Analysis of heart rate variability at rest and during aerobic exercise: a study in healthy people and cardiac patients

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ABSTRACT

Objective: To analyse HRV at rest in healthy people and in patients with acute myocardial infarction (AMI) and how it changes during aerobic exercise.

Methods: The heartbeat signal was recorded beat to beat for 15 minutes at rest and 15 minutes while pedalling in 10 healthy and active men (H group) and 10 cardiac patients (C group). The statistical parameters in the time domain were calculated as well as the spectral analysis applying the Fast Fourier Transform (FFT) and Poincare's graphic analysis (PGA).

Results: At rest, H group have an average SDRR (standard deviation of RR intervals) of 71.24 msec, a pRR50 (percentage of differences higher than 50 msec in RR intervals) of 9.97% and a PGA called ''comet-type''. The C group have a SDRR of 36.69 msec, a pRR50 of 1.69%, and a PGA ''torpedo-type''. These data show a low or moderate risk for healthy people and a high risk for patients. The FFT analysis lies in the very-low-frequency (VLF) zone in both groups.

During exercise, H group shows a significant decrease in all parameters; the PGA turns to ''torpedo-type'' and the FFT remains in the VLF zone. However, C group is characterised by the maintenance of pRR50, no change in PGA and a second peak in FFT in the high-frequency zone.

Conclusion: The HRV at rest and during aerobic exercise follows a different pattern in healthy people and in patients and it provides further information about performance during exercise.

Assessment of heart rate variability (HRV) is based on analysis of consecutive RR intervals and it may provide quantitative information on the modulation of cardiac vagal and sympathetic nerve input. So, HRV is a result of interactions between the autonomous nervous system (ANS) and the cardiovascular system in such a way that its analysis provides us with a non-invasive study of the ANS activity over the heart.[1]

A high HRV in sinus rhythm is indicative of health and it shows a good adaptability of the cardiovascular system, while a low HRV indicates a bad health condition, an abnormal heart function or an inadequate adaptability of the ANS. The abnormal HRV is considered as a risk marker in most of the models of cardiac death, an altered autonomous control being the most common mechanism involved.[2–4]

Acute myocardial infarction (AMI) may cause a regional sympathetic and parasympathetic dysfunction by interruption of the fibres which pass across the affected zone. The HRV appears to be decreased after an AMI and it recovers in the course of 6 to 12 months, but remaining lower than in healthy people.[5]

Concerning the measured parameters for HRV, the best prognosis information is provided by the standard deviation of RR intervals (SDRR)[6–9] and the percentage of differences higher than 50 msec in successive RR intervals (pRR50).[10] SDRR lower than 50 msec and pRR50 lower than 3% identify patients with a severely decreased HRV, while SDRR higher than 100 msec and pRR50 higher than 3% indicate a normal HRV. Despite everything, the physiological mechanisms involved in the higher risk related to a decreased HRV in cardiac patients are not known in full.

Both sympathetic and parasympathetic systems have an important role in the HR control during exercise, with predominance of sympathetic activity which involves a HR increase.[11] However, when exercise is performed in a routine way over time these effects may be different because the training induces a lower HR both at rest and during submaximal work.

Some studies have analysed the changes in HRV after acute exercise[12] and other authors report the response obtained according to the kind of exercise,[13] its intensity[14] or duration.[15–17]Likewise, HRV has been used for detecting overtraining, but without agreement. So, Hedelin *et al*[18] reported an increased HRV in overtrained skiers while another study[19] found no change in HRV when nine canoeists were deliberately overtrained. On the other hand, Pichot *et al*[30] reported a decreased HRV in overtrained athletes.

Therefore, many studies have investigated HRV at rest in cardiac patients as in healthy people with the aim of detecting cardiac disorders, and many studies have investigated the effects of physical work in HRV, analysing it before and after exercise; but we have not found studies in which HRV is assessed during exercise compared with that at rest both in patients and in healthy people.

The aim of this paper is to analyse HRV at rest in healthy people and in patients with AMI and how it changes during aerobic exercise. The hypothesis is that this pattern will be different, and it may provide further information about the exercise prescription in patients with myocardial infarction.

MATERIAL AND METHODS

We have studied 20 subjects, all of them male, divided into two groups: one (H group) made up of 10 healthy and active men (age 26.5 (SD 3.3) years; height 179.3 (6.6 cm; weight 80.4 (11.8 kg) and the

Table 1 References for the statistical parameters in the time domain, including the risk level stratification

Averaged RR interval	RR<750 ms → high
	RR 750–900 ms → moderate
	RR>900 ms → low
SDRR	SDRR<50 ms → high
	SDRR 50–100 ms → moderate
	SDRR>100 ms → low
pRR50	pRR50<3% → high
	pRR50 ⩾3% → low
SDARR	SDARR<8 ms → high
	SDARR 8–12 ms → moderate
	SDARR ⩾12 ms → low
SDRR index	SDRR index <25 ms → high
	SDRR index = 25–40 ms→ moderate
	SDRR index ⩾40 ms → low

pRR50, percentage of differences higher than 50 msec in RR intervals; SDARR, standard deviation of averaged RR intervals over 5 minute periods; SDRR, standard deviation of RR intervals.

other (C group) made up of 10 cardiac patients (age 61.1 (4.7) years; height 165.3 (5.3) cm; weight 86.9 (11.1) kg).

Every subject in the C group had at least one episode of AMI, was a member of the Asociación de Pacientes Cardiacos de Sevilla y Provincia and was taking part in the phase III of a cardiac rehabilitation programme. One of the patients did not complete the procedure totally, so he was excluded. All the episodes of AMI had happened between 1 and 8 years before the study, so none of the patients had suffered an acute episode in the last year.

The subjects in H group had no pathological record and they practised physical activity at least 3 days a week.

Every subject in both groups was informed about the contents of the investigation and was requested to give written consent. The study had the approval of the ethical committee of the Centro Andaluz de Medicina del Deporte (CAMD).

The heartbeat signal was recorded using a Polar S810i™ monitor (Kempele, Finlandia) in a RR mode (beat to beat).

Prior to the test, all the patients in C group underwent a medical examination including medical record, electrocardiogram and cardiac ultrasound scan. This examination was performed by a cardiologist from the CAMD. The healthy subjects answered a questionnaire about their medical history to assess the absence of pathological record and their activity habits.

The heartbeat signal was recorded in every subject over 15 minutes at rest and for another 15 minutes while pedalling in a cycle ergometer with a constant intensity. Both registers were separated by a 30 minute period. The intensity of exercise for the cardiac patients was 75% of the maximal HR reached in the ergometry according to the discharge information from the hospital. This HR was chosen because it is the value at which the patients usually work in their rehabilitation sessions. Since this HR value represents around 60% of the maximal theoretical HR (calculated as 220−age), this was the intensity chosen for the healthy subjects.

The duration of the records (15 minutes) guarantees a data sequence long enough for the analysis.[21 22] These records were incorporated to the computer through an infrared interface (Polar IR), using the Polar Precision Performance software (version 3), and then data were included in a database for statistical and graphical analysis.

According to the recommendations of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology,[8] the following parameters were calculated in the time domain: the average RR duration, SDRR, the standard deviation of averaged RR intervals over 5 minute periods (SDARR), the mean of SDRR (SDRR index) and the pRR50. All data are expressed as mean and standard deviation. In order to establish the statistical significance, a Student t test was used, taking into account a p value lower than 0.05 as a level of significance. The variance of all data series was calculated and *F* test was used to determine whether the variances were different.

A spectral analysis was performed applying the Fast Fourier Transform (FFT) with the Sigwiev v1.96 software, as well as a Poincare's analysis in which consecutive RR intervals are represented in a two-dimensional diagram.

Table 1 shows the reference values for the statistical parameters. Concerning the spectral analysis of FFT, we have considered the following frequency zones:[8] high frequency (HF) from 0.15 to 0.4 Hz; low frequency (LF) from 0.04 to 0.15 Hz; very low frequency (VLF) from 0.03 to 0.04 Hz and ultra low frequency (ULF) less than 0.003 Hz. With respect to the Poincare's analysis, we have used the graphical models proposed by Woo *et al*.[22]

Table 2 Data for statistical parameters in the time domain

	H group				C group			
	Rest		Exercise		Rest		Exercise	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
RR interval	777.01	57.32	514.18	11.53	859.54	91.14	687.98	54.33
SDRR	71.24	22.47	17.34	3.59	39.69	14.75	17.86	5.31
SDRR index	66.63	16.06	16.36	3.58	32.65	12.36	16.98	4.89
SDARR	16.34	15.41	4.38	2.53	17.04	12.99	4.92	3.23
pRR50	9.94	5.70	0.30	0.33	1.70	2.25	0.48	1.02
Total R waves	1182.00	102.32	1786.80	48.78	1040.00	132.54	1328.11	105.57
HR (beats/min)	77.61	5.91	116.75	2.58	70.53	7.73	87.67	6.47

HR, heart rate; pRR50, percentage of differences higher than 50 msec in RR intervals; SDARR, standard deviation of averaged RR intervals over 5 minute periods; SDRR, standard deviation of RR intervals.

RESULTS

Table 2 shows the values obtained in the time domain for both groups at rest and during exercise. The risk stratification based on the averaged data at rest is shown in table 3; in SDRR and pRR50 we observe a higher risk for cardiac patients.

Figure 1 shows the reduction in the averaged RR interval in both groups from the rest record to the exercise record, while figs 2 and 3 depict the evolution of SDRR, SDARR and SDRR index and fig 4 shows the change in pRR50 from rest to exercise.

The p values for the four comparison situations are presented in table 4. A high statistical significance is observed between rest and exercise for mean RR intervals, SDRR, SDARR and SDRR

Table 3 Risk stratification at rest according to time domain parameters

	Healthy	Patients
Average HR	Moderate risk	Moderate risk
RR interval	Moderate risk	Moderate risk
SDRR	Moderate risk	High risk
SDRR index	Low risk	Moderate risk
SDARR	Low risk	Low risk
pRR50	Low risk	High risk

HR, heart rate; pRR50, percentage of differences higher than 50 msec in RR intervals; SDARR, standard deviation of averaged RR intervals over 5 minute periods; SDRR, standard deviation of RR intervals.

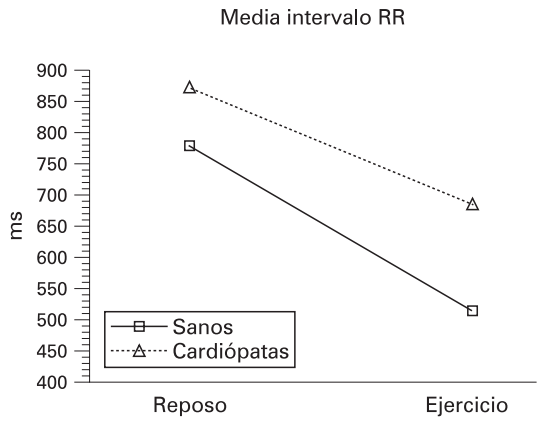

Figure 1 Averaged value (msec) of RR interval at rest and during exercise for healthy people and cardiac patients.

Figure 2 Changes in parameters of time domain from rest to exercise in healthy people.

index, both in the healthy and in the patient group, while pRR50 shows a significant change only in the H group. When both groups are compared at rest, we find significant differences in all parameters except SDARR, but when they are compared during exercise only RR interval shows significance.

In the Poincare's analysis (fig 5) a reduction in both longitudinal and transversal axes is observed in the healthy group, while in patients the transversal axis remains nearly unchanged.

In the FFT analysis, the frequency spectrum in the healthy group lies in the VLF zone (0.024 (SD 0.03) Hz at rest vs 0.004 (SD 0.002) Hz during exercise) and five subjects show a second peak both at rest (64.2% of maximal peak) and during exercise (45.54% of maximal peak). In the cardiac patients the frequency spectrum is also located in the VLF zone (0.003 (SD 0.003) Hz at rest vs 0.037 (SD 0.01) Hz during exercise), but only three subjects show a second peak at rest (49.97% of maximal peak, into the LF zone) while eight of them show it during exercise (36.01% of maximal peak, into the HF zone); one patient even presents a third peak in the HF zone with 26.27% of the maximal peak. Figures 6 and 7 show a sample of FFT for a healthy subject and a cardiac patient both at rest and during exercise.

DISCUSSION

The study of HRV is widely used in medical practice, to such an extent that in most of Holter's equipments a basic analysis of HRV is available. There is even commercialised equipment for HRV analysis, but this are usually focused on statistical parameters in order to assess a risk stratification. However, in this equipment the user is not able to access the original data, which was fundamental to this study. For this reason, we choose the use of a heart rate monitor selecting a beat-to-beat mode in order to get an original register of RR intervals and, in this way, to be able to include as many ways of analysis as appropriate.

According to the literature, healthy people have a high HRV at rest and this improves their capacity for adaptation to different and unpredictable stimuli.[23 24] However, a large number of factors can influence HRV, and the most interesting are disease and exercise.

However, cardiac patients have lower HRV at rest than healthy people[25] and they show some characteristic differences:[5 22 26]

1. Patients with AMI show resting values of RR intervals, SDRR and pRR50 lower than healthy people. Likewise, patients with chronic heart failure show values of SDRR and SDARR significantly lower than healthy people.
2. With the FFT analysis, the power spectrum of HRV is characterised by three components: high frequency, low frequency and very low frequency;[27] but in patients with AMI the low-frequency oscillations are predominant at rest, and this reflects sympathetic activity.
3. Finally, the transversal diameter in Poincare's graphic is much lower in cardiac patients than in healthy people.

As the age is an important factor which affects the HRV, the differences between the groups may be a confounder in the results. However, the pattern we have observed in both groups is in accord with the expected performance for every age.[27]

Otherwise, it is known that sportsmen have higher HRV at rest than sedentary people and this reflects a parasympathetic predominance. Particularly, SDRR, pRR50 and high-frequency spectrum are higher in sportsmen than in sedentary people.[28]

HRV is usually measured at rest, even when the changes with exercise are analysed. In those cases registers at rest are obtained before and after exercise. However, we think that it would be important to assess HRV during effort, and this kind of study is not frequent.

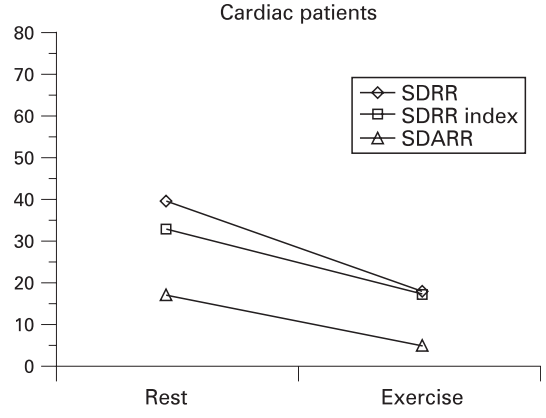

Figure 3 Changes in parameters of time domain from rest to exercise in cardiac patients.

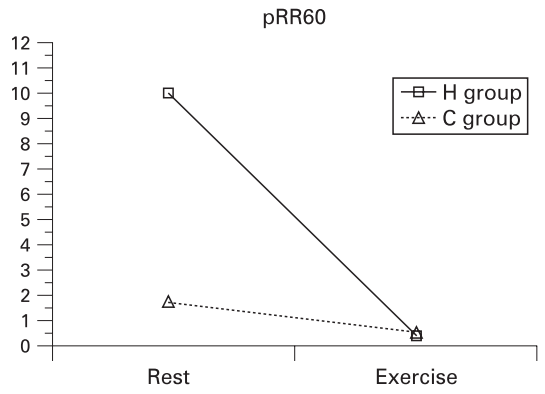

Figure 4 Changes in pRR50 from rest to exercise both in healthy people and in patients.

Taking this into account, we know that:

1. During an exercise on a cycle ergometer at 50% VO_{2max} performed by healthy people, the parameters indicating parasympathetic activity (as pRR50) decreased.[28]
2. There is no agreement in spectral analysis. According to some researchers,[29] during exercise there is a progressive decrease of parasympathetic activity on the sinusal node, while others[30] consider that during intense exercise there is an increase of the HF component, at the same time that the LF component and the LF/HF index decrease.
3. Poincare's graphic analysis shows a decrease of the transversal diameter in healthy people as a consequence of the parasympathetic activity disappearance; and this occurs at submaximal exercise (50% VO_{2max}),[23] during a gradual effort test until ventilatory threshold[31] or during an exercise with a constant load of 80 W.[32]

Regarding HRV during exercise in cardiac patients, we have found only one study. It reports a HR increase in patients with AMI during an aerobic exercise on a cycle ergometer; on the basis of a reduction in HF component during exercise,[33] the authors conclude that it is due to a decrease of the parasympathetic activity.

There is agreement on the fact that SDRR[6–9] and pRR50[10] provide the best prognostic information. In fact, in our study we find that both SDRR and pRR50 at rest show a high risk in cardiac patients, reflecting a decrease in parasympathetic activity on the heart.

Numerous studies[3 34 35] report that ULF, VLF or LF components in the spectral analysis reflect the level of health in a subject at rest. Using the FFT, we have found a predominance of VLF spectrum at rest and during exercise in both healthy people and patients. However, we can emphasise two significant differences: the width of the frequency spectrum in healthy people at rest is higher than in cardiac patients; and cardiac patients show a second peak in the HF zone during exercise. We have not found any reference to this second peak in previous papers, so we have no clear interpretation for it. This finding could be related to loss of variability or it could be related just to ventricular ectopy or β-blocker ingestion. We cannot be sure whether the use of β-blockers could be affecting the response of cardiac patients. For example, it may be surprising that HR at rest is lower in patients than in healthy people (table 2).

Table 4 Significance level $p<0.005$

	HR vs HE	CR vs CE	HR vs CR	HE vs CE
RR Interval	0.000	0.000	0.029	0.000
SDRR	0.000	0.001	0.002	0.803
SDRR IndEX	0.000	0.001	0.000	0.757
SDARR	0.016	0.017	0.917	0.687
p-RR50	0.000	0.079	0.001	0.616

CE, cardiac patients during exercise; CR, cardiac patients at rest; HE, healthy subjects during exercise; HR, healthy subjects at rest.

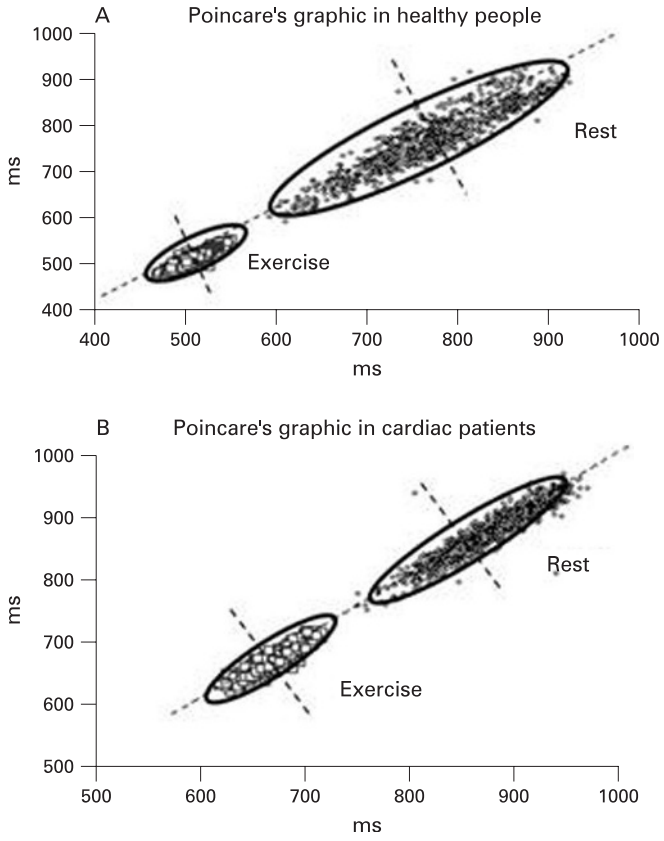

Figure 5 Model of Poincare's graphic observed in healthy people (A) and in patients (B), at rest and during exercise.

Finally, in the Poincare's graphic analysis we have found a decrease in both diameters in the H group (fig 5A) from rest to exercise. This change is more evident in the longitudinal axis and it probably means that HRV is reduced as a consequence of a decreased parasympathetic activity. However, in the C group (fig 5B) a decrease in parasympathetic activity is already observed at rest with a decreased HRV, and this situation is slightly modified during exercise.

In short, we can summarise the HRV performance at rest in healthy people and in cardiac patients as follows: the healthy people have an average SDRR of 71.24 msec and a pRR50 of 9.97%, and the Poincare's analysis shows the graphic called comet-type by Woo *et al*.[22] The cardiac patients have a SDRR of 36.69 msec, a pRR50 of 1.69%, and a torpedo-type Poincare's graphic.[22] So, these data show a low or moderate risk for healthy people and a high risk for patients.

During exercise, the HRV in healthy people is characterised by a significant decrease in averaged duration of RR intervals, SDRR, SDRR index, SDRRA and pRR50; likewise, the Poincare's graphic turned into a torpedo-type and the FFT spectrum remained in the VLF zone. However, the HRV in cardiac patients is characterised by a lower decrease of RR

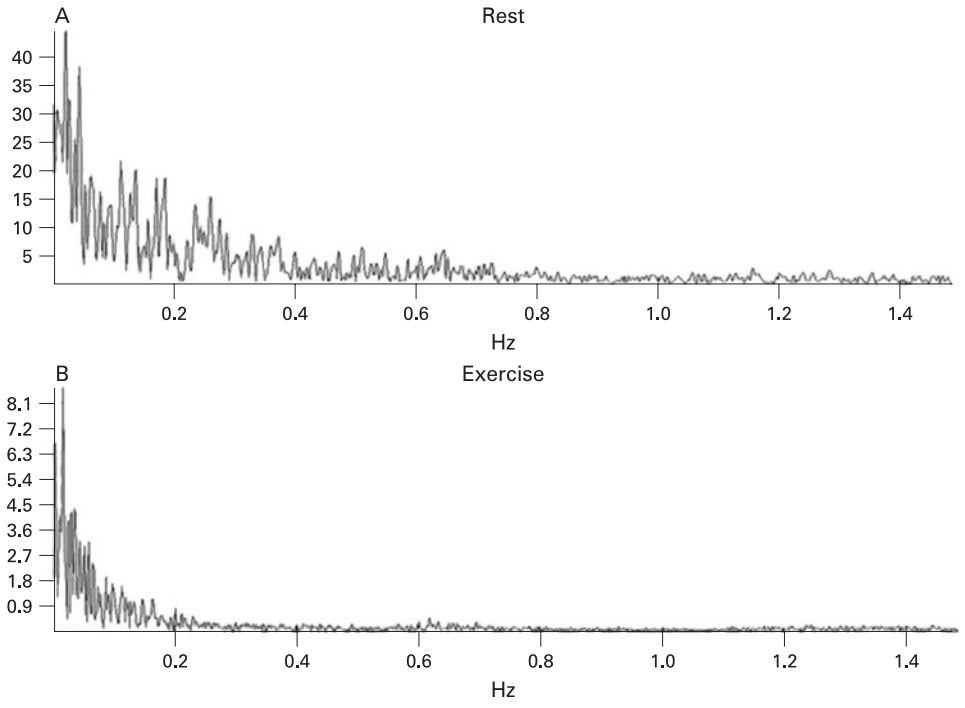

Figure 6 A sample of FFT for a healthy subject at rest (A) and during exercise (B).

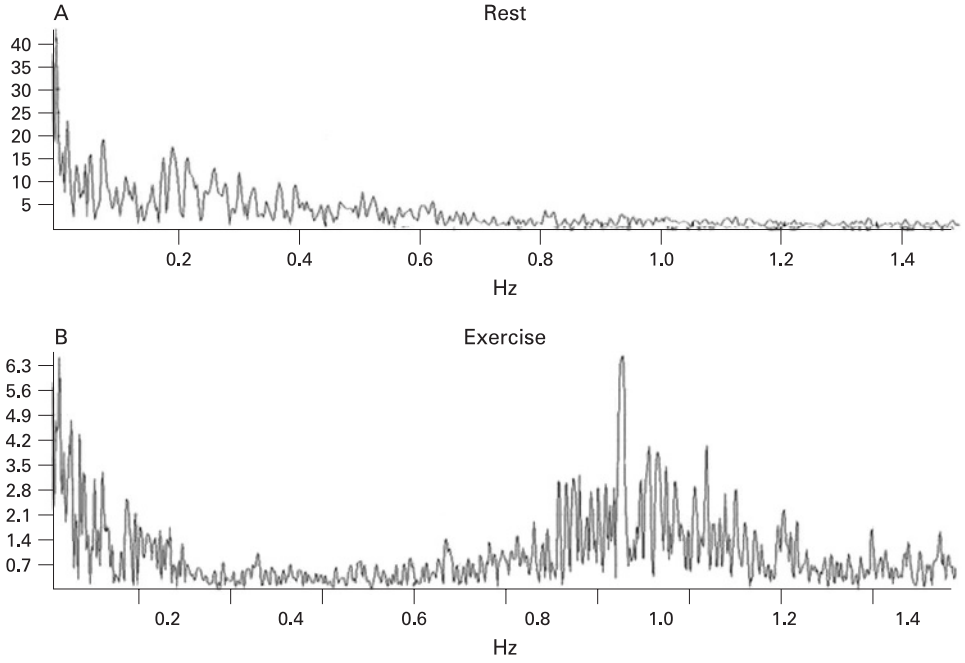

Figure 7 A sample of FFT for a cardiac patient at rest (A) and during exercise (B).

intervals, SDRR, SDRR index and SDRRA, the maintenance of pRR50, no change in Poincare's graphic (torpedo-type) and the presence of a second peak in FFT in the HF zone.

So, the main differences from rest to exercise are that pRR50 decreases in healthy people while remaining constant in cardiac patients, and that most cardiac patients have a second peak in FFT in the HF spectrum.

In conclusion, the HRV at rest and during aerobic exercise follows a different pattern in healthy people and in patients with AMI and it provides further information about performance during exercise.

Competing interests: None.

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