Night and Day Changes in Heart Rate and Blood Pressure Fractal Dimensions from 24-hour Ambulatory Blood Pressure Monitoring Devices

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Abstract

Ambulatory blood pressure monitoring (ABPM) devices allow measuring changes of BP and heart rate (HR) by periodically inflating an arm cuff. Due to the low sampling rate, only simple indices of BP variability (V) have been considered so far, such as the standard deviation (SD) or the coefficient of variation (CV) of average BP levels over day and night periods. Our aim is to describe day-night changes in a specific feature of ABP complex dynamics: the fractal dimension (FD); and to evaluate whether FD provides complementary information to SD or CV in the description of 24h BPV.

We obtained HR and systolic (S) and diastolic (D)BP time series from ABPM readings taken every 15' during the day (6:00-22:00) and every 30' at night (22:00-06:00) in 67 hypertensive subjects, and compared daytime vs. nighttime values of SD, VC and FD. FD was estimated by the Higuchi's algorithm (FD_H) and by the recently proposed Katz's corrected algorithm (FD_C). From day to night, SD decreased significantly ($p<0.01$) for SBP, DBP and HR, while VC decreased significantly ($p<0.05$) for HR only. FD showed a different behavior, increasing significantly ($p<0.05$) for DBP.

Therefore FD provides additional information on night/day changes of ABP dynamics not included in SD or CV assessment.

1. Introduction

Ambulatory blood pressure monitoring (ABPM) devices describe 24-hour changes of blood pressure (BP) and heart rate (HR) by periodically inflating an arm cuff (figure 1). ABPM devices provide clinically important information quantifying daytime and nighttime mean values of BP and HR while minimally interfering with daily activities and sleep. However, due to the low number of measures (usually between 2 and 4 per hour), few indices of BP variability have been considered so far, the most common being the standard deviation (*SD*) or the coefficient of variation (*CV*=*SD*/mean) of average BP levels, separately computed over the day and the night.

Recently, however, we showed that it is possible also to calculate a specific feature of ABP complex dynamics, the fractal dimension *FD*, even from the short BP and HR time series provided by ABPM devices [1]. Aim of this work is to describe changes between day and night in *FD* of BP and HR over a large population of subjects, and to evaluate whether *FD* provides complementary information to *SD* or *CV*.

2. Methods

2.1. Subjects and data collection

The study was performed on 67 hypertensive subjects (36 males, 31 females) with average age 65.4±4.6 years and body mass index 28.3±2.7 kg/m^2 (mean±standard deviation). After a 2-week wash out period from any previous anti-hypertensive pharmacological treatment, each participant underwent a 24-hour ABPM performed

Figure 1. Subject wearing an ABPM device for 24-hour recording of arterial blood pressure.

by a validated oscillometric device (Spacelabs 90207; SpaceLabs, Redmond, Washington, USA) with the arm cuff placed on the non-dominant arm (see figure 1). ABPM recordings started in the morning at around 10 AM and lasted 24 hours, with BP readings scheduled every 15 minutes during the day (06:00-22:00) and every 30 minutes at night (22:00-06:00). During each recording, subjects were required to attend their usual daily activities, only refraining from unusual exercise or from behavioral challenges.

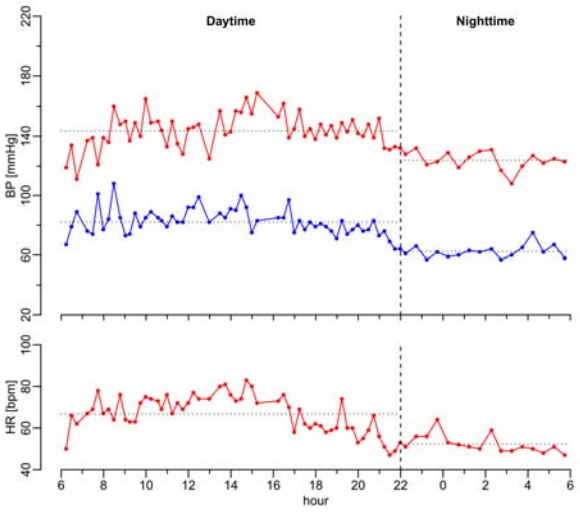

Figure 2. Example of 24h recordings of SBP, DBP and HR in one subject. The horizontal segments indicate daytime and nighttime mean levels. Automated readings were obtained every 15 min during daytime and every 30 min during night

2.2. Data analysis

Dedicated software transformed the original ABPM data into text files containing the 24-hour time series of systolic (S)BP, diastolic (D)BP and HR (figure 2 shows an example in one subject). Two segments of data were derived from each time series. The nighttime segment was composed by the sequence of 16 consecutive ABPM measures taken between 22:00 and 6:00 hours. The daytime segment was obtained by considering readings obtained between 6:00 and 22:00 hours, including 64 measures. We have previously shown by means of synthesized signals that *FD* can be adequately measured in the range between 1.1 and 2.0 even from so short segments of data [1].

Mean value, *SD* and *CV* of each time series were separately calculated over day and night subperiods.

The daytime and nighttime *FD* was also calculated for each time series. This was done by means of two estimators based on different algorithms: the Higuchi's estimator [2], FD_H, and the Katz's corrected estimator [3], FD_C.

Briefly, the Higuchi's method derives the following k curves from the original time series $\{y_i\}$ of N points:

$$y_m, y_{m+k}, y_{m+2k},\ldots, y_{m+Pk} \quad (1)$$

with $1 \le m \le k$ and $P=\mathbf{int}[(N-1)/k]$. The length of each curve is:

$$L_m(k)=\sum_{j=1}^{P}\left|y_{m+jk}-y_{m+(j-1)k}\right|\frac{N-1}{P\cdot k^2} \quad (2)$$

and the average length for all the curves is:

$$L(k)=\frac{1}{k}\sum_{j=1}^{k}L_j(k) \quad (3).$$

For fractal time series, $L(k)$ increases as k^{-FD}. Therefore FD_H is estimated as slope of the regression line between $L(k)$ and k in a *log-log* scale, with k between 1 and k_{MAX}. In this study, we set k_{MAX} =4. Calculations were performed with source code provided in [4].

The second *FD* estimator, FD_C, has been recently derived correcting a flaw in the Katz's method [3]. Given the time series $\{y_i\}$ of N points, its length L and extension d are:

$$L=\sum_{i=1}^{n-1}\left|y_{i+1}-y_i\right| \quad (4)$$

$$d=\max\{y_i\}-\min\{y_i\} \quad (5)$$

and

$$FD_C=\log(L)/\log(d). \quad (6)$$

However, to avoid overestimation bias for strongly anticorrelated data, $\{y_i\}$ is split into consecutive overlapping windows of length $n_W<N$, where n_W is the average length of segments with extension at least equal to $d/2$. In this study we set n_W =8.

Daytime and nighttime values were statistically compared by paired t-test (means) or by the Wilcoxon-Mann-Whitney test (*SD*, *CV*, FD_H and FD_C) setting the threshold for statistical significance at α= 5%. The symbols * and ** were used to indicate p values respectively lower than 0.05 and 0.01.

3. Results

Mean values are reported in table 1. SBP, DBP and HR means were significantly higher during the day.

Table 1. Daytime and night time values of the time series (mean ±standard deviation)

Time Series	Day	Night
SBP (mmHg)	150.9 ±10.2	133.0 ±14.2 **
DBP (mmHg)	89.9 ±10.4	75.1 ±9.8 **
HR (bpm)	76.1 ±11.2	63.5 ±9.6 **

Figure 3 compares day and night values of *SD* and *CV*. The overall BP variability, as quantified by *SD* of SBP

and DBP, is significantly lower at night. The decrease in BP overall variability is similar to the decrease in BP mean value, and no significant changes between day and night were thus observed for *CV* of SBP (day: 8 ±2%; night: 8 ±3%) and of DBP (day: 11 ±3% ; night: 11 ±4%). As to HR, not only the overall variability *SD*, but also *CV* was significantly lower at night.

Day and night changes of *FD* as obtained by both the FD_H and FD_C estimators are shown in figure 4. Even if based on different algorithms, FD_H and FD_C described exactly the same day-night changes of *FD*. In particular, *FD* of DBP was significantly higher at night (FD_H =1.92±0.26; FD_C =2.04±0.48) than during the day (FD_H =1.83±0.12; FD_C =1.84±0.20).

By contrast, *FD* of SBP did not differ significantly between day (FD_H =1.83±0.11, FD_C =1.85±0.19) and night (FD_H =1.86±0.21, FD_C =1.92±0.35). It is also worth noting that SBP estimates during daytime correspond to daytime estimates of DBP up to the last decimal (FD_H: SBP = 1.83, DBP =1.83; FD_C: SBP =1.85; DBP =1.84)

Moreover, also *FD* of HR did not differ significantly between day (FD_H =1.78±0.13, FD_C =1.77±0.22) and night (FD_H =1.80±0.26, FD_C =1.82±0.43).

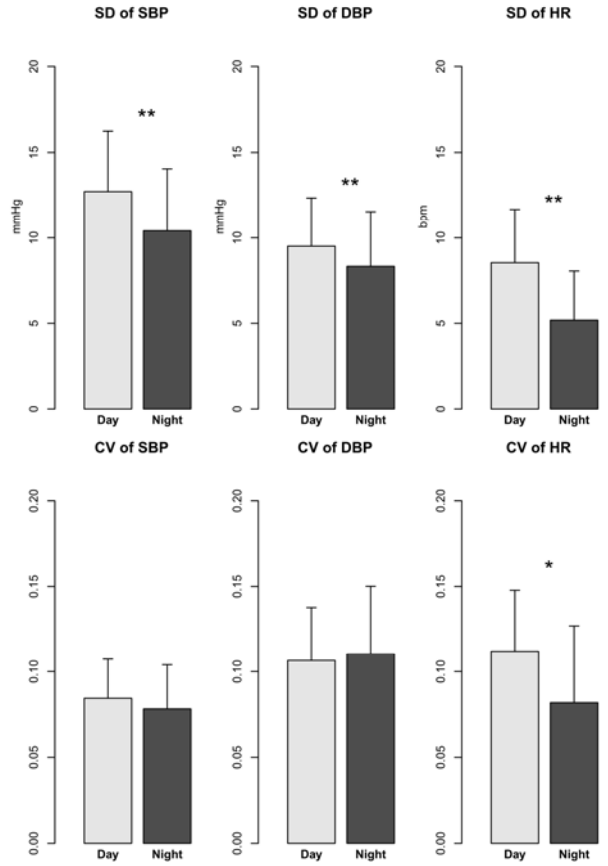

Figure 3. Comparison of SD and CV between day (light gray) and night (dark grey).

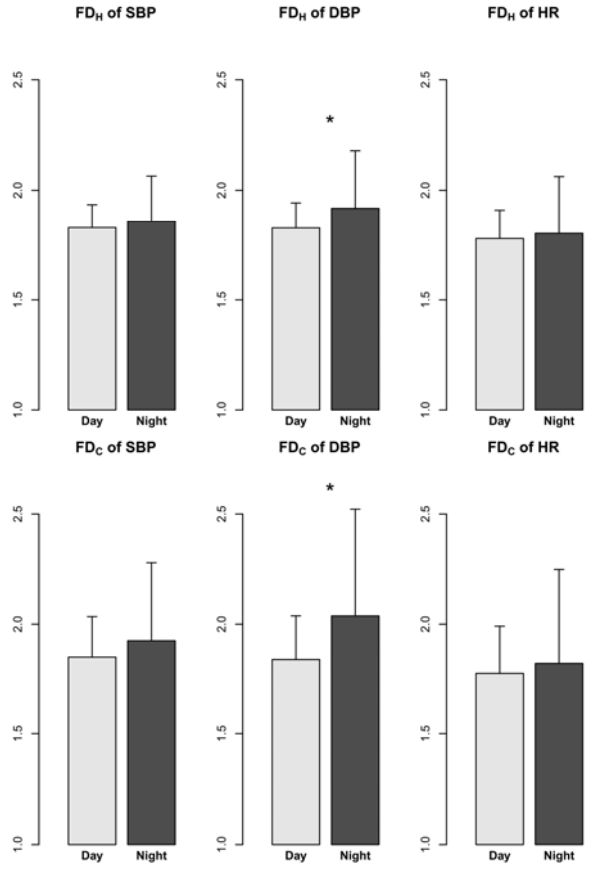

Figure 4. Comparison between day and night of *FD* values estimated by Higuchi's (FD_H) and "corrected" (FD_C) algorithms.

4. Conclusions

A lower mean BP value and a lower value of the overall BP variability, *SD*, are expected at night because of the lower activity levels as compared to the day, and this finding was clearly observed in our results. *CV*, which quantify the amplitude of the fluctuations as fraction of the mean level, indicates that night-day changes of the mean and night-day changes of *SD* run in parallel for BP, because *CV* is exactly the same during the day and during the night for SBP and DBP as previously shown [5,6].

Unlike *SD* and *CV*, which are measures related to the amplitude of the fluctuations, *FD* describes the degree of *convolutedness* of the time series. Our results indicate that *FD* actually quantifies aspects of 24h ambulatory BP complex dynamics not detectable by *SD* or *CV*. In fact, the fractal dynamics does not depend directly on the amplitude of the oscillations, because *FD* did not change for SBP and HR even if their *SD* changed importantly. Moreover, the fractal analysis seems to reveal differences in the control of SBP and DBP over the 24 hours that are not detected by *SD* or by *CV*. In fact, we observed that

SBP and DBP fractal structures are characterized by the same *FD* during the day, while at night significant changes occur for DBP only. It is possible that the fractal structure of DBP is influenced more than that of SBP by long-term changes in the regulation and control of peripheral vascular resistance. Therefore the presence of night-day differences only in the *FD* of DBP might reflect changes in the regulation of vascular resistances at night, likely associated to the lying position.

Finally, it is worth noting that we obtained the same trends using *FD* estimators based on different algorithms (FD_H and FD_C) and this strengthens our results.

References

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