Relationships Among Heart Rate, Patterns of Ischemic Change and Time of Day

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Abstract

Using 18 records of newly developed Long Term ST Database we studied diurnal variations of ischemia and heart rate among patients exhibiting salvo, periodic and sporadic temporal patterns of transient ischemia. The results show, that ischemia increases during the morning interval. Heart rate increase during ischemic episodes is the highest for the sporadic group. Increased sympathetic tone precedes sporadic episodes during the day and night, but not during the morning interval. The results support our hypothesis, that vasospasms are responsible for salvo pattern, and physical exertion for sporadic episodes.

1. Introduction

Previous study [1] using the European Society of Cardiology Database (ESC DB) [2] has described distinctly different patterns of transient ischemic changes: salvo patterns (bursts of episodes, separated by short intervals), periodic patterns (quasi-periodic episodes, separated by longer intervals) and sporadic patterns (isolated episodes, appearing without any regularity). Due to the limitations of the ESC DB (2 hour records), it was difficult to differentiate between these patterns. The new Long Term ST Database (LTST DB) [3], which is currently under development, consists of 24 hour annotated records, and enables more reliable recognition of patterns of ischemia. Furthermore, it enables the extensive studies of diurnal variations of ischemia and heart rate among subjects.

In this paper we test a hypothesis, that the salvo patterns occur due to the coronary vasospasms and vasoconstrictions, and that the physical activity and increased oxygen demand cause sporadic patterns. We studied time- and frequency-domain parameters of the instantaneous heart rate (IHR) in the neighborhood of ischemic episodes for the records exhibiting typical salvo, periodic and sporadic patterns, and for different intervals of records (day, night and morning).

2. Methods

Among the first 37 records of the LTST DB (of which 8 contain only non-ischemic episodes), we selected records showing typical temporal patterns of transient ischemic episodes. We identified salvo pattern in 6 records, se0103, se0113 (see figure 1), se0127, se0125, se0129, se0154, periodic pattern in 6 records, s20612, s20788, s21067, se0106, sb0004, sb0007, and sporadic pattern in another 6 records, s19922, s20538, s20586 (see figure 2), s21098, sb0001, sifc06. Each record was divided into day, night and morning interval. Times in which patients were asleep (night) are not provided within the LTST DB, so we identified sleeping interval by observing trends of heart rate (lower and smoother), time series of QRS complex KL coefficients (changes of body position are reflected as sudden step changes), and appearance of noises (less present). Morning interval was defined as a period of 90 minutes, following the sleeping interval. The rest of the record was considered to be the day interval. For the records, we obtained uniformly sampled and smoothed IHR time series. Then we derived time- and frequency-domain parameters of the IHR. Parameters were obtained over several intervals in the neighborhood of ischemic episodes: 3-minute interval starting 6 minutes prior to ischemia onset (B0), 3-minute interval starting at the beginning of ischemia (B1), 6-minute interval prior to onset of ischemia (B2), interval during ischemia (I), and the non-ischemic part of the record ($\bar{\text{I}}$). Aggregate average statistics for all groups during different intervals of the records were derived from obtained measurements. We derived three time series in the frequency domain: LF - fraction of total IHR power in low frequency band (0.04 to 0.15 Hz), HF - fraction of total IHR power in high frequency band (0.15 to 0.4 Hz), and LF/HF - the sympatho-vagal ratio. To compute LF and HF powers, we used adaptive

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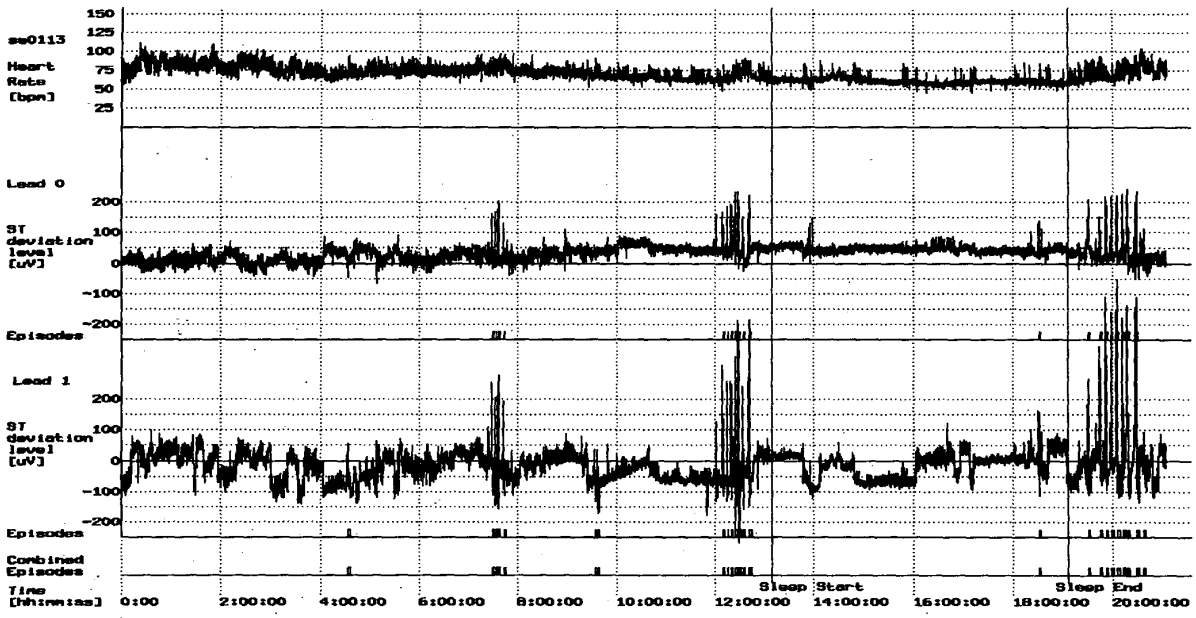

Figure 1: Time trends of record se0113 from the salvo group. From top to bottom: instantaneous heart rate; ST segment deviation level for lead 0 (J+80ms); ischemic episodes for lead 0; ST segment deviation level for lead 1; ischemic episodes for lead 1; combined ischemic episodes for both leads in the sense of logical OR function. The two vertical lines represent the time of falling asleep and the time of awakening.

autoregressive method with a recursive least-square algorithm. The order of the model used was 12, while the forgetting factor λ was 0.985. To assess statistically significant differences of time- and frequency-domain measurements of the IHR for the groups and for the intervals of the records the Student's t-test was used.

3. Results

Table 1 summarizes appearance of ischemic events through all intervals of records. Ischemia is the most common during the morning interval, while it is the least likely during the night. For the periodic group and much more evidently for the sporadic group, the percentage of ischemia duration dramatically rises in the morning interval in comparison to the salvo group. Table 2 shows aggregate average heart rates for all groups through different intervals of records. The mean heart rates as well as their variations through the intervals of records are the highest for the sporadic group. Aggregate average ratios of the mean heart rate in the intervals B1 (HR_{B1}) against B0 (HR_{B0}) are summarized in table 3. Mean heart rate during ischemia (B1) is higher than that prior to ischemia (B0) in all cases but the increase is almost three times as large for the sporadic group (18.8%) as for the salvo group (6.3%) during the day interval. Figure 3 shows aggregate average normalized LF and HF powers for the salvo, periodic and sporadic group outside ischemia ($\bar{\text{I}}$), prior to ischemia (B2) and during ischemia (I) throughout different intervals of records, while figure 4 shows sympatho-vagal ratios. The LF power for the salvo group changes only very slightly in all intervals of records. During B2, the LF power noticeably rises for the sporadic group during the day and night interval, but interestingly, falls during the morning interval. The LF power for the sporadic group significantly falls during I in comparison to the interval B2 during the day interval ($p < 0.02$) and during entire record ($p < 0.007$). Furthermore, the LF power for the sporadic group significantly falls during I in comparison to

	Day	Night	Morning	Record
Salvo	94 (5.22)	48 (5.59)	13 (7.36)	155 (5.48)
Periodic	112 (15.50)	53 (10.89)	14 (36.12)	179 (15.00)
Sporadic	20 (2.64)	4 (0.20)	8 (6.31)	32 (2.04)

Table 1: Number of episodes per group per different intervals of records. Aggregate average percentages of duration of ischemia are bracketed.

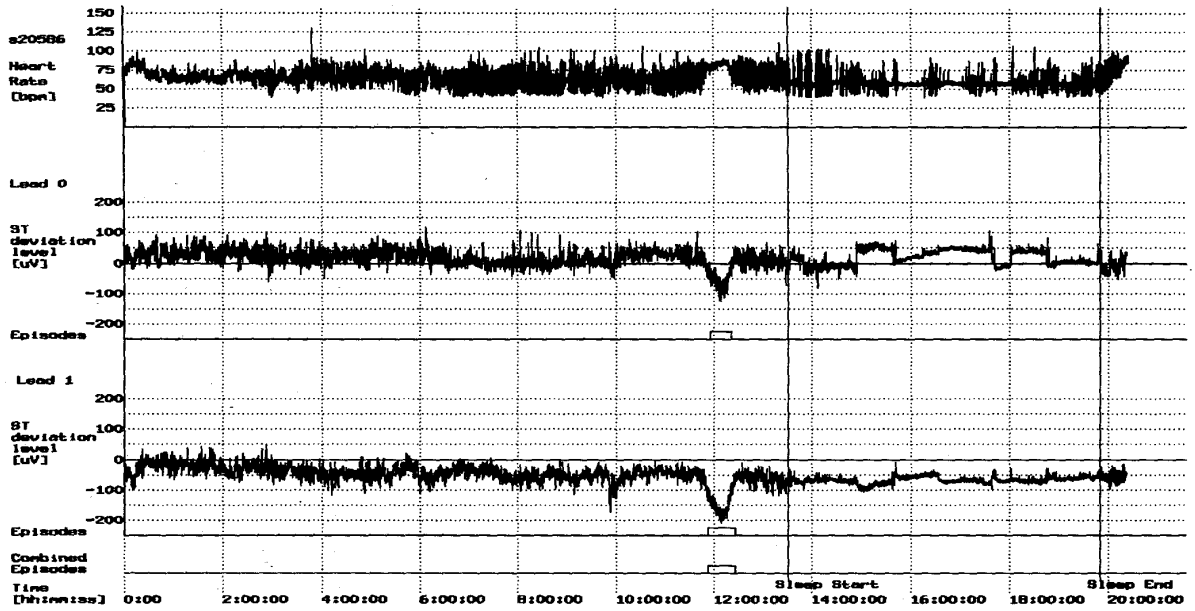

Figure 2: Time trends of record s20586 from the sporadic group. (For legend see caption to figure 1.)

	Day	Night	Morning	Record
Salvo	70.776	60.495	76.854‡	67.780
(std)	8.989	5.749	12.097	10.033
Periodic	78.302	68.296	76.470	74.554
(std)	10.276	7.550	10.726	10.726
Sporadic	83.392	65.797⋆	84.351•	77.102
(std)	11.138	7.260	11.949	13.757

Table 2: Aggregate average heart rates for all groups during intervals of records. ‡ $p < 0.006$ versus night for the salvo group. ⋆ $p < 0.04$ versus day for the sporadic group. • $p < 0.04$ versus night for the sporadic group.

	Day	Night	Morning	Record
Salvo	1.063	1.092	1.043	1.060
Periodic	1.097	1.201	1.091	1.123
Sporadic	1.188	1.286	1.095	1.168

Table 3: Aggregate average ratios of the mean heart rate in the intervals B1 and B0 (HR_{B1}/HR_{B0}).

the salvo group in all intervals, except during the night (day: $p < 0.03$, morning: $p < 0.04$, record: $p < 0.003$). The HF power for the sporadic group stays approximately equal to the HF power for the salvo group in B2 during the day interval, drops during the night interval, but interestingly rises during the morning interval. The HF power for the sporadic group significantly falls during I in comparison to the interval B2 during the day interval ($p < 0.02$) and during entire record ($p < 0.01$). Finally, the HF power for the sporadic group significantly falls in I in comparison to the salvo group in all intervals except during the night (day: $p < 0.05$, morning: $p < 0.02$, record: $p < 0.002$).

4. Discussion and conclusions

The newly developed LTST DB is intendent to be a reference polygon to assess the performance of transient ischemia detectors and to enable basic studies connected to physiological mechanisms responsible for ischemia. The 24 hour duration of the records enables more accurate division of the records into groups with characteristic temporal patterns of ischemia and in-depth studies of diurnal variations of ischemia and heart rate.

Records with sporadic pattern mostly exhibit depressions in the ST segment deviation level, which are connected to heart rate increase due to the physical activity [4] , while records with salvo pattern exhibit elevations. Appearence of ischemia in the records agrees with well known observation, that incidence of ischemia increases during the morning interval [5]. We found that this is true for all groups, but was the most prominent for the sporadic group. This increase is linked with physical activity, but it could also appear due to the lower ischemia threshold in the morning interval.

Variations of the mean heart rate throughout the records are the greatest for the sporadic patterns. During the night interval, the sporadic group exhibits no-

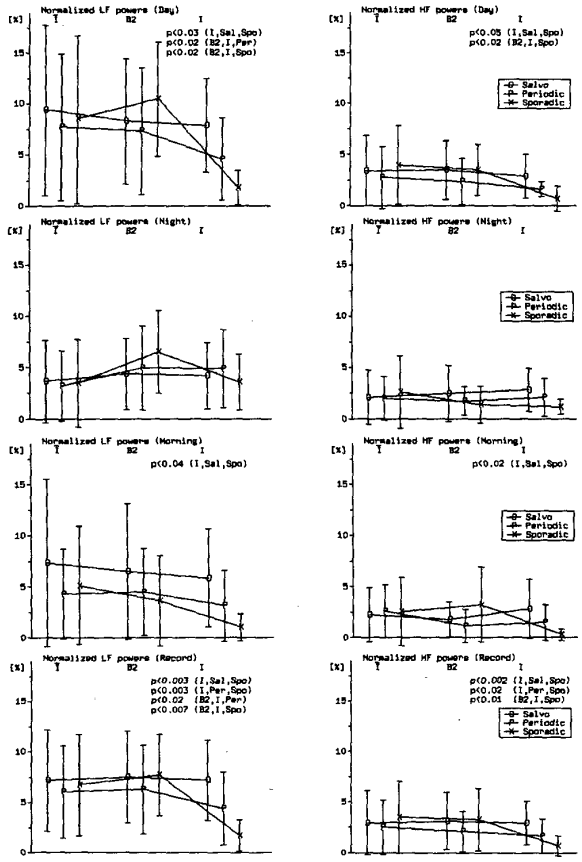

Figure 3: Aggregate average normalized LF (left) and HF (right) powers with standard deviations for the salvo, periodic and sporadic group during different intervals of records.

ticeably lower mean heart rate (and lower percentage of ischemia duration) in comparison to the other intervals of records, specially to morning interval. This suggests that the sporadic patterns occur due to the physical exertion. The salvo group exhibits only slight rise of duration of ischemia during the morning interval in comparison to other intervals of records. This suggests that the salvo patterns are not linked to physical activity, but to other reasons such as vasospasms, vasoconstrictions and endothelial factors.

Frequency-domain results show that sporadic episodes are preceeded with an increase of sympathetic tone during the day and night interval, but with a decrease during the morning. Sporadic patterns of ischemia are accompanied with significant drop of sympathetic tone during ischemic episodes for the day and morning intervals. Changes in autonomous nervous system in the intervals coinciding with ischemic

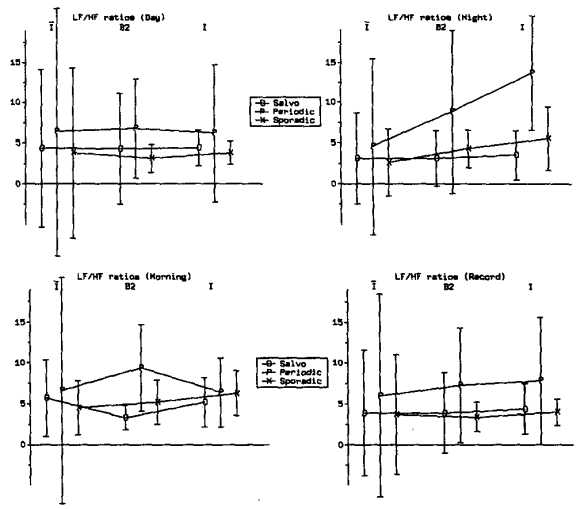

Figure 4: Aggregate average LF/HF ratios with standard deviations for the salvo, periodic and sporadic group during different intervals of records.

episodes of the salvo patterns are not significant.

The observations in this study support our hypothesis, that the salvo patterns result from the vasospasms and vasoconstrictions, while the sporadic patterns occur due to the physical activity.

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