heart rate of approximately 70 beats per minute (bpm), which corresponds to a cardiac cycle duration of approximately 0.86 seconds. We refer to a single beat of the heart, and the following relaxation period, as the cardiac cycle. The cardiac cycle consists of two main phases:

- Systole duration $\approx 0.15 - 0.3$ seconds. Heart contracts, propelling blood into the arteries. The "lub-dub" sound derives from the start and end of systole, when the heart valves close.
- Diastole duration ≈ 0.7 seconds. Heart relaxes, allowing the chambers to fill with blood.

The blood volume of human is approximately 5.7-6.0 liters of blood, flowing a full cycle approximately every 70 beats. The energy driving the flow comes from oxygen and nutrients absorbed from food, creating waste products that must be removed; the *coronary artery*'s responsibility. The buildup of waste products results in Arteriosclerosis, a narrowing of the artery.

Our concern is the flow of blood in the macrocirculatory system. We develop mathematical models descibing the hemodynamics of arterial and large venous segments, refered to as *compliant vessels*, then we extend our models to macrocirculation networks.

2 Preliminaries

Mathematical Notation

- $\mathbb{R}$ denotes the set of real numbers.
- $\mathbb{R}^n$ denotes n-dimensional Euclidean space.
- $\mathbb{R}^{m \times n}$ denotes the set of $m \times n$ real-valued matrices.
- ∂A denotes the boundary of a set A.
- ∇ denotes the gradient operator.
- $\nabla \cdot$ denotes the divergence operator.
- ∇^2 denotes the Laplacian operator.

Symbols

2.1 The Navier Stokes System

In *continuum mechanics*, matter is modeled by *continuous fields*. For instance, to model the behavior of an *incompressible* fluid in time, one could use a **pressure field** and a **velocity field**. At *atomic scales*, this model breaks down—fluids as fluids are discrete collections of molecules, not continuous fields. However, at the macroscopic scale, one can hope that such models remain accurate.

$$\text{TODO: Add system} \tag{1}$$

2.1.1 NS-Sytem Derivation

2.2

3 Coronary Artery Stenosis (CAS)

Coronary artery stenosis (CAS) is the narrowing of the coronary arteries due to the buildup of plaque. This narrowing can restrict blood flow to the heart muscle, leading to various cardiovascular problems, including chest pain (angina), heart attacks, and other serious complications. Current methods for predicting coronary artery stenosis are rudimentary; and often prediction does mean coronary artery stenosis obstruction ([1]). . There is a need for more accurate and reliable methods to predict and assess the severity of CAS. narrowing can restrict blood flow to the heart muscle, leading to various cardiovascular problems, including chest pain (angina), heart attacks, and other serious complications. Current methods for predicting coronary artery stenosis are rudimentary; and often prediction does mean coronary artery stenosis obstruction. . There is a need for more accurate and reliable methods to predict and assess the severity of CAS.

We perform a literature survey of arterial blood flow using known methods from the literature, with the hope of understanding the computational challenges and tradeoffs of various *mathematical models*.

Make some comment about ”correct terminology for describing the types of coronary arterial stenosis is ”coronary artery stenosis morphology.” and ref figures in DOI: 10.1056

Understand Dr. Zhou’s statement: Regarding the assumption about the absence of a vortex, I cannot defini-

4 Literature Review

5 Appendix

References

[1] Add authors here. “Add exact title here”. In: *European Heart Journal* (2021). DOI: 10.1093/eurheartj/ehab332. URL: https://watermark.silverchair.com/ehab332.pdf.

References

Code Listings

Optional Space for sumplementary code listings of computations done while investigating

Code 1: Algorithm 16.5

```
function foo()
    println("Hello World)
end
```