MD Tanvir Rahman Faisal

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College & Department: College of Engineering, Mechanical Engineering

Research interests/project:

I am the only Biomedical Engineering (BME) research investigator in Mechanical Engineering and one of very few in the College of Engineering. Our expertise lies in musculoskeletal biomechanics and the mechanics of cellular materials. The Our research interests lie at the interface of biology and engineering with the goals to investigate biomedical issues using mathematical and engineering principles and to explore the fundamentals of bio-inspired design for engineering systems and structures. In this journey, we apply a combined approach of theory, simulations and experiments to study the mechanical response at multiple length scales. Area of Research:

1. Orothopaedic Biomechanics
    a. Knee Osteoarthritis
    b. Osteoporotic (Hip) Fracture Risk prediction
2. Tissue Engineering
3. Design and Mechanics of Architected Cellular Materials
4. AI in Orthopaedics

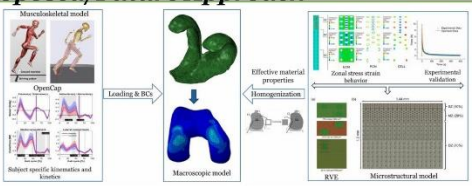
Scroll down to view more information on Dr. Faisal's Musculoskeletal Mechanics & Multiscale Materials Lab.

Multiscale Modeling of Articular Cartilage: Integrating Subject-Specific Kinetics & Kinematics, Homogenization, and Fibril-Reinforced FE Approaches

Problem Description

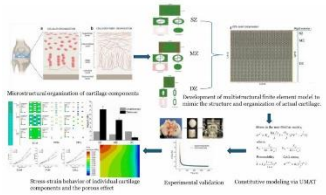
- Research Problem
  - Accurately modeling the depth-dependent biomechanics of articular cartilage is difficult due to its intricate, multi-scale structure and its pivotal role in osteoarthritis progression
- Limitations on Current State of the Art:
  - Existing approaches often ignore personalized musculoskeletal loads and the multiscale interactions among collagen fibrils, ECM, PCM, and chondrocytes, leading to oversimplified cartilage behavior and incomplete insight into degeneration mechanisms.
- Research Goal
  - Integrate musculoskeletal kinematics, homogenization techniques, and a multi-structural fibril-reinforced model to reveal zone-specific cartilage behavior, improving OA diagnosis and regenerative strategies.

Proposed/Future Approach



- **Short term:** Integrate subject specific kinetics and kinematics to FEA, material homogenization, developed macroscopic 3D model.
- **Long term:** Improve multiscale modeling technique of cartilage

Current Research



- Develop a multi-structural fibril reinforced finite element model.
- Validate the model accuracy with experiment.
- Investigating the deformation behavior of individual cartilage component in zonal and radial direction under physiological loading conditions.

Future Research Scope & Opportunity

- Advanced multiscale modeling with subject specific gait parameters.
- Bio-chemo-mechanical modeling
- AI driven simulation and parameter optimization.
- Cartilage scaffold design informed by modeling insights.

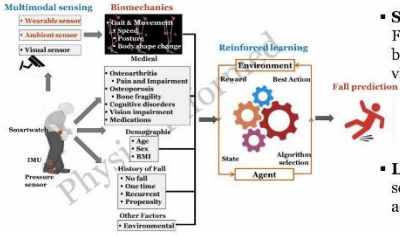
Musculoskeletal Mechanics & Multiscale Materials (4M) Lab

Predictive Biomechanics: Estimating Fall Risk through Integrated Multimodal Sensing and Physics-based Machine Learning

Problem Description

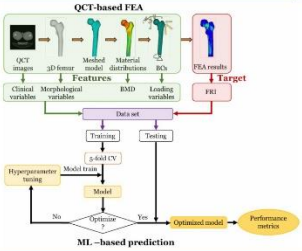
- Research Problem
  - Fall risk depends on multitude of factors (physical health, medications, cognitive impairment, biomechanics), and has high inter-patient variability
- Limitations on Current State of the Art:
  - Limited integration of physical reality, health conditions, biomechanics, and ML. Also, existing ML/AI literature focusses on fall detection using either computer vision or medical records
- Research Goal
  - The goal of this research is to improve **fall risk prediction** by extending existing actuarial models with multi-modal sensing, learning and biomechanics

Proposed/Future Approach



- **Short term:** Automated FEA, materials property, biomechanical modeling via multimodal ML
- **Long term:** Multimodal sensing, biomechanics, and actuarial model

Current Research Accomplishment



- Computational modeling via Finite Element Analysis
- 3D reconstruction of femur using DL
- Interpretable ML to find the root cause of hip fracture risk

Future Research Scope & Opportunity

- A complete AI driven fall predictive modeling using multimodal sensing, biomechanics, and actuarial model
- Wearable sensor systems for fall risk assessment
- Computational biomechanics
- Image processing and image-based biomechanics
- Hip implant design

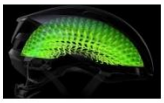
Musculoskeletal Mechanics & Multiscale Materials (4M) Lab

Application Specific Design and Analysis of Cellular Metamaterials via Experiments and Computation

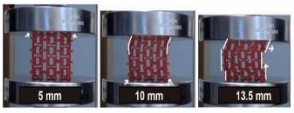
Problem Description

- Research Problem
  - Cellular materials can be used in tissue engineering, large structural applications , energy harvesting as well as in many applications, specially weight critical application, unit cell design dictate the properties
- Limitations on Current State of the Art:
  - Versatile design, one design does not fit for all. multifunctional properties are still difficult to achieve, coupling of design and base materials are still missing
- Research Goal
  - Application specific design and analysis of cellular materials comprising mechanical meta materials, 2d/3D lattice and auxetics

Proposed/Future Approach



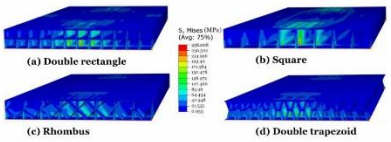
- **Short term:** Design of metamaterials for helmet, stent, and tissue engineering



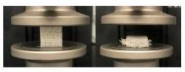
- **Long term:** Automated tool for metamaterials design and multiscale modeling and additive manufacturing , soft robotics

Current Research Accomplishment

Structural Application: Bridge Deck



Tissue Engineering



- Computational modeling via Finite Element Analysis
- Experiments with 3D printed samples, materials fabrication
- Scaffolds design for tissue engineering

Future Research Scope & Opportunity

- Design of cellular metamaterials for different application in multiple scales and Biomimetics
- Computational mechanics
- Experimental mechanics
- 3D printing

Musculoskeletal Mechanics & Multiscale Materials (4M) Lab

Musculoskeletal Mechanics & Multiscale Materials (4M) Lab
PI: Tanvir R. Faisal, Ph.D.

Who we are

Synopsis: As of now, I am the only Biomedical Engineering (BME) research investigator in Mechanical Engineering and one of very few in the College of Engineering. Our expertise lies in musculoskeletal biomechanics and the mechanics of cellular materials. The Our research interests lie at the interface of biology and engineering with the goals to investigate biomedical issues using mathematical and engineering principles and to explore the fundamentals of bio-inspired design for engineering systems and structures. In this journey, we apply a combined approach of theory, simulations and experiments to study the mechanical response at multiple length scales.

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Proposed/Future Approach

- Orthopaedic Biomechanics
  - Knee Osteoarthritis
  - Osteoporotic (Hip) Fracture Risk prediction
- Tissue Engineering
- Design and Mechanics of Architected Cellular Materials
- AI in Orthopaedics

What and How We Do?

- Computational (Bio-)Mechanics
  - Finite Element Analysis (FEA)
  - Image processing
  - Coding
- Experimental (Bio-)Mechanics
  - In vitro testing
  - Histology and Microscopy
- Machine and Deep Learning (AI/ML/DL)

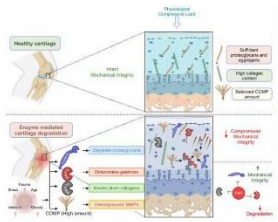
Research Scope & Opportunity

- In vitro and in vivo experiments
- Design and Analysis of cellular metamaterials
- FEA
- ML/DL modeling
- Bio-instrumentation
- Programming and Coding
- Collaborative work with experts from medical doctors and computer science and others...

Musculoskeletal Mechanics & Multiscale Materials (4M) Lab

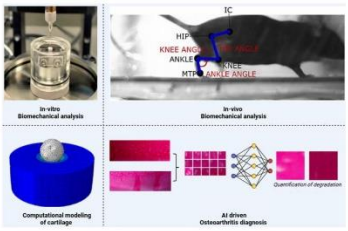
Experimental Investigation of Articular Cartilage Mechanics to Delay Osteoarthritis (OA) Initiation and Progression

Problem Description



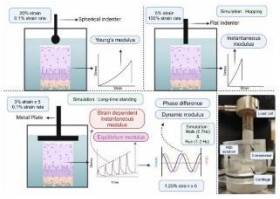
- Research Problem
  - Early detection of osteoarthritis (OA) is a challenge but crucial for delaying disease progression
- Limitations on current Research
  - Identifying biomarkers, lack of understanding the pathomechanics of cartilage damage and subsequent prevention
- Research Goal
  - Investigate the OA pathophysiology due to biochemical and biomechanical markers

Proposed/Future Approach

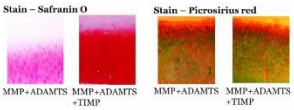


- **Short term:** In vitro and in vivo test with different biochemical and biomechanical markers. AI driven quantitative histomorphometry
- **Long term:** In vivo prevention testing

Current Research



- In vitro assessment of the role of degradative enzymes
- Understanding bio-chemo-mechanical effect of OA progression
- Histomorphometry and histology



Future Research Scope & Opportunity

- In vitro and in vivo experiments
- Histology, histopathology and Immunohistochemistry
- Microscopy and Imaging
- Mechanical testing
- Image analysis
- Collaborative work with orthopaedic surgeons and MD students