A Longitudinal Observation of Non-invasive Fetal ElectroCardiogram (LONGFECG) Dataset: Advancing Prenatal Monitoring

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Abstract

Fetal electrocardiography (FECG) is crucial for monitoring fetal health during pregnancy, particularly analysing heart rate and QRS components. From the 28th week of gestation onwards, FECG extraction becomes challenging due to the vernix caseosa, a non-conductive fatty layer forming on the fetal body that degrades the signal quality. The lack of real-world datasets hampers the benchmarking and development of robust algorithms for this critical gestational phase.

To address this gap, we introduce the Longitudinal Observation of Non-invasive Fetal ElectroCardiogram (LONGFECG) dataset, soon available on PhysioNet. The dataset includes 40 recordings from 9 pregnant participants between 30 to 38 weeks, collected under IRB approval. Each 40-minute session utilizes a high-density electrode setup (26 abdominal, 4 on the back, 2 on the chest) at 1024 Hz using the g.tec HiAmp amplifier. Participants body mass index (BMI) ranged from 21.7 to 35.3 kg/m^2, ensuring diverse physiological representation.

This dataset fills a critical gap in non-invasive FECG research, fostering innovation in non-invasive monitoring and improving prenatal care: the longitudinal nature and the high density electrode setup are the key features, which enable the analysis of temporal changes in FECG morphology and quality as gestation progresses.

1. Introduction

Antepartum fetal monitoring is crucial to mitigate the risk of stillbirth by assessing fetal well-being during pregnancy. For nearly 4 decades, techniques assessing fetal heart rate (FHR) patterns have been used to monitor fetal well-being [1]. Clinical guidelines worldwide recommend antepartum monitoring for high-risk pregnancies, typically starting in the third trimester and continuing once or twice weekly until delivery. These guidelines offer recommendations on the indications, timing, and methods for effective antepartum fetal monitoring, with the primary goal of detecting early signs of fetal distress that could result in long-term neurological impairment or death [2], [3].

The most commonly used antepartum technique is the non-stress test (NST). This test includes monitoring a patient's maternal heart rate, FHR, and uterine activity for at least 20 minutes at a clinic or hospital. In the NST, clinicians assess the FHR for accelerations and decelerations in response to fetal movements or uterine contractions.

Non-invasive fetal ECG (NI-FECG) offers the potential for continuous fetal surveillance. However, they remain technically challenging due to the weak nature of fetal signals, which are often obscured by maternal ECG, electromyographic interference, and environmental noise. A comprehensive review of signal processing techniques for NI-FECG [4] highlights both the advantages and limitations of current algorithms. Benchmark studies such as the PhysioNet/Computing in Cardiology Challenge 2013 [5] underscore the importance of continued research in developing sophisticated algorithms that address the unique challenges of NI-FECG.

From the 28th week of gestation, the monitoring challenge increases due to vernix caseosa [6], a waxy, non-conductive natural barrier, protecting the fetus but significantly attenuating the electrical signals emanating from its heart. This layer starts dissolving soon after appearing, but the dissolution rate varies among fetuses.

Volume conductor models show that its distribution affects both morphology and strength of the NI-ECG [7], and that the vernix on the back reduces signal quality more than on the front, while its presence on the head is minimally disruptive [9]. This period requires strategic electrode placement and advanced processing strategies to maximise the possibility of detecting the FHR [9].

1.1 Prior Datasets

Previous datasets for NI-FECG have contributed to advancements in signal processing. The Abdominal and Direct Fetal Electrocardiogram Database (ADFECGDB) [10] contains recordings from women in labor, while the

Daisy dataset [11] offers one short recording per patient. The dataset by Matonia et al. [12] includes late pregnancy (32–42 weeks) and labor recordings with four abdominal leads but omits the 28–32 week window when vernix has the most impact. The PhysioNet/Computing in Cardiology Challenge 2013 dataset [5] includes short, heterogeneous 4-lead recordings, and some synthetic ones. The Non-Invasive Fetal ECG Arrhythmia Database [13] focuses on arrhythmias and contains 26 recordings with limited channel numbers. The Non-Invasive Fetal Electrocardiogram Database [10] provides 55 recordings from a single participant between 21 and 40 weeks, using 2 thoracic and 3–4 abdominal channels. Finally, the NInFEA dataset [14], the first open-access multimodal early pregnancy dataset, covers weeks 21–27 which are before the vernix period.

1.2 The LONGFECG Dataset

The LONGFECG dataset combines three critical features: longitudinal coverage across gestation, extended electrode configurations, and covering the signal attenuation challenges caused by vernix caseosa. The LONGFECG dataset offers extended recordings duration, of approximately 40 minutes, with high density electrode setup and a longitudinal design spanning gestational weeks 30 to 38. With multiple sessions per subject, it enables the analysis of temporal changes in FECG morphology, signal quality, and physiological variability. These features make it an invaluable resource for developing and benchmarking advanced algorithms, particularly those targeting the challenges introduced by vernix caseosa, and for advancing fetal monitoring techniques.

2. Included Population

In the study, women with singleton pregnancy, older than 18 years, with gestational age at or above 30 weeks, followed at Valley Perinatal Services (AZ, United States) were included. The study was approved by an independent institutional review board (Advarra IRB approval number: Pro00064512) and all participants provided informed consent.

The study included nine pregnant participants which contributed 3 to 8 recordings, for a total of 40 recordings. The participants' BMI before pregnancy ranged from 21.73 to 35.34, with a mean BMI of 28.5 ± 5.7, ensuring a diverse representation of physiological conditions. Patients' details are shown in Table 1.

3. Material and Methods

In this study, the data acquisition setup was designed to ensure comprehensive and high-quality recordings of maternal and fetal ECG signals on women with singleton pregnancy.

Table 1. Participant information: subjects, age at first recording, pregestational BMI, number of recordings, gestational age (week).

subjects	Age	BMI	#recordings	Gestational Age
s1	21	22	6	[31.85 37.57]
s2	21	35	6	[32.57 37.28]
s3	28	23	4	[30.57 33.71]
s4	26	29	3	[30.57 37.28]
s5	30	33	3	[32.71 38.71]
s6	32	35	8	[30.85 37.28]
s7	18	23*	3	[31 34]
s8	20	32	4	[32 36]
s9	37	24	3	[32.42 34]

*BMI at GA = 31weeks

3.1 Setup

Biopotential signals were acquired using the FDA-cleared, CE-approved g.tec g.HIAMP amplifier, transmitting data via USB at a 1024 Hz sampling rate. All the input channels are referenced to GND (unipolar configuration). G.tec GammaClip and Ambu NF electrodes were used. The integrated impedance measurement was employed to control skin–electrode contact impedance before each session. The controlled environment minimized noise and motion artifacts.

A high-density active electrode configuration was used: 26 on the maternal abdomen, 4 on the back, and 2 on the chest, as shown in Figure 1. The configuration was selected to optimize FHR capture by targeting the most probable abdominal locations while adding back electrodes for broader spatial coverage. Two chest electrodes were also placed to provide a maternal reference lead for signal processing techniques which are based on a maternal reference lead. The ground electrode was placed on the patient's left hip.

3.2 Data collection procedure

Each participant underwent at least three 40-minute recording sessions between gestational weeks 30 and 38, seated in a reclined position to minimize movement artifacts. The abdomen, thorax, and lower back were cleaned, and electrode sites prepared with abrasive tape (3M Red Dot Trace Prep) to reduce impedance.

To ensure a good quality recording, all non-necessary electronic equipment (e.g. tv, radio, etc.) were turned off. Smartphones were preferably in flight mode for the duration of the measurement. The computer (with g.tec g.Recorder software) was not connected to power during the measurement.

Electrodes were positioned according to the predefined layout and once good contact of the electrodes with the skin was verified, the data started being recorded (g.tec recorder v1.20.03). Data collection was monitored in real-time to ensure electrode connectivity and signal integrity.

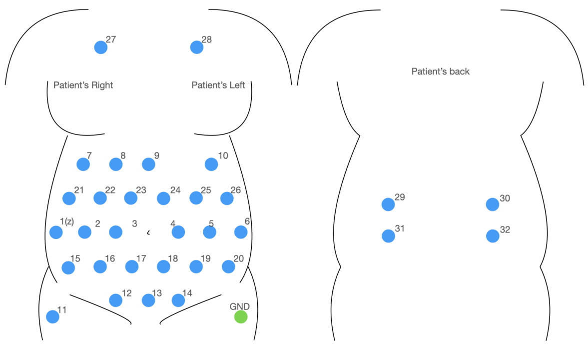

Figure 1. Electrode positioning.

4. Data Quality Assessment

Although the dataset was acquired under highly controlled conditions to optimize recording quality, common-mode noise was still present in some sessions, reflecting real-world recording challenges. These recordings were intentionally retained to ensure the dataset captures realistic conditions, making it more valuable for algorithm development and benchmarking. Table 2 shows the relative common-mode power (normalized power in the 59–61 Hz band) for each recording. While most sessions display values near zero, indicating minimal main interference, recordings such as Rec 4, Rec 7, Rec 17 Rec 18, and Rec 20 show markedly higher levels.

To characterize the dataset, the maternal signal-to-noise ratio (SNR) is shown in Figure 2. The thoracic channels (27 and 28) exhibit the highest SNR, as expected due to their proximity to the maternal heart. Abdominal channels show lower SNR, with variability depending on electrode placement on the maternal abdomen. Notably, channels positioned on the right side of the patient tend to have higher SNR. Channel 1, used during impedance measurements with the g.tec system, is excluded from the figure.

Figure 3 provides an example of a 10-second segment from the last session of subject 7 (recording 33), showing six channels after preprocessing (band-pass filtered, and power-line interference removed).

Table 2. Common-mode relative power recording per recording. Values are expressed in units of 10^{-3}.

Rec	Q25	Q75	Rec	Q25	Q75
1	0,036	0,095	21	0,013	0,018
2	0,001	0,005	22	0,074	0,403
3	0,005	0,022	23	0,040	0,244
4	0,138	1,295	24	0,049	0,394
5	0,006	0,037	25	0,011	0,062
6	0,144	0,635	26	0,112	0,425
7	0,072	1,263	27	0,245	0,716
8	0,103	0,975	28	0,023	0,118
9	0,009	0,030	29	0,001	0,016
10	0,198	0,748	30	0,017	0,038
11	0,073	0,532	31	0,023	0,119
12	0,204	0,389	32	0,030	0,111
13	0,005	0,032	33	0,006	0,008
14	0,011	0,032	34	0,588	0,639
15	0,005	0,030	35	0,022	0,044
16	0,004	0,021	36	0,122	0,461
17	0,320	2,114	37	0,050	0,134
18	0,893	1,907	38	0,010	0,029
19	0,120	0,364	39	0,008	0,037
20	1,891	7,393	40	0,026	0,215

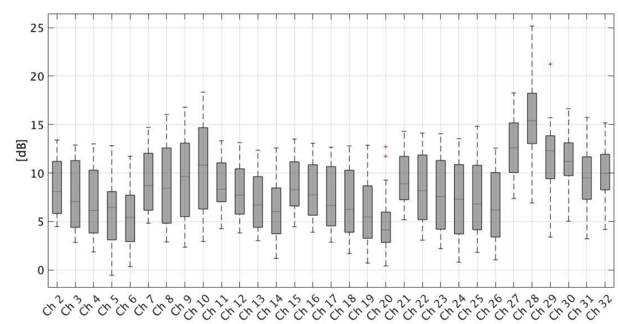

Figure 2. Maternal Signal-to-Noise Ratio per channel.

Figure 3. Example of a 10-second segment from six prepressed channels of s7-3 (Rec 33).

5. Discussion

The dataset presented in this study offers several advantages for advancing NI-FECG monitoring. Its longitudinal design allows researchers to analyze temporal changes in NI-FECG morphology and signal quality as gestation progresses. The extended 40-minute recordings ensure sufficient data for robust analysis, while the high-density electrode configuration maximizes the probability of capturing fetal signals during challenging gestational periods.

Including recordings during the vernix caseosa window is a key strength. Vernix caseosa presents significant challenges to fECG detection due to its non-conductive properties, attenuating fetal signals during late gestation. It typically appears from 28 weeks, by starting at 30 weeks, we capture at least half of this blanking window and enable the development and testing of advanced signal processing techniques aimed at extracting FHR under these conditions. The diversity in maternal BMI and gestational stages increase the significant value of the dataset. It allows for the exploration of inter- and intra-subject variability, making the dataset applicable across a range of clinical scenarios.

One limitation is the absence of an external ground truth for FHR validation. While cardiotocography is a standard tool for fetal monitoring, spatial constraints arising from the high-density electrode setup made its integration impractical. Other potential reference methods, such as handled doppler, were unsuitable due to the extended recording durations.

6. Conclusion

This dataset represents a significant advancement in non-invasive fetal ECG research, offering a unique combination of longitudinal design, extended recordings, high spatial density, and data captured during the challenging vernix caseosa window. By providing multi-electrodes, multi-session, high-resolution recordings, this dataset addresses critical gaps in existing resources and opens new opportunities for prenatal monitoring innovations and improved clinical outcomes.

References

[1] O. D. Umana, E. S. Vadakekut, and M. A. Siccardi, "Antenatal fetal surveillance." StatPearls. StatPearls Publishing, 2024.

[2] G. A. Macones, "Intrapartum fetal heart rate monitoring: Nomenclature, interpretation, and general management principles." Obstetrics & Gynecology, Jul. 2009.

[3] S. Santo et al., "Agreement and accuracy using the FIGO, ACOG and NICE cardiotocography interpretation guidelines," Acta Obstetricia et Gynecologica Scandinavica, vol. 96, pp. 166–175, Feb. 2017, doi: 10.1111/aogs.13064.

[4] R. Kahankova et al., "A review of signal processing techniques for non-invasive fetal electrocardiography," IEEE Reviews in Biomedical Engineering, vol. 13., pp. 51–73, 2020. doi: 10.1109/RBME.2019.2938061.

[5] I. Silva et al., "Noninvasive fetal ECG: The PhysioNet/computing in cardiology challenge 2013.", Computing in cardiology 2013. IEEE, 2013.

[6] T. F. Oostendorpt, A. V. Oosteromt, and H. W. Jongsma+, "The effect of changes in the conductive medium on the fetal ECG throughout gestation," Clin. Phys. Physiol. Meas, vol. 10. p. 11, 1989. Available: http://iopscience.iop.org/0143-0815/10/4B/002

[7] E. Keenan, C. K. Karmakar, and M. Palaniswami, "The effects of asymmetric volume conductor modeling on non-invasive fetal ECG extraction," Physiol. Meas., Jun. 2018, doi: 10.1088/1361-6579/aae305.

[8] F. Andreotti, J. Behar, S. Zaunseder, J. Oster, and G. D. Clifford, "An open-source framework for stress-testing non-invasive foetal ECG extraction algorithms," Physiol. Meas., vol. 37, pp. 627–648, 2016, doi: 10.1088/0967-3334/37/5/627.

[9] J. Uv, M. Maleckar, and H. Arevalo, "Impact of vernix caseosa distribution on non-invasive fetal ECG morphology: A computational study." IEEE transactions on bio-medical engineering, 2024, doi: 10.1109/TBME.2024.3476379.

[10] A. L. Goldberger et al., "PhysioBank, PhysioToolkit, and PhysioNet components of a new research resource for complex physiologic signals." 2000. Available: http://www.physionet.org

[11] K. U.Leuven, B. D. Moor, P. D. Gersem, B. D. Schutter, and W. Favoreel, "DAISY : A database for identification of systems," 1997. Available: https://api.semanticscholar.org/CorpusID:14612237

[12] A. Matonia et al., "Fetal electrocardiograms, direct and abdominal with reference heartbeat annotations," Scientific Data, vol. 7, Dec. 2020, doi: 10.1038/s41597-020-0538-z.

[13] J. A. Behar, L. Bonnemains, V. Shulgin, J. Oster, O. Ostras, and I. Lakhno, "Noninvasive fetal electrocardiography for the detection of fetal arrhythmias," Prenatal Diagnosis, vol. 39, pp. 178–187, 2019, doi: https://doi.org/10.1002/pd.5412.

[14] E. Sulas, M. Urru, R. Tumbarello, L. Raffo, R. Sameni, and D. Pani, "A non-invasive multimodal foetal ECG–doppler dataset for antenatal cardiology research," Scientific Data, vol. 8, Dec. 2021, doi: 10.1038/s41597-021-00811-3.

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