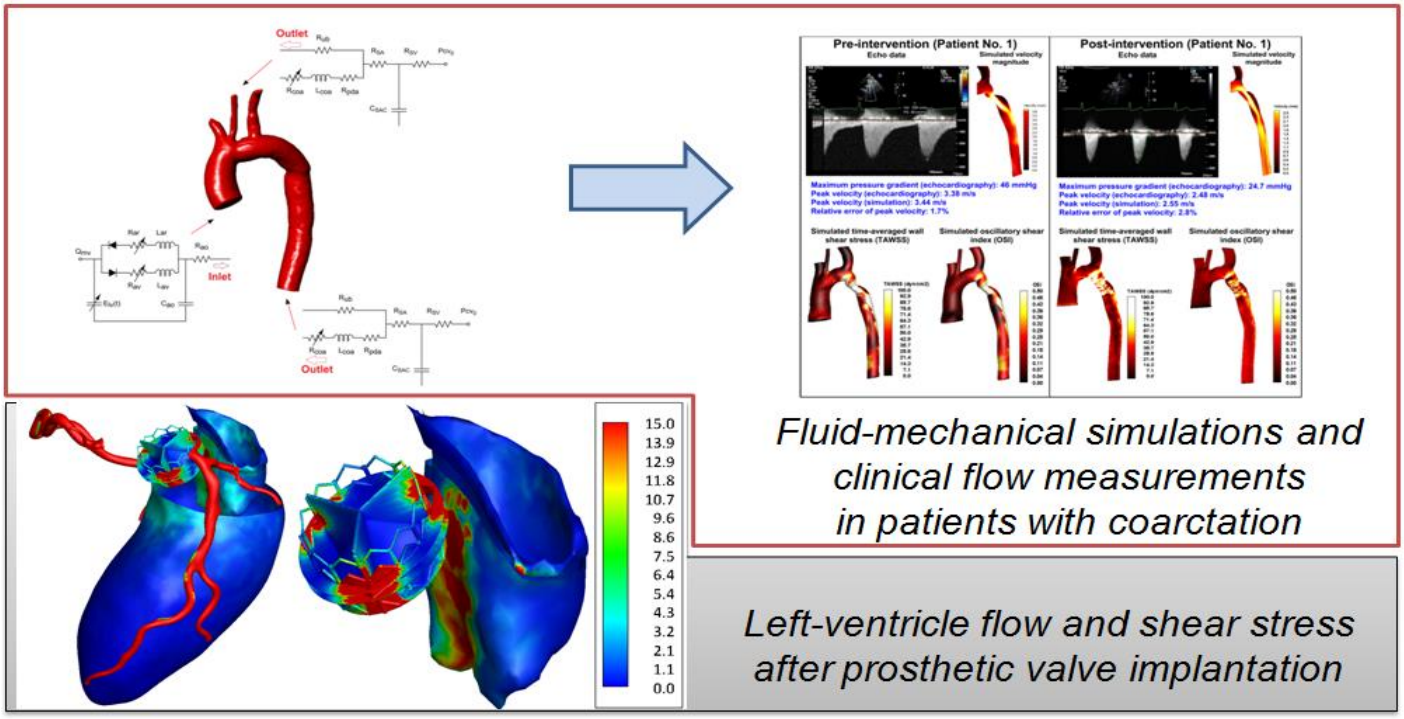
Department of Mechanical Engineering
School of Computational Science and Engineering
School of Biomedical Engineering
McMaster University

MECHENG 762 (BIOMED 762)
Computational Modeling of Circulatory System
Term 2 (January – April 2024)



https://www.eng.mcmaster.ca/mech/people/faculty/zahra-k-motamed

Instructor: Dr. Zahra Motamed
Office: *ABB-C* 307
Email: motamedz@mcmaster.ca
Office hours: Mondays, 4 to 5 pm

Lectures: **Mondays, 1 to 4 pm**
Tutorials: none
Laboratories: none

Course website: via *Avenue to Learn* (avenue.mcmaster.ca)

Course Description & Objectives

The circulatory system consists of the heart and a network of vessels that transport the blood. The heart consists of two pulsatile pumps in series and circulates blood through the vasculature. The vasculature

consists of arteries, arterioles, capillaries, venules and veins. The circulatory system also includes local circulation subsystems such as cerebral, pulmonary and renal circulations. Mechanics of the circulatory system may be studied from two biomechanical perspectives: solid mechanics of the blood vessels and fluid mechanics of the blood flow. The main objectives of the course are to learn basics of modeling of circulatory mechanics and getting familiar with the current challenges involved in the modeling process. Computational modeling of circulatory system presents formidable mathematical and computational challenges: modeling must incorporate motions of blood and vessel walls, complex biomechanics of the heart, a large network of the blood vessels with complicated geometries, persistent pulse-driven changes in flow and pressure, complicated exchanges happening in local circulatory subsystems and in some cases behavior of blood cells. After a brief review of circulatory physiology and fluid mechanics, the course will progress from modeling blood flow in small-scale steady/pulsatile to model large-scale or complex pulsatile flow. This course will cover various methods for modeling mechanics of the circulatory system and its subsystems. We will discuss the application of these concepts in the development of circulatory medical devices (e.g., stents, grafts, heart valves, trans-catheter valves and ventricular assist devices).

Significance

The main purpose of modeling circulatory mechanics is to study circulatory diseases. *In vivo* measurements are difficult, and even impossible in some cases. Non-invasive measurements are useful but do not always allow studying realistic conditions. Computational modeling of the circulatory system can fill this gap by playing major roles in uncovering causes of pathologies, in enabling prediction of effectiveness of interventions, in allowing systematic testing of possible clinical solutions, and in enabling personalization of interventions. Additionally, development and innovation of extra-corporal systems strongly rely on knowledge of the circulatory mechanics. Therefore, modeling is crucial for design and development of medical devices, and for evaluating of the hemodynamic effects of medical devices after implantation in the patient body.

Course Topics

Major topics to be covered *include:*

- Anatomy and physiology of cardiovascular system
- Flow, pressure and wave reflection in the circulatory system
- Medical image modalities and acquisition
- Medical image processing
- 3-D geometry reconstruction
- Fundamentals of hemodynamics
- Boundary conditions
- Computational fluid dynamics methods
- Soft tissue mechanics and computational fluid structure interaction
- Multi-scale simulations
- Lumped parameter mathematical models

Audience

This course has been designed for graduate students in science and engineering interested in learning about circulatory mechanic and its biomedical applications. The course will be of particular interest of students in the following departments and schools:

Mechanical Engineering, Chemical Engineering, Computing and Software, Electrical and Computer Engineering, Engineering Physics, School of Biomedical Engineering and School of Computational Science & Engineering. Students from the Faculty of Health Sciences are also welcomed to register for the course.

Email Policy

All emails directed to the instructor should include a subject prefix of "ME [course number]-[subject]".

Course Materials

Lecture Notes

The lectures notes will be made available on *Avenue*. The lectures notes do not always repeat materials from supplementary references.

Textbooks

There is no specific textbook for this course. The instructor will provide reading material including course notes, articles, videos and schematics. Following are some useful references for the course:

- Yamaguchi T (2000) Clinical Application of Computational Mechanics to the Cardiovascular System, Springer.
- Zamir M (2016) Hemo-Dynamics, Springer.
- Humphrey JD (2001) Cardiovascular Solid Mechanics: Cells, Tissues, and Organs, Springer.
- Guccione JM, Kassab GS, Ratcliffe MB (2010) Computational Cardiovascular Mechanics: Modeling and Applications in Heart Failure, Springer.
- Chandran KB, Rittgers SE, Yoganathan AP (2012) Biofluid Mechanics: The Human Circulation, Second Edition, CRC Press, Taylor & Francis Group.
- Nichols W, O'Rourke M, Vlachopoulos C (2011) McDonald's Blood Flow in Arteries, Sixth Edition, CRC Press, Taylor & Francis Group.
- Waite L, Fine JM (2017) Applied Biofluid Mechanics, Second Edition, McGraw Hill.
- Waite L (2006) Biofluid Mechanics in Circulatory Systems, McGraw-Hill.
- Kleinstreuer C (2006) Biofluid Dynamics: Principles and Applications, CRC Press, Taylor & Francis Group.

Evaluation

The final grade will be calculated by combining presentations, term project paper and the final exam as follows. The percentage marks will be converted to a final letter grade using the standard conversion scale shown in the McMaster Graduate Calendar.

First presentation **(February 12h & 19th** & Abstract **(February 9th)**	**20%** (10 minutes **presentation** of project definition and one-page **abstract** defining the project)
Second presentation **(April 1st & April 8th)**	**25%** (15 minutes **presentation** of project update)
Term project paper	**45%** (Deadline for submission: **April 22nd**)
*Contributing to class discussions in synchronous sessions	**10%**

* In this course, class discussion about the subject matter helps better understanding of the material. To encourage learning from peers and interactive and effective learning, 10% bonus mark is considered for contributing to class discussions in synchronous sessions.

Term Project: All students will be required to work individually on a research project. The final deliverable will be a written research report. Each student will select a topic related to **cardiovascular engineering** (not related to their thesis research) and will prepare a report. The research report **should be written as a scientific journal article**. **This article can be either an original modeling research paper or a comprehensive review paper about modeling of circulatory system**. Some potential topics (but not limited to) are listed below:

- Device modeling: ventricular assist devices, trans-catheter heart valves, stents, grafts, etc.
- Circulatory surgical planning modeling
- Cell-level modeling: red blood cells, platelets, white blood cells, endothelial cells, etc.
- Modeling of vascular and mini-vascular pathologies
- Modeling of ventricular pathologies
- Modeling of valvular pathologies

Presentation: Each student will give three presentations.

Attendance: ***Class attendance is highly recommended***.

Class Website: All registered students will have access to the class website via *Avenue* (avenue.mcmaster.ca). Class announcements, course information and course documents are contained on this website. This website will be continuously updated with related information throughout the semester.

Learning Outcomes

Upon successful completion of the course, it is expected that the students will be able to:

- Understand medical imaging
- Know specific circulatory diseases and how they are related to mechanics

- Understand fluid and solid mechanics models currently used for circulatory research problems
- Understand the effect of mechanical forces on various circulatory cells
- Understand biomechanical issues in select circulatory medical devices
- Be familiar with the state-of-the-art computational modeling methods
- Have the understanding and the capability to develop simple models of circulatory function under varying preload, afterload, and contractility
- Have the understanding and the capability to develop simple models of blood flow in devices and circulatory system
- Have the understanding and the capability to develop simple models of stress and strain in blood vessels and heart tissue
- Develop critical thinking regarding the current research challenges in circulatory mechanics
- Have the understanding and the capability to carry out a circulatory-mechanics research project

Notice Regarding Possible Course Modification

The instructor and university reserve the right to modify elements of the course during the term. The university may change the dates and deadlines for any or all courses in extreme circumstances. If any modifications become necessary, reasonable notice and communication with the students will be given with explanation and the opportunity to comment on changes. It is the responsibility of the student to check their McMaster email and course websites weekly during the term and to note any changes

Equity, Diversity, and Inclusion

Every registered student belongs in this course. Diversity of backgrounds and experiences is expected and welcome. You can expect your Instructor to be respectful of this diversity in all aspects of the course, and the same is expected of you. The Department of Mechanical Engineering is committed to creating an environment in which students of all genders, cultures, ethnicities, races, sexual orientations, abilities, and socioeconomic backgrounds have equal access to education and are welcomed and treated fairly. If you have any concerns regarding inclusion in our Department, in particular if you or one of your peers is experiencing harassment or discrimination, you are encouraged to contact the Chair, Associate Undergraduate Chair, Academic Advisor or to contact the Equity and Inclusion Office.

Physical and Mental Health

For a list of McMaster University's resources, please refer to the Student Wellness Centre. There is also a list of resources appended to this document.

Academic Integrity

You are expected to exhibit honesty and use ethical behaviour in all aspects of the learning process. Academic credentials you earn are rooted in principles of honesty and academic integrity. **It is your responsibility to understand what constitutes academic dishonesty. Academic dishonesty is to knowingly act or fail to act in a way that results or could result in unearned academic credit or advantage.**

This behaviour can result in serious consequences, e.g. the grade of zero on an assignment, loss of credit with a notation on the transcript (notation reads: "Grade of F assigned for academic dishonesty"), and/or suspension or expulsion from the university. For information on the various types of academic dishonesty please refer to the Academic Integrity Policy, located at https://secretariat.mcmaster.ca/university-policies-roceduresguidelines/

The following illustrates only three forms of academic dishonesty:

- plagiarism, e.g. the submission of work that is not one's own or for which other credit has been obtained.
- improper collaboration in group work.
- copying or using unauthorized aids in tests and examinations.

Authenticity / Plagiarism Detection

Some courses may use a web-based service (Turnitin.com) to reveal authenticity and ownership of student submitted work. For courses using such software, students will be expected to submit their work electronically either directly to Turnitin.com or via an online learning platform (e.g. A2L, etc.) using plagiarism detection (a service supported by Turnitin.com) so it can be checked for academic dishonesty. Students who do not wish their work to be submitted through the plagiarism detection software must inform the Instructor before the assignment is due. No penalty will be assigned to a student who does not submit work to the plagiarism detection software. All submitted work is subject to normal verification that standards of academic integrity have been upheld (e.g., on-line search, other software, etc.). For more details about McMaster's use of Turnitin.com please go to www.mcmaster.ca/academicintegrity.

Courses with an On-Line Element

Some courses may use on-line elements (e.g. e-mail, Avenue to Learn (A2L), LearnLink, web pages, capa, Moodle,ThinkingCap, etc.). Students should be aware that, when they access the electronic components of a course using these elements, private information such as first and last names, user names for the McMaster e-mail accounts, and program affiliation may become apparent to all other students in the same course. The available information is dependent on the technology used. Continuation in a course that uses on-line elements will be deemed consent to this disclosure. If you have any questions or concerns about such disclosure please discuss this with the course instructor.

Online Proctoring

Some courses may use online proctoring software for tests and exams. This software may require students to turn on their video camera, present identification, monitor and record their computer activities, and/or lock/restrict their browser or other applications/software during tests or exams. This software may be required to be installed before the test/exam begins.

Conduct Expectations

As a McMaster student, you have the right to experience, and the responsibility to demonstrate, respectful and dignified interactions within all of our living, learning and working communities. These expectations are described in the Code of Student Rights & Responsibilities (the "Code"). All students share the responsibility of maintaining a positive environment for the academic and personal growth of all McMaster community members, **whether in person or online.**

It is essential that students be mindful of their interactions online, as the Code remains in effect in virtual learning environments. The Code applies to any interactions that adversely affect, disrupt, or interfere with reasonable participation in University activities. Student disruptions or behaviours that interfere with university functions on online platforms (e.g. use of Avenue 2 Learn, WebEx or Zoom for delivery), will be taken very seriously and will be investigated. Outcomes may include restriction or removal of the involved students' access to these platforms.

Academic Accommodation of Students with Disabilities

Students with disabilities who require academic accommodation must contact Student Accessibility Services (SAS) at 905-525-9140 ext. 28652 or sas@mcmaster.ca to make arrangements with a Program Coordinator. For further information, consult McMaster University's Academic Accommodation of Students with Disabilities policy.

Requests for Relief for Missed Academic Term Work

McMaster Student Absence Form (MSAF): In the event of an absence for medical or other reasons, students should review and follow the Academic Regulation in the Undergraduate Calendar "Requests for Relief for Missed Academic Term Work".

Academic Accommodation for Religious, Indigenous or Spiritual Observances (Riso)

Students requiring academic accommodation based on religious, indigenous or spiritual observances should follow the procedures set out in the RISO policy. Students should submit their request to their Faculty Office *normally within 10 working days* of the beginning of term in which they anticipate a need for accommodation or to the Registrar's Office prior to their examinations. Students should also contact their instructors as soon as possible to make alternative arrangements for classes, assignments, and tests.

Copyright and Recording

Students are advised that lectures, demonstrations, performances, and any other course material provided by an instructor include copyright protected works. The Copyright Act and copyright law protect every original literary, dramatic, musical and artistic work, **including lectures** by University instructors.

The recording of lectures, tutorials, or other methods of instruction may occur during a course. Recording may be done by either the instructor for the purpose of authorized distribution, or by a student for the purpose of personal study. Students should be aware that their voice and/or image may be recorded by others during the class. Please speak with the instructor if this is a concern for you.

Extreme Circumstances

The University reserves the right to change the dates and deadlines for any or all courses in extreme circumstances (e.g., severe weather, labour disruptions, etc.). Changes will be communicated through regular McMaster communication channels, such as McMaster Daily News, A2L and/or McMaster email.