

imebi Time domain parameters can be estimated more precisely than frequency domain parameters in the analysis of heart rate variability

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Introduction

Cardiovascular disease (CVD) is still the leading cause of death and morbidity in industrialized nations, accounting, for example, for about 42 % of all deaths in Germany [1]. A large number of risk factors contribute to CVD, among those, autonomic dysfunction as indicated by reduced heart rate variability (HRV) is associated with an increased risk of CVD incidence and mortality. Heart rate variability is defined as the variation in time between consecutive heartbeats, and several measures have been proposed for its measurement. Most of them are based on the tachogram, the time series of beat-to-beat time differences (R-R intervals). HRV analysis thus has to rely largely on the statistical methods of time series analysis, and, corresponding to the dichotomy of methods in time series analysis, the proposed measures can be divided in time domain and frequency domain methods [2].

Whereas the estimation of time domain parameters is straightforward, estimation of frequency domain parameters is complicated by the fact that the estimation process consists of two steps: In the first step, the spectrum of the tachogram is estimated, and in the second step the frequency domain HRV parameters are derived from this estimated spectrum. In general, the statistical variability that is induced by the estimation of the spectrum is ignored in further analysis, thus systematically overestimating the precision of frequency domain HRV parameters. Additionally, as the common spectral estimates have rather insufficient statistical properties (e.g., the periodogram is an inconsistent estimator of the true spectrum) we expect this statistical variability to be of relevant size. To our knowledge and up to now there has been no systematic investigation on the size of this overestimation of precision and its potential impact on interpretation of HRV parameters.

In the following we give the results of a simulation study to compare statistical precision and variability of the SDNN, LF power, HF power, and the LF/HF ratio as the most prominent time domain and frequency domain parameters, respectively.

Methods

Simulated tachograms with a length of $N=512$ observations were generated from a AR(1) process $Y_t = \phi Y_{t-1} + \varepsilon_t$, $\varepsilon_t \sim N(0, \sigma^2)$. It can be shown [3, p. 53] that the true SDNN of a tachogram from this process equals $\sqrt{\frac{\sigma^2}{1-\phi^2}}$, and the true spectrum of the process is [3, p. 154]: $f(\omega) = \frac{\sigma^2}{2\pi} \times \frac{1}{(1+\phi^2 - 2\phi \cos \omega)}$.

Based on this equation, true values for LF, HF and the LF/HF ratio can be calculated from the integral [4]: $\int_a^b f(\omega) d\omega = \frac{\sigma^2}{\pi(\phi^2-1)} \times \arctan \frac{(\phi-1)^2(\phi^2-1)(\tan \frac{b}{2} - \tan \frac{a}{2})}{(\phi-1)^4(\phi^2-1)^2 \times \tan \frac{b}{2} \times \tan \frac{a}{2}}$ by setting $b=0.4$ and $a=0.15$ for the HF, and $b=0.15$ and $a=0.04$ for the LF power.

We varied parameter values for the AR(1) parameter ϕ and the residual variance σ^2 and generated 10.000 tachograms for each combination of ϕ and σ^2 . Realistic values for ϕ and σ^2 were derived from a random sample of 41 subjects of the CARLA study [5] with regular tachograms. From each tachogram we calculated the estimated SDNN as the standard deviation of the R-R intervals, and LF, HF, and LF/HF ratio as areas under the curve from the raw periodogram. Additionally we also estimated all frequency domain parameters from a smoothed periodogram where smoothing was performed with a Tukey-Hanning kernel with a fixed bandwidth of 5 periodogram ordinates.

To describe statistical precision we calculated the relative percentage bias [6] $RPB = \left(\frac{\bar{\hat{\theta}} - \theta}{\theta} \right) \times 100$, where θ stands for the respective true parameter value (true SDNN,

LF, HF, or LF/HF ratio as derived from the equations above) and $\bar{\hat{\theta}}$ for the corresponding mean estimated value $\bar{\hat{\theta}} = \frac{1}{10.000} \sum_{i=1}^{10.000} \hat{\theta}_i$, $\hat{\theta}_i$ being the estimated value from the i -th simulation run.

To describe statistical variability we calculated the relative percentage standard deviation [6] $RPSD = \left(\frac{SD(\hat{\theta})}{\bar{\hat{\theta}}} \right) \times 100$, with $SD(\hat{\theta}) = \sqrt{\frac{1}{10.000-1} \sum_{i=1}^{10.000} (\hat{\theta}_i - \bar{\hat{\theta}})^2}$ as the empirical

standard deviation over all simulations for the respective parameter. The simulation study and all analyses were programmed in SAS, 9.1.

Results

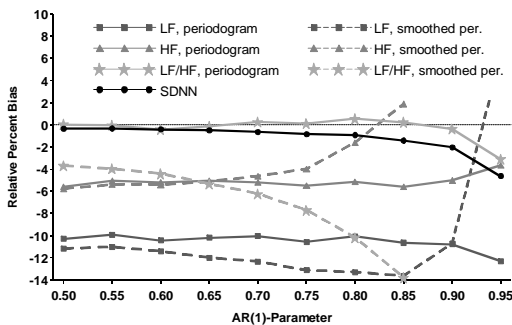
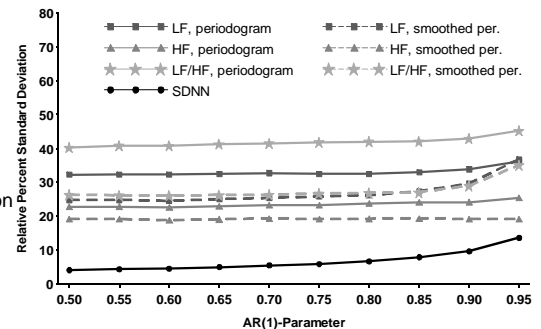


Figure 1 (statistical precision): Relative percent bias (RPB) for the respective HRV parameters

Figure 2: (statistical variability) Relative percent standard deviation (RPSD) for the respective HRV parameters



Conclusion/ Discussion

In HRV analysis time domain parameters can be estimated with smaller bias and considerably smaller variability as compared to frequency domain parameters. This result was found despite the fact that the simulation study was set up in the best possible way to give valid results for the frequency domain parameters: We generated tachograms from a stationary process without ectopic beats or other arrhythmic events, and chose tachogram length as a power of 2 ($512=2^9$). These optimized conditions will not be given with real life data, instead a number of preprocessing steps (trend removal, interpolation of ectopic beats, zero padding, tapering) will be necessary [2].

It is a limitation of our simulation study that it uses a rather simplistic model for tachogram generation. We decided to use an AR(1) process mainly because computation of true values of the frequency domain parameter requires complicated integrals, and using AR processes with higher orders would make these integrals essentially intractable. However, we would expect the same differences between time domain and frequency domain parameters with larger AR orders.

We finally conclude that frequency domain parameters should be interpreted with caution in the measurement of heart rate variability and only if important physiological reasons suggest their use.

References

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