Computerized Algorithm for Baseline Estimation of Fetal Heart Rate

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Abstract

On the present work, we propose an algorithm that after unstable segments identification by the first derivative estimates the baseline of antepartum fetal cardiotachograms. Therefore, 50 records 5 minutes long, derived from abdominal ECG, were processed according to the methods of Dawes, Mantel, and our proposal. Besides visual analysis, statistical differences among methods were established. More appropriate visual fits of the baseline were gotten by our proposal (76%) than Mantel (22%) and Dawes (2%). Since lower mean baseline was computed from Mantel (137.8±8.4 bpm) than from Dawes (140.4±8.4 bpm) and our proposal (140.0±8.4 bpm), different account for accelerations and decelerations were also found. Our proposal showed advantages to estimate the baseline of cardiotachograms as it was properly adjusted at the beginning of the traces, depended of only 15 seconds of valid segments and corresponded more closely to the visual baseline.

1. Introduction

Precise baseline estimation is the critical step for a proper analysis of the fetal cardiotachogram (CTG); hence, expert definitions of baseline, accelerations and decelerations have been outlined [1,2]. Such definitions, however, have resulted in a circular problem, since baseline is determined previous accelerations and decelerations exclusion, but these are identified previous baseline recognition. Hence, visual interpretation remains as a subjective procedure with significant intra- and inter-observer disagreements [3-7], which have not been resolved even when strict definitions are applied [8,9].

Computerized analysis of the CTG has been suggested to eliminate disagreements. However, Bracero et al [9] recently presented results that besides confirmed the intra- and inter-observer disagreements of human experts, showed discrepancies between these and the computer. Moreover, the same authors observed that the computer detected a higher proportion of non-reactive traces which were less associated with proved adverse outcomes.

Since the computerized detection of baseline, accelerations and decelerations did not improve the positive prediction, we assume that current approaches for CTG analysis should be reviewed. In fact, although some of them are nowadays used at the bedside, they still showing problems such as a) uncertainty at the beginning of the traces, b) displacement following large swings within the trace, and c) dependency of traces 6 to 10 minutes long at least [10].

Prompted by these observations, the aim of the present work was to propose an algorithm that reduces such problems in antepartum CTGs, in particular when applied to short term records.

2. Materials

50 antepartum CTGs, derived from abdominal electrocardiograms (ECGa), were recorded from 50 pregnant women attending their pregnancy and labor at the Centro de Investigación Materno Infantil, in Mexico City. After patients gave informed consent according to the Declaration of Helsinki, they were included as participants and their physical and obstetrical characteristics corresponded to women 18 to 34 years old, 57 to 72 Kg of body weight, single pregnancy with low to middle perinatal risk, and 32 to 40 weeks of gestation. As ECGa in this study was not used as clinical test, perinatal outcomes were not considered.

3. Methods

3.1. Signal acquisition

ECGa was digitized on a PC with the Acknowledges System MP100 (BIOPAC, CA, USA) at 1.0 kHz, during 5 minutes. Mothers in left lateral decubitus were recorded with bipolar lead by mean of a bioelectric amplifier AB621G (Nikon Kohden, Tokyo, Japan). An AgCl electrode was used as leg reference, while two others were placed at the abdominal maternal surface 18-20 cm distant, previous standard cleansing of the respective skin areas. The positive electrode was fixed on the pubis, while the negative was on and around the umbilical area. These electrode positions guaranteed measurable fetal QRS complexes which were separated from the ECGa by resting the maternal QRS complexes [11]. Fetal heart rate (FHR) was computed from the measured beat-to-beat RR intervals, and the derived time series were processed in according to the algorithms of Dawes et al (Dw) [12], Mantel et al (Mn) [10], and our present proposal (Pp).

3.2. Signal processing and analysis

The algorithms of Dw and Mn to determine the FHR baseline were applied as described [10,12], except that the time series of FHR were used as beat-to-beat instead of the average of 3.5 s and 2.5 s usually employed by Dw and Mn, respectively.

Our algorithm, Pp, was divided on three steps (Figure 1). The first one made an overall smoothing of the time series based on a moving average of the FHR with a Hanning window of 27 points. On the second step, abrupt changes of the time series were identified by first derivative amplitude (dFHR) and time thresholds. Thus, segments with dFHR surpassing the level of 1.0 beats/minute/second (bpm/s) were eliminated, and the remaining were averaged (μ), but only those $\geq$15 s long and between $\mu\pm$10 bpm were validated as possible baseline segments. To obtain the final estimation of the baseline, on the third step, the validated segments underwent cubic spline interpolation, linear extrapolation at both ends of the time series when necessary, and a third order zero-phase low-pass filtering with cut off frequency of 0.033 Hz. This filter assumed valid baseline fluctuations as two cycles per minute or lower [1].

Besides a visual analysis, baselines estimated by each method were processed to compute time-domain parameters, in bpm, as Mean (Bmean), Standard Deviation (Bstdev), Minimum Value (Bmin), Maximum Value (Bmax), and Range (Brange). On the frequency-domain, the power spectral density of the baselines was estimated and the bandwidth (Bbw) was computed assuming a stable frequency response when attenuation of –3 decibel was observed. Finally, the effect of the estimated FHR baseline on the number of records with- and the total sum of- accelerations and decelerations was evaluated. These events were uniformly defined as differences between the original CTG and the estimated baseline, where the differences indicate a segment of successive values with the same sign that reaches a peak (acceleration) or a nadir (deceleration) of at least 15 bpm in less than 30 s, and has a total duration of at least 15 s.

3.3. Statistical analysis

For Bmean, Bstdev, Bmin, Bmax, Brange and Bbw, handled as quantitative parameters, the mean and standard deviation were obtained to test statistical differences, whereas occurrence of accelerations and decelerations were described as counting and proportions

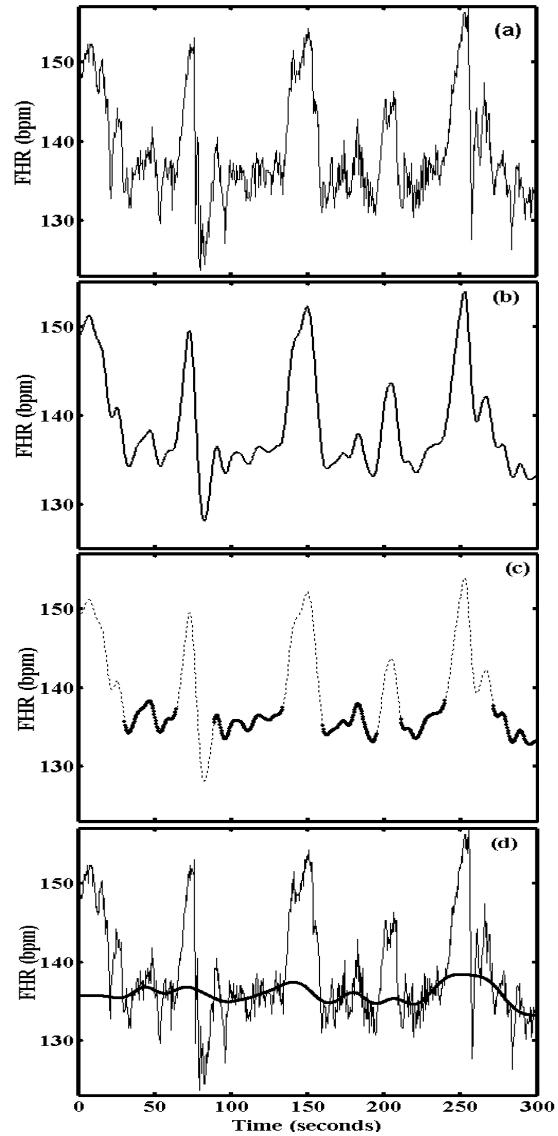

Figure 1. Sequence of signal processing to estimate the fetal heart rate (FHR) baseline: a) original signal, b) smoothed signal, c) separation of stable (darker lines) and abrupt changes (lighter lines) segments, d) estimated baseline on the original signal, after cubic spline interpolation, extrapolation and filtering of the stable segments.

used to assess inter-observer agreement. Comparisons of quantitative data were done by analysis of residuals and by repeated-measures one-way analysis of variance, followed by *post hoc* Tukey's test to pinpoint differences. Inter-observer agreement to detect accelerations and decelerations was assessed by the proportion of agreement (*PA*) for multiple observers, and the kappa statistic, both statistics with 95% confidence interval (CI) [13]. *PA* values whose lower limit of CI was above 0.5 indicated significant agreement. For kappa values above 0.75, between 0.4 and 0.75 and below 0.4, agreement beyond chance was considered excellent, fair to good, and poor, respectively. Bias among algorithms were evaluated by the Cochran's test whose significance was given by χ^2 statistic. For all hypothesis test, $p<0.05$ was considered statistically significant.

4. Results

From the 50 traces of FHR, the best visual fit were obtained by Pp in 72%, Mn in 26%, and Dw in only 2%. Figure 2 presents an example of the baseline estimated by the three algorithms, during stable and abrupt changes of the FHR. Dw tracked the modal of the FHR with low oscillations, but its baseline estimation trended to be elevated, even during stable FHR, and it often failed at the ends of the time series. Mn improved the tracking of the modal; however, its baseline estimation was inclined to give lower values during stable segments of the FHR and shifted upward or downward more than expected when abrupt changes were present. Pp displayed a better tracking of the modal, along and at the ends of the time series, but it also followed slow changes of the FHR and its baseline estimation failed when several oscillations and/or stable segments of short duration (<15 s) come intercalated.

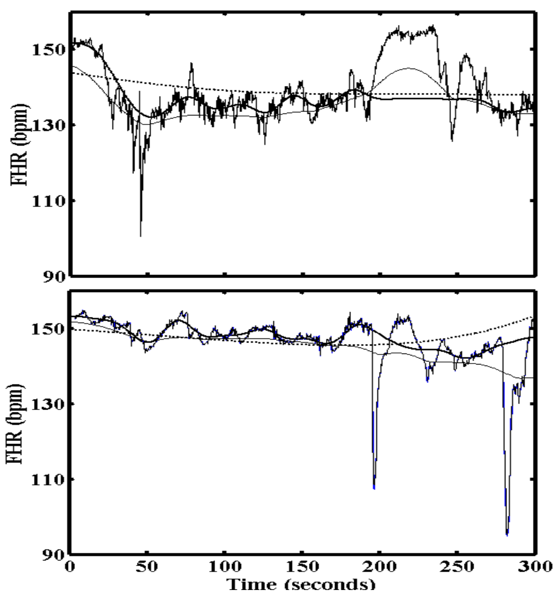

Figure 2. Fetal heart rate (FHR) baseline estimated on two traces with abrupt changes by the algorithms of Dawes et al (dotted line), Mantel et al (solid lighter line), and our proposal (solid darker line). Note the shift of Mantel toward the direction of abrupt changes, and the trend to be elevated of Dawes.

Table 1 depicts the quantitative results of the baseline parameters. Bmean and Bmax from Mn showed lower values ($P<0.05$) than those from Dw and Pp. The same statistical differences were observed in Bmin, but it added significant differences ($P<0.05$) between Pp and Dw. Brange from Pp was statistically higher ($P<0.05$) than Brange from Mn. In regarding to Bbw, all methods presented significant differences ($P<0.05$).

Table 1. Comparison of baseline quantitative parameters derived from the computerized algorithms.

	Dw	Mn	Pp
Bmean (bpm)	140.37 †	137.78	140.04 †
	(8.39)	(8.36)	(8.44)
Bstdev (bpm)	2.10	2.50	2.70
	(1.63)	(1.13)	(1.09)
Bmax (bpm)	144.64 †	142.32	145.49 †
	(9.81)	(9.43)	(8.57)
Bmin (bpm)	136.82 †	133.05	134.71 *†
	(8.25)	(8.40)	(8.88)
Brange (bpm)	7.82	9.27	10.78 †
	(6.33)	(3.68)	(4.06)
Bbw (Hz)	1.77E-3†	2.33E-3	6.49E-3 *†
	(4.13E-4)	1.78E-3	(4.99E-3)

Values as mean (s.d.). *$P<0.05$, vs DW; † $P<0.05$, vs Mn. Dw, Dawes et al; Mn, Mantel et al; Pp, present proposal; Bmean, baseline mean; Bstdev, baseline standard deviation; Bmax and Bmin, maximum and minimum value of the baseline; Brange, baseline range; Bbw, baseline bandwidth.

Since the slopes and intercepts were non significant different from zero, but the proportion of positives were 0.98 and 1.0 by analysis of residuals, systematic bias were found on Bmean between Mn in respect to Dw and Pp, respectively. The same analysis showed non significant bias on Bmean between Dw and Pp.

As a result of the FHR baseline estimated on the 50 traces, the number of records with accelerations and the total number of these were: 20 records with a total of 29 accelerations by Dw, 25 with 41 by Mn, and 19 with 31 by Pp. Results for decelerations were as follow: 21 records with a total of 31 decelerations by Dw, 0 with 0 by Mn, and 5 with 10 by Pp.

As shown on Table 2, the kappa statistic for acceleration indicated poor, and fair to good, agreement between algorithms, but for deceleration it always pointed to a poor agreement. In case of traces with absence of both, accelerations and decelerations, the *PA* value was found above 0.5, so that acceptable agreement was inferred. However, *PA* for traces with occurrence of any of the events showed values below 0.5, thus a non-acceptable agreement was assumed on the detection of accelerations and decelerations. The χ^2 statistic indicated significant bias ($p<0.05$) on the detection of acceleration between Mn (41) against both Dw (29) and Pp (31); and on the detection of deceleration between Dw (31) versus Mn (0) and Pp (10).

Table 2. Inter-observer agreement to detect absence (-) or occurrence (+) of accelerations (Accel) and decelerations (Decel), in short term fetal heart rate tracings.

	Observers	*kappa*	*PA*(-)	*PA*(+)	χ^2
Accel	Dw vs Mn	0.35 to 0.74	0.57 to 0.74	0.35 to 0.58	p<0.01*
	Pp vs Dw	0.35 to 0.73			p>0.05
	Pp vs Mn	0.40 to 0.75			p<0.05*
Decel	Dw vs Mn	0.01 to 0.23	0.62 to 0.77	-0.15 to 0.10	p<0.01*
	Pp vs Dw	0.02 to 0.35			p<0.01*
	Pp vs Mn	0.18 to 0.51			p>0.05

Values of *kappa* and *PA* as 95% confidence interval.
Dw, Dawes et al; Mn, Mantel et al; Pp, present proposal; *PA*, proportion of agreement. * significant bias

5. Discussion

The main findings of the present study were that a) there are significant differences among computerized algorithms on the estimation of the FHR baseline of short term tracings and, consequently, on the detection of accelerations and decelerations, and b) our proposal showed differences with classical methods [10,12], but it also presented fair agreement with Dw to detect accelerations and with Mn to detect decelerations.

It was visually and qualitatively confirmed that Dw trended to override the FHR baseline [9,10]. Such a trend in Dw determined systematic bias that provokes an overestimation of the number of decelerations with respect to both Pp and Mn, whereas the number of accelerations was equivalent to those detected by Pp, but it gave a lower number than the obtained by Mn.

Mn, on the other side, had the opposite bias observed on Dw, as Mn trended to give lower values of the FHR baseline. Hence, an overestimation of the number of accelerations was noticed on Mn with respect to Pp and Dw, while the number of decelerations was non different from those of Pp, but it was lower than from Dw.

The differences found among the algorithms might be explained by a) the filter characteristics they use and b) the way to slip away from abrupt changes of the CTG. All the algorithms are based on low-pass filters with different cut off frequency, where the highest correspond to Pp (0.033 Hz) and the lowest to Dw (centered at 0.0016 Hz). Despite Pp used a higher cut off frequency, it was less affected by abrupt changes on the CTG because these were identified and eluded before the filter were applied. Mn used a filter close to our proposal, but their recursive method was insufficient to contend with abrupt changes and miscalculation of accelerations ensued.

In conclusion, our method show advantages because it was properly adjusted at the beginning of the traces, depended of only 15s of valid segments and corresponded more closely to the mean values of the baseline segments. The best tracking of Pp might be explained by the higher bandwidth and a better detection of stable and abrupt changes of the CTG.

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