[1] Define the problem

Activities

1. Ask your question explicitly.
2. Identify domains,
   1. physiological, and
   2. mechanical.
3. Identify structure of interest.
4. Identify characteristics of modeled sample(s),
   1. demographics,
   2. state (in vivo, in vitro, in situ), and
   3. health condition.
5. Identify scales,
   1. spatial, and
   2. temporal scale.
6. Identify desired utility.
7. Identify expected outcomes.

[2] Define your metrics

Activities

1. Identify variables to make decisions in relation to defined problem,
    1. which can be acquired directly from simulation results, or
    2. which require further processing of simulation results.
2. Identify variables to evaluate correspondence of simulation results to reality,
    1. which can be acquired directly from simulation results, or
    2. which require further processing of simulation results.

[3] Check availability

Activities

1. Search for previous models developed to resolve similar problems, which can be reused for simulations relevant to the problem.
2. Search for previous models developed to resolve other problems, which can be repurposed and reused for simulations relevant to the problem.
3. Check access to information that can be used directly to assemble the model, e.g., derivative data presented in the form of geometries, meshes, material properties, loading conditions, etc.
4. Check access to raw data that can be processed and used to build the model, e.g., imaging of the structure of interest, raw physiological testing data.
5. Identify existing knowledge and data to evaluate correspondence of simulation results to reality.

[4] Acquire data

Activities

1. Collect data to inform anatomical properties of the model.
2. Collect data to inform physiological/material properties of the model.
3. Collect data to inform simulation scenarios of the model, e.g. loading.
4. Collect data to evaluate correspondence of simulation results to reality.
5. Use data management system to organize data and keep them under version control.

[5] Choose simulation software

Activities

1. Choose simulation software relevant to physiological and mechanical domains of interest.
2. Decide which version of the simulation software you will be using.
3. Choose solution strategy available within the simulation software relevant to domains of interest.
4. If default setting is not desirable, determine convergence criteria used for completion of a simulation.
5. Verify capabilities of the simulation software relevant to the components needed to solve the problem.
6. If licensing (cost) is an issue, identify alternative simulation software.
7. If necessary, integrate your own code into existing simulation software.
8. If necessary, rebuild simulation software based on available software libraries.

[6] Process data (pre-processing)

Activities

1. Process anatomical data to define the geometry of the model:
    1. imaging to geometry (segmentation),
    2. geometry to mesh (meshing), and
    3. set definitions on mesh, to define regions for prescription of properties, loading conditions, interactions, etc in model assembly.
2. Process physiological/material data to define physiological/material properties of the model, i.e., constitutive modeling to obtain material coefficients from stress-strain data.
3. Extract loading and boundary conditions from data relevant to simulation scenarios.
4. Extract biomechanical metrics, relevant to simulation output variables, from raw data collected to evaluate correspondence of simulation results to reality.
5. Use data management system to organize derivative data and keep them under version control.
6. Use version control system to organize and keep track of data analysis code and scripts.

[7] Assemble model

Activities

1. Assemble derivative data, e.g. meshes, physiological/material parameters (constitutive coefficients) to define subcomponents of the model, i.e. anatomical and physiological representation of biological structures.
2. Define interactions between subcomponents of the model, i.e. mechanical connections and data exchange pathways between subcomponents.
3. Prescribe simulation scenarios, i.e. loading and boundary conditions, relevant to the defined problem.
4. Use version control system to organize and keep track of different model assemblies.

[8] Conduct simulations

Activities

1. Conduct simulations to assess mesh convergence (a verification step).
2. Conduct simulations to evaluate correspondence of simulation results to reality (a validation step).
3. Conduct simulations to evaluate uncertainty of simulation results (a sensitivity analysis step).
4. Conduct simulations to make decisions in relation to the defined problem.
5. Use data management system to organize simulation results and keep them under version control.

[9] Process simulation results (post-processing)

Activities

1. Visualize and extract variables, which can be acquired directly from simulation results,
   1. relevant to mesh convergence,
   2. relevant to correspondence of simulation results to reality, and
   3. relevant to uncertainty in simulation predictions.
2. Process simulation results to calculate and store variables
   1. relevant to mesh convergence,
   2. relevant to correspondence of simulation results to reality, and
   3. relevant to uncertainty in simulation predictions.
3. Visualize and extract variables that can be acquired directly from simulation results, which can potentially be useful to make decisions in relation to the defined problem.
4. Process simulation results to calculate and store variables that can potentially be useful to make decisions in relation to the defined problem
5. Use data management system to organize processed simulation results and keep them under version control.
6. Use version control system to organize and keep track of code and scripts for analysis of simulation results.

[10] Interpret results

Activities

1. Confirm the association between variables used to evaluate correspondence of simulation results to reality to those used to make decisions in relation to defined problem.
2. Indicate the influence of the bounds of verification, validation, and sensitivity analysis results on potential errors in making decisions in relation to defined problem.
3. Indicate the practical implications of potential errors in making decisions in relation to defined problem.
4. Make decisions in relation to defined problem.

[11] Report

Activities

1. Document study indicating
   1. model identifiers & structure,
   2. simulation conditions, parameters, and solution settings,
   3. verification & validation, uncertainty estimation, sensitivity,
   4. assumptions and limitations, and
   5. availability.
2. Prepare a User's Guide describing the model in detail with sample use cases, e.g. simulation scenarios.
3. Publish implications of simulation results for scientific review of modeling workflow and conclusions of simulations.
4. Conform to available recommendations for reporting[1]

References

1. Erdemir A, Guess TM, Halloran J, Tadepalli SC, Morrison TM. Considerations for reporting finite element analysis studies in biomechanics. J Biomech. 2012 Feb 23;45(4):625-33.

[12] Share

Activities

1. Choose licensing for dissemination, e.g. public (at various levels) or private.
2. Disseminate raw data used for modeling, e.g., imaging, physiological/mechanical testing, ideally in human readable, openly accessible, or standardized formats .
3. Disseminate derivative data used for modeling, e.g., geometries, meshes, constitutive coefficients, ideally in human readable, openly accessible, or standardized formats.
4. Disseminate model(s), ideally in human readable, openly accessible, or standardized formats.
5. Disseminate workflows, i.e., specifications of building the model, conducting simulations, and evaluating and interpreting simulation results.
6. Provide access to data management and source code version control systems during development and/or afterwards.
7. Utilize sustainable repositories for long term dissemination of release versions of data, derivative data, scripts, model(s), etc.