Comparison of Cardiotocography and Fetal Heart Rate Estimators Based on Non-invasive Fetal ECG

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Introduction: Non-invasive fetal ECG (NI-FECG) extraction algorithms enable long-term continuous beat-to-beat monitoring of the fetal heart rate (FHR), as opposed to the current gold standard in FHR monitoring, cardiotocography (CTG). We investigated the generalizability of a selection of NI-FECG extraction algorithms from the Computing in Cardiology 2013 (CinC13) Challenge and compared them to the CTG using a new set of recordings.

Methods: Four-channel NI-FECG was recorded simultaneously with a CTG trace from 34 pregnant women with a gestational age of 29-41 weeks. The FECG and CTG were sampled at 1 kHz and 4 Hz respectively, with an average duration of 290 seconds. Seven algorithms were tested: A constant FHR estimate of 143 BPM, the winning CinC13 entry from Varanini *et al*. and five algorithms from the unofficial top-scoring CinC13 entry by Behar *et al*. A 13th-order median filter was applied to smoothen the FHR estimates to better match the smooth CTG trace. Two accuracy measures were used: 1) The RMSE between the FECG-based FHR and CTG trace averaged over all recordings; 2) The Pearson correlation coefficient ρ between the FECG-based FHR and CTG trace from which the average of all recordings $\bar{r}$ was obtained.

Results: The algorithms with the lowest RMSEs are Behar's FUSE-SMOOTH, the constant FHR, and Varanini (RMSE = 12.8, 13.0, 14.2 BPM respectively). The Varanini algorithm delivers best correlation with the CTG trace ($\bar{r} = 0.73$) with 41% of the recordings having $\rho > 0.8$, whereas the other algorithms have $\bar{r} \leq 0.59$ and $\leq 29\%$ of the recordings with $\rho > 0.8$.

Conclusion: The Varanini algorithm delivers best overall performance, however the large differences in ρ among recordings indicate that FHR is estimated accurately in some recordings and poorly in others, due to large differences in signal quality. Future algorithms should therefore quantify the confidence of the FHR estimate by e.g. estimating the signal quality.

Table 1. Performance of a selection of the tested algorithms.

Algorithm	Avg. RMSE	$\bar{r}$ (95% CI)	($\rho_{\min}$, $\rho_{\max}$)	Recs. w. $\rho > 0.8$
Varanini	14.2 BPM	**0.73 (0.52, 0.85)**	(-0.37, **0.99**)	**41**%
FUSE-SMOOTH	**12.8** BPM	0.53 (0.28, 0.71)	(**-0.35**, 0.99)	26 %
Const-HR	13.0 BPM	0.01 (-0.06, 0.09)	(-0.41, 0.48)	0 %