UiO University of Oslo
Faculty/Institute/Department/Name

Recipient:

Date: 9 November 2017

Evaluation of " Flow of biological fluids in patient specific geometries" by Helena Svihlova

The following is an evaluation of the PhD thesis by Helena Svihlova. The evaluation report is written in the format usually used in Norway.

The content and objective of the dissertation:

The objective of the thesis is to investigate whether patient-specific computational modeling of blood flow in aneurysms and stenotic valves can expand our knowledge of human physiology possibly to the extent of being relevant for clinical use. The dissertation is based on five articles, two of which are published in clinical journals, two in "International Journal of Engineering Science", and finally the participation in benchmark study "the CFD Rupture Challenge 2013".

The two papers in clinical journals (as well the benchmark study) concern aneurysm blood flow and its relation to stroke caused by aneurysm rupture. Current clinical rupture indicators are not very precise and this fact has motivated many attempts to improve. Here, CFD simulations are performed in order to assess whether CFD-based indicators enable rupture prediction that is more precise than the clinical indicators currently used (such as e.g. volume, surface area, aspect ratio). The methodology used in these investigations of the thesis is state-of-the-art and carefully used. The conclusion is therefore, however, disappointing – the complex simulations provided by CFD do not seem to provide significant additional value compared to the traditional indicators, at least in the way they are used in this study. While there may be many reasons for this failure, similar results have been reported by several others research groups (e.g. my recent PhD student Ø. Evju came to a similar conclusion). Hence, as this thesis suggest, the computational biomechanics community may have been overly optimistic concerning rupture prediction. Alternatively, the precise mechanism involved in the mechanotransduction of aneurysms development and rupture has not been disclosed yet. The studies continue with volume-matched comparison. While refinement of the traditional indicators is warranted to advance this field, it seems ad hoc. A more systematic approach would be to check the correlations between the different indicators to identify to what extent the indicators are surrogates of each other or span truly independent features. In fact, we have done this (a part of the PhD project of Evju) and found that most of the indicators are largely uncorrelated, further H. Meng et. al. constructed improved indicators as superpositions of

Postal address:
E-mail:
www.uio.no

the traditional indicators. While also this approach seems ad hoc, at least it provides a systematic, constructive approach to indicator matching analysis.

In the last part of the thesis, derived from the last two papers, the topic of pressure estimation based on velocity measurement is discussed. Two methods, PPE and STE, are described and compared with traditional estimated based on variants of Bernoulli´s equation. Since Bernoulli´s equation describes stationary flow of an inviscid fluid or gas, it seems dubious to employ this derivation to any kind of physiological flows. Still, Bernoulli is the explanation posed by various medical textbooks and papers. As in the case of aneurysms, it seems obvious that CFD has the potential to advance also this field. The PPE method is closely related to pressure correction schemes often used for flow simulations while the STE method was new to me. It was interesting to see the improvement this method provided compared to the PPE method. Both of these methods seem to be very well suited for clinical use. But also in this part of the thesis I miss an analysis that uncover the correlation between the different methods. I suspect that a study with a sufficient number of patient-specific geometries would demonstrate strong correlations between the different techniques. Clinicians usually only need to differentiate between healthy and risky states and for that purpose the absolute value of pressure or WSS may not be important. As such, Bernoulli may be a sufficient surrogate.

The candidate´s original contribution:

The thesis is based on the results from five papers. These papers all have five or more authors and it is therefore hard to assess the candidate´s original contribution to the individual papers. I assume that simulations and post-processing is mostly performed by Svihlova, in all five papers. Further, since she is as the first author in the last two papers that she here has contributed significantly to the writing. Finally, that the thesis is her own writing. The thesis is clearly written and well organized. It has as a number of misprints and odd sentences, but it describes clearly the work that has been done. To summarize, based on these assumptions, the candidate demonstrates clearly her ability to conduct and document research on the highest level.

The scientific standard of the dissertation:

The choice of approaches, numerical methods and software tools for addressing the clinical, biomechanical problems posed here are at the research front as demonstrated by the fact that the results have been published in high quality journals. In particular, I believe the results form the pressure drop reconstruction in the last two papers may be valuable in clinical setting and may spear-point new research in biomechanics, numerics for this highly relevant topic. The main weakness of the thesis is a proper discussion of the assumptions and a discussion of the significance where the results are related to other findings, as described more under the next section.

The candidate´s perspective on the research area:

Computational modeling in biomechanics is a rapidly evolving subject that has advanced significantly in the recent decades due the increasingly powerful computers. Cerebral aneurysms in particular and cardiovascular diseases in general are of of the most popular subjects within this field. A number of issues have been addressed and discussed in this field, e.g., the effect of non-linear viscosity, fluid-structure interaction, boundary conditions, transitional/turbulent effects, numerical artifacts and resolution. Still, the number of contributions in this field is still today relatively small and I would argue that it is possible keep track of field. While it is impossible to provide a complete overview of the field in a journal paper, due to page limitations, a PhD thesis can/should provide a comprehensive overview. This dissertation only provides a partial overview of the field. This is the most serious weakness of an otherwise excellent thesis. For example, section 1.4 is weak – there are many studies not mentioned that would provide a more solid foundation for this work. Aside of this weakness there is also a general lack of quantification in discussions/conclusions. Finally, I miss a discussion of how the quantifications compare with related results.

The technical quality of the dissertation:

The candidate demonstrates a broad experience that spans from segmentation of medical images in various formats to implementation and simulations with several different software framework, such as Fstrin, FEniCS, and Fluent, and various numerical techniques. She has also participated in benchmark efforts (Berg et. al. 2015). The thesis clearly contains novel and non-trivial work as demonstrated by five papers in well-renowned journals – in fact, in my view, it is rare that a PhD-student´s work results in five papers. There is a clear bias towards mathematical and methodological rigor rather than biomechanical and physiological rigor/relevance, a fact that may be regarded as both positive and negative, depending of the eye of the beholder.

The conclusion:

The dissertation is clearly worthy of being defended.

Sincerely yours

Kent-Andre Mardal, University of Oslo, Now 9, 2017