Ultrasound Based Computational Fluid Dynamics Assessment of the Brachial Artery

Darshigaa Gurumoorthy[1] , Juan Pablo Gonzalez-Pereira[2] , Jenna Racine[3] , J. Igor Irugetagoyena[3] , and Alejandro Roldán-Alzate[1,2,4]

[1]Biomedical Engineering, University of Wisconsin-Madison [2]Mechanical Engineering, University of Wisconsin-Madison [3]Maternal and Fetal Medicine, University of Wisconsin-Madison [4]Radiology, University of Wisconsin-Madison

Cardiovascular Fluid Dynamics Laboratory

Introduction

Background

- Pre-eclampsia [PE] - pregnancy specific syndrome affecting 3-5% of all pregnancies.
  - Associated with significant mortality and morbidity of both the person and the foetus.
  - Leading cause of maternal, prenatal and neonatal mortality.
  - PE is currently characterized by the presentation of high blood pressures along with proteinuria (presence of proteins in urine).
  - If left untreated, PE leads to maternal eclampsia, liver rupture, stroke, pulmonary oedema or kidney failure. Further, it increases the risk of future cardiovascular diseases.
  - Children born to preeclamptic patients tend to be predisposed to bronchopulmonary dysplasia and cerebral palsy.
  - Despite the prevalence, there is a lack of understanding of the pathologies that lead to PE

- Early diagnosis is key for effective management of this condition

- Currently, symptomatically, the diagnosis involves blood pressure tests and urine tests.

- Other proposed tests include invasive and expensive diagnostic tools such as MiRNA testing.

- Underlying conditions such as pre-existing hypertension leads to underdiagnosis of PE and/or misdiagnosis.

Previous studies have established protocols using Wall Shear Stress (WSS) derived parameters as an indicator for PE using computational fluid dynamics.

Aim

Validate this methodology using a larger patient cohort and better investigate the relationship between WSS, hypertension and PE.

Materials and Methods

Patient Information

- Normotensive (NT), hypertensive (HT) and PE patients in their second and third trimesters of a singleton pregnancy were recruited. Exclusion criteria included eclampsia, preterm labor, rupture of membranes, evidence of systemic infections. multifetal gestations and an active autoimmune condition.
- All patients were matched for age, gestational period and parity. All PE patients were prescribed blood pressure medication (labetalol, hydralazine or nifedipine) and magnesium for seizure prophylaxis. Co-morbidities in the PE patients included fetal growth restriction (n=1) and gestational diabetes (n=1). One of the NT pregnant patients had prior morbid obesity and type 2 diabetes mellitus, treated with gastric bypass surgery.
- The study is HIPAA compliant and approved by the The Health Sciences Institutional Review Boards of the University of Wisconsin and UnityPoint-Health Meriter Hospital

Computational Fluid Dynamics

Figure 1: BA WSS evaluation pipeline. *A) BA contour, B) BA length, C) velocity profile from doppler, D) pre and E) post-occlusion BA models.*

- 2-D Ultrasound (US) scans and doppler scans of the brachial artery of patients of NT, HT and PE patients were processed using a custom MATLAB script to generate 3-D models
- These models accounted for the non-circular cross-sections and non-linear structures of the brachial artery pre and post occlusion using a sphygmomanometer
- Flow curves were then quantified for each model using the doppler scans.
- The models and flow curves thus obtained were imported into SimVascular to simulate blood flow in the modelled artery.
- Time averaged WSS (TWASS), peak systolic WSS, oscillatory shear index (OSI) and TWASS/OSI were obtained.

Results

- Around 115 models were created. Flow curves pre and post occlusion were created for each model.
- Further simulations and calculations are underway to calculate WSS derived parameters.
- These simulations will be used to further investigate the effects of underlying hypertension, including differences between HT, NT and PE Patients.

Conclusions

- This method could prove to be more accessible as it eliminates the need for invasive and expensive diagnostic tools.
- Allows for faster processing of images to provide more patient specific models.
- This enables for a more accurate diagnosis of PE as opposed to the currently available methods.

Future Work

- Process more models
- Optimization and automation of the described process

References

1. Ben W J Mol, Claire T Roberts, Shakila Thangaratinam, Laura A Magee, Christianne J M deGroot, G Justus Hofmeyr, Pre-eclampsia, The Lancet, Volume 387, Issue 10022,2016, Pages 999-1011, ISSN 0140-6736, https://doi.org/10.1016/S0140-6736(15)00070-7. (https://www.sciencedirect.com/science/article/pii/S0140673615000707)
2. Eric AP Steegers, Peter von Dadelszen, Johannes J Duvekot, Robert Pijnenborg, Pre-eclampsia, The Lancet, Volume 376, Issue 9741, 2010, Pages 631-644, ISSN 0140-6736, https://doi.org/10.1016/S0140-6736(10)60279-6. (https://www.sciencedirect.com/science/article/pii/S0140673610602796)
3. James J Walker, Pre-eclampsia, The Lancet,Volume 356, Issue 9237, 2000, Pages 1260-1265, ISSN 0140-6736, https://doi.org/10.1016/S0140-6736(00)02800-2. (https://www.sciencedirect.com/science/article/pii/S0140673600028002)
4. Jaszczuk I, Koczkodaj D, Kondracka A, Kwaśniewska A, Winkler I, Filip A. The role of miRNA-210 in pre-eclampsia development. Ann Med. 2022 Dec;54(1):1350-1356. doi: 10.1080/07853890.2022.2071459. PMID: 35543206; PMCID: PMC9103497.
5. Pewowaruk RJ, Racine J, Iruretagoyena JI, Roldán-Alzate A. Ultrasound Based Computational Fluid Dynamics Assessment of Brachial Artery Wall Shear Stress in Preeclamptic Pregnancy. Cardiovasc Eng Technol. 2020 Dec;11(6):760-768. doi: 10.1007/s13239-020-00488-6. Epub 2020 Oct 6. PMID: 33025370; PMCID: PMC9021976.

Acknowledgements

We would like to acknowledge Dr. Chad Vezina and Dr. Kristina Penniston of the SPUUR program.
We would also like to thank Dr.Alejandro Roldán-Alzate, Juan Pablo Gonzalez-Pereira and James Rice of the CVFD Lab.

CAIRIBU O'BRIEN CENTERS — Collaborating for the Advancement of Interdisciplinary Research in Benign Urology