Development of a Novel Fetal Heart Rate Triangulation Algorithm for Multiple Gestation Pregnancies

Cost-effective Healthcare: Relieving the Financial Burden During Pregnancy

A Thesis Prospectus
In STS 4500
Presented to
The Faculty of the
School of Engineering and Applied Science
University of Virginia
In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science in Biomedical Engineering

By
Camila Galavis

October 27, 2023

Technical Team Members:
Torrance Fredell
Brendan Shea

On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

Camila Galavis

ADVISORS

Technical advisor: Dr. Kristen Naegle, Dr. Natasha Sheybani, Department of Biomedical Engineering

STS advisor: Peter Norton, Department of Engineering and Society

General Research Problem

How can prenatal care be improved in the United States?

Improving prenatal care in the United States is one of the biggest contributors for keeping expectant mothers and their fetuses safe. Access to quality prenatal care is imperative, as inadequate healthcare can lead to detrimental consequences for both, the mother and the fetus. According to a study run by Martin and Osterman (2023), 12.5% of mothers had inadequate prenatal care throughout their entire pregnancies. There are multiple reasons why a mother might have inadequate healthcare, but the most pressing reasons include financial constraints, limited access to healthcare services, and disparities in the healthcare access and quality across the United States.

Minority and lower-income women often face the most barriers accessing adequate prenatal care, resulting in higher rates of maternal mortality. A recent study showed African American women being nearly three times more likely to die from pregnancy-related causes than their white counterparts according to the Center of Disease Control (Stafford, 2023). Making healthcare more cost effective in terms of the visits and the cost of the devices used would play a vital role in providing healthcare for low-income pregnant women, as well as expanding Medicaid coverage. Studies have shown that states which expanded Medicaid under the Affordable Care Act experienced a nearly 6% decrease in maternal mortality rates compared to non-expansion states (Eliason, 2020). Education and outreach efforts must be intensified to address gaps in knowledge and awareness about the significance of prenatal care. Telehealth services can play a pivotal role in increasing access, particularly for those in underserved areas (Nelson and Holschuh, 2021). By addressing these critical areas, we can work towards better outcomes for mothers and infants throughout the United States.

Development of a novel fetal heart rate monitor for multiple-gestation pregnancies

In multiple-gestation pregnancies, how may a human fetal heart rate monitor safely locate and distinguish fetal heartbeats in utero?

For my capstone project, I am working under the advising of Dr. Kristen Naegle and Dr. Natasha Sheybani, both whom are faculty of the Biomedical Engineering Program, and two fellow undergraduate BME students, Torrance Fredell and Brendan Shea to develop a novel, array based fetal heart rate monitor for multiple gestation pregnancies. Multiple gestation (twins, triplets, etc.) births account for approximately 3% of all live births in the United States (Gill et al., 2023). Nearly all multiple gestation births are preterm due to complications in the reading of the fetuses' heartbeats, often resulting in low birthweight and additional health complications for the infants. Therefore, with the high risk associated with multiple pregnancies, technological improvements are needed to further develop fetal monitoring. In standard clinic practice, the usual technology for fetal heart rate (fHR) monitoring is the Doppler ultrasound (US) (Hamelmann et al., 2020). Doppler US fHR monitoring is a commonly used method for determining fetus health in all pregnancy types (singletons, twins, triplets, etc). There are known limitations to the Doppler US such as inaccurate beat-to-beat estimation of fHR and frequent periods of signal loss, which is severe in the case of multiple gestations, presenting problems for the birthgiver, fetus, and doctors.

The primary objective of this project is to enhance the accuracy of a fHR monitor for multiple gestation pregnancies, ensuring optimal functionality while also maximizing the comfort and safety of the pregnant individual. The development of a Doppler US array concurrently with a MATLAB script, that is capable of spatial detection, and triangulation and differentiation of fHR for multiple fetuses without manual placement can improve the evaluation

of fetal health for health personnel and patients alike. We will develop a non-invasive method to seamlessly generate phantom heartbeats through the integration of microphones into a phantom gel that mimics the various layers of human tissue that surround a typical uterus, while avoiding the creation of unintended artifacts. One main focus is to refine the MATLAB code to filter and analyze US data to account for the varying acoustic impedances of tissues surrounding the uterus, as well as accounting for potential variations in fetal positions within the womb by using the integrated microphones inside the phantom gel. Additionally, modification of the mechanism for physically securing the Doppler US to the birthing person will allow for increased comfort and improved access to the lower back for epidural administration. These aims address the need for enhanced technology in multiple gestation infant care, with a focus on maternal comfort and fetal health.

Cost-effective Healthcare: Relieving the Financial Burden During Pregnancy

In the US, how do nonprofit advocacies and public health agencies help uninsured, underinsured, and low-income women and families manage the cost burdens of pregnancy?

Women with multiple-gestation pregnancies that are uninsured, underinsured, or are low-income, suffer greatly with the cost burdens of pregnancy. These costs encompass prenatal care, delivery, and postpartum care. Being unable to get sufficient healthcare risks these women's lives as well as their children's.

Women that are uninsured, underinsured, or from low-income in the United States that have multiple-gestation pregnancies, tend to spend more on prenatal care, delivery, and postpartum care than a singular gestation pregnancy (Tommy's, 2023). In a study by Lemos et al. (2013), "pregnancies with the delivery of twins cost approximately 5 times as much when

compared with singleton pregnancies; pregnancies with delivery of triplets or more cost nearly 20 times as much", which creates an even bigger financial burden if women do not have the right buffer for expenses. According to The Commonwealth Fund (TCF, 2020), the U.S. spends nearly twice as much as the average OECD on healthcare, therefore creating a financial burden on the U.S population, making the healthcare sector regarding Obstetricians and Gynecologists (OBGYN) a big participant in this question as well as The American College of Obstetricians and Gynecologists (ACOG). ACOG's mission is to maintain the highest standards of clinical practice for women's health care, strongly advocate for quality health care for women, and provide education for its members and the public. OBGYN doctors decide which course of action to take in every pregnancy, and the risks and costs associated with this, since they have special training regarding women's health (Petruska, 2022).

Public health agencies and nonprofit advocacies such as March of Dimes (MOD), Planned Parenthood, and Maternal and Child Health Bureau (MCHB), that offer support for prenatal care, sex education, and financial support like access to Medicaid and CHIP, among other things, can help relief the financial burden of underinsured, uninsured, or low-income women with the services they provide (MCHB, 2023). For instance, March of Dimes' mission is to "lead the fight for the health of all moms and babies. Our goals are to end the preventable maternal health risks and deaths, end preventable preterm birth and infant death, and close the health equity gap", and they do so by advocating for improving maternal and infant health policy by offering evidence-based education, different programs that take care of the baby as well as the mother, research, and partnerships (MOD 2022). Planned parenthood is a public health organization whose mission is to ensure all "all people have access to the care and resources they need to make informed decisions about their bodies, their lives, and their futures" (Planned

Parenthood, 2023). Planned parenthood is one of the biggest providers of sex education and telehealth appointments, so that every person is informed about their decisions and can learn more through the programs and funds it offers. Lastly, MCHB helps women understand the eligibility for Medicaid and CHIP, and helps ensure that every woman has health insurance coverage. MCHB also has a new funding system that will help women through the financial burdens of pregnancy and birth associated costs (Chou, 2020).

Researchers have investigated the correlation between socioeconomic status and the disparity in healthcare, and have found that women in lower social classes tend to not seek healthcare because of the financial burden it imposes (Braveman, et al., 2004). Braveman et al realized that disparities in healthcare were highly correlated with socioeconomic status, and that those women who were not at least 300% above the poverty income seeked delayed or no prenatal care at all. For the significant associations, mothers with lower socioeconomic position (SEP) compared to those with higher SEP, had poorer maternal-child health (MCH) outcomes (Daoud, et al., 2015). This association was consistently seen in health status indicators, parental health, labor and delivery experiences, and the overall experience of healthcare services. Daoud et al. also concluded in this study that the mother's education had the biggest magnitude of MCH inequality amongst all of the factors, which is why it is so important for advocacies to impel sex education amongst every woman. Others have found that higher mortality rate is associated with the socioeconomic status of women, especially those who are non-Hispanic Black and unmarried. This higher mortality rate is associated with cesarean deliveries, unintended births, unmarried status, yet four or fewer prenatal visits were significantly associated with the increased maternal mortality ratio (Moaddab, et al., 2018). This study also mentioned that differences in mortality rate amongst women could be the result of variations in funding,

oversight, or organization of state health care services and could reflect the intrinsic quality of available health care, yet another reason why public health organizations advocate for these groups of uninsured, underinsured, or low-income women. A study by Baldwin et al. (1998) showed that a Medicaid-enhanced prenatal care has been more likely to demonstrate a better effect on outcomes, due to the bigger enrollment on the Medicaid expansion system and the amount of low-income or uninsured women who enrolled in this program. This ensured them prenatal care since the first trimester of pregnancy, contrary to only the last trimester or none at all, and it was shown that low birthweight in children diminished after the Medicaid expansion started in Washington in 1988. Medicaid expansion and eligibility has been advocated for by many public health organizations and advocacies, who believe in equitable healthcare for all women, and thus is a service that is still continuing to grow.

References

ACOG (2023). Our Commitment to Changing the Culture of Medicine and Eliminating Racial Disparities in Women's Health Outcomes. *The American College of Obstetricians and Gynecologists (ACOG)*. https://www.acog.org/about/our-commitment-to-changing-the-culture-of-medicine-and-eliminating-racial-disparities-in-womens-health-outcomes

Baldwin, L. M., Larson, E. H., Connell, F. A., Nordlund, D., Cain, K. C., Cawthon, M. L., Byrns, P., & Rosenblatt, R. A. (1998). The effect of expanding Medicaid prenatal services on birth outcomes. *American Journal of Public Health*, *88*(11), 1623–1629. https://doi.org/10.2105/AJPH.88.11.1623

Braveman, P. A., Egerter, S. A., Cubbin, C., & Marchi, K. S. (2004). An Approach to Studying Social Disparities in Health and Health Care. *American Journal of Public Health*, *94*(12), 2139–2148. https://doi.org/10.2105/AJPH.94.12.2139

Chou, D. (2020). Looking Outward to Look Within: The Health Resources and Services Administration Maternal Mortality Summit, and What It Means for Women Everywhere. *Annals of Internal Medicine*, *173*(11_Supplement), S1–S2. https://doi.org/10.7326/M19-3259

Daoud, N., O'Campo, P., Minh, A., Urquia, M. L., Dzakpasu, S., Heaman, M., Kaczorowski, J., Levitt, C., Smylie, J., & Chalmers, B. (2015). Patterns of social inequalities across pregnancy and birth outcomes: A comparison of individual and neighborhood socioeconomic measures. *BMC Pregnancy and Childbirth*, *14*(1), 393. https://doi.org/10.1186/s12884-014-0393-z

Eliason, E. L. (2020). Adoption of Medicaid Expansion Is Associated with Lower Maternal Mortality. *Women's Health Issues: Official Publication of the Jacobs Institute of Women's Health*, *30*(3), 147–152. https://doi.org/10.1016/j.whi.2020.01.005

Gill, P., Lende, M. N., & Van Hook, J. W. (2023). Twin Births. In *StatPearls*. StatPearls Publishing. http://www.ncbi.nlm.nih.gov/books/NBK493200/

Hamelmann, P., Vullings, R., Kolen, A. F., Bergmans, J. W. M., van Laar, J. O. E. H., Tortoli, P., & Mischi, M. (2020). Doppler Ultrasound Technology for Fetal Heart Rate Monitoring: A Review. *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control*, *67*(2), 226–238. https://doi.org/10.1109/TUFFC.2019.2943626

Joyce A. Martin, & Osterman, M. J. K. (2023). Changes in Prenatal Care Utilization: United States, 2019-2021. *National Vital Statistics Report*, *72*(4).

Lemos, E. V., Zhang, D., Van Voorhis, B. J., & Hu, X. H. (2013). Healthcare expenses associated with multiple vs singleton pregnancies in the United States. *American Journal of Obstetrics and Gynecology*, *209*(6), 586.e1-586.e11. https://doi.org/10.1016/j.ajog.2013.10.005

MOD (2022). Accomplishments 2022. *March of Dimes* .https://www.marchofdimes.org/about-us/accomplishments-2022

MCHB (2023). Maternal and Child Health Bureau. *MCHB*. https://mchb.hrsa.gov/

Moaddab, A., Dildy, G. A., Brown, H. L., Bateni, Z. H., Belfort, M. A., Sangi-Haghpeykar, H., & Clark, S. L. (2018). Health Care Disparity and Pregnancy-Related Mortality in the United States, 2005–2014. *Obstetrics & Gynecology*, *131*(4), 707. https://doi.org/10.1097/AOG.0000000000002534

Nelson, G. A., & Holschuh, C. (2021). Evaluation of Telehealth Use in Prenatal Care for Patient and Provider Satisfaction: A Step Toward Reducing Barriers to Care. *The Journal for Nurse Practitioners*, *17*(4), 481–484. https://doi.org/10.1016/j.nurpra.2020.12.026

Planned Parenthood (2023). Who We Are | Planned Parenthood. *Planned Parenthood.* https://www.plannedparenthood.org/about-us/who-we-are

Petruska, Sara (2022). Making Sense of Childbirth Pain Relief Options. *The American College of Obstetricians and Gynecologists (ACOG).* https://www.acog.org/womens-health/experts-and-stories/the-latest/making-sense-of-Childbirth-pain-relief-options

Stafford, K. (2023). *Why do so many Black women die in pregnancy? One reason: Doctors don't take them seriously*. AP NEWS. Retrieved October 26, 2023, from https://projects.apnews.com/features/2023/from-birth-to-death/black-women-maternal-mortality-rate.html

TCF (2020). The Commonwealth Fund. U.S. Health Care from a Global Perspective, 2019: Higher Spending, Worse Outcomes?. *The Commonwealth Fund*. https://doi.org/10.26099/7avy-fc29

Tommy's (2023). Multiple pregnancy. *Tommy's*. https://www.tommys.org/pregnancy-information/im-pregnant/multiple-pregnancy