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SHORT COMMUNICATION

Heart Rate and Increased Intravascular Volume

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Summary

The objective was to establish whether an intravascular volume increase leads to a heart rate (HR) increase without increased sympathetic tonus. HR changes at rest and at deep breathing (6/min – simulated increase of atrial filling pressure) were measured in patients after heart transplantation. Evaluation of dependency of HR changes on breathing depth was done through a new time series methodology. The data was evaluated through graphs displaying a significant increase in the graph area at deep breathing, when compared with breathing at rest ($p < 0.01$). We presume that an increase in HR corresponds to increased intravascular volume and malfunctioning kidneys.

Key words

Kidneys • Heart rate • Atrial mechanisms • Intravascular volume • Breathing

An increased heart rate at rest is an important prognostic indicator for the majority of cardiovascular diseases. This is especially valid in case of essential arterial hypertension, chronic heart failure, and coronary heart disease (Attubato *et al.* 1994, Mancia 1997, Kára *et al.* 1999a,b). An increase in heart rate (HR) at rest is also related to increased sympathetic tonus at rest, which significantly influences the development of the above mentioned diseases and substantially assists in the origin of the so-called Reaven's syndrome.

A malfunction of the regulatory kidneys' function, that finally leads to the retention of body fluids, also considerably influences the progression of essential arterial hypertension. An increase of intravascular volume generates a number of negative consequences:

- it enables the final fixation of increased values of systemic blood pressure;
- it speeds up the progression of essential hypertension towards chronic heart failure;
- it speeds up the progression of chronic heart failure towards its terminal forms.

The objective of our experiment was to establish whether an increased heart rate at rest will also reflect any changes of intravascular volume (apart from increased sympathetic tonus), i.e. the malfunction of excretory function of kidneys.

To eliminate the influences of sympathetic innervation, we have evaluated the changes of heart rate in patients after orthotopic heart transplantation. To simulate the increased intravascular volume (and

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increased atrial filling pressure), we have used deep breathing at the rate of 6 respirations per minute. During a deep breath onset occurs an increased return of blood to heart. The filling pressure of the right atrium increases and the atrium enlarges, as it is in the case of increased intravascular volume due to the retention of body fluids.

Methods

Ten patients after orthotopic heart transplantation (9 men, average age 51.6 years, average time since the transplant 88.8 days), were subjected to strict standard conditions. None of the patients exhibited any signs of transplant rejection at the examination time (endomyocardial biopsy grade 0 was undertaken 24 h before the measurement).

We have measured and evaluated HR changes at spontaneous breathing and at controlled breathing at the level of 50-75 % of the vital capacity at the rate of 6 respirations per minute. The frequency and depth of breathing were optically regulated by means of a Light Emitting Diode Indicator (LED). A detailed briefing and training of the patients preceded each measurement. Individual measurements took 5 min and the break between individual measurements was 5 min.

Electrocardiogram (model 90308, SpaceLabs, Redmond, USA), blood pressure (Finapres 2300, Ohmeda, Louisville, USA) and breathing (ANNA 1 – our inventive system) were continually recorded in a time-synchronized manner.

We developed the spirometric ANNA 1 system with analogue and digital outputs to exactly record the depth of breathing (Fritsch-Yelle *et al.* 1999). Its construction enables time synchronization of the frequency recording and depth of breathing (in ml) with other recorded signals. The recorded analogue signals are digitized via Digital to Analogue 16 bit Converters with minimal sampling frequency of 500 Hz for each channel. Our ScopeWin ANS software undertook recording and data processing.

Earlier studies evaluating HR changes in patients after heart transplantation used the so-called standard methods, which are based either on the evaluation of average heart rate together with other statistically derived values (standard deviation, etc.) or on the application of spectral analysis methods. These methods are simple to use and easy for data processing. However, they exhibit some limitations because they are not suitable for differentiation discrete changes in heart rate, that are characteristic for transplanted hearts, and they offer very little information about the behavior changes of the examined system in time.

For these reasons, we have used a new approach for calculation of HR dependence on the depth of breathing. It applies methods of digital quadrature detection and digital filtering. We have calculated the dependency of HR on the depth of breathing (the increase of atrial filling pressure) as a time function. The behavior of the investigated transfer system (depth of breathing – heart rate) was analyzed in the frequency band corresponding to the frequency of breathing.

The obtained data was graphically appraised in standardized three dimensional XYt graphs (Fig. 1), where the X-axis represents the relative heart rate changes (in ms; scale in our study: 1 mm = 0.37 ms), the Y-axis represents the relative breathing volume changes (in ml; scale in our study: 1 mm = 22 ml) and the t-axis represents the time (in s). The t-axis is absent due to the two-dimensionality of the Figure 1.

Each recorded ellipse symbolizes the changes during one breathing cycle. The 6 ellipses per minute or 30 ellipses during a 5-min measurement period were obtained at the controlled breathing rate of 6 respirations per minute. Thirty ellipses form the resulting XYt graph. This methodology enables recording of even very small discrete changes, which cannot be registered by the standard methods.

The influence of breathing depth (change of the right atrium filling pressure) on HR is assessed as the internal free area of the ellipse. The area of the ellipse is calculated as

$$S = \pi \times a \times b$$

where S = the area of the ellipse (in mm^2); a = the longitudinal half-axis of the ellipse (in mm); b = the latitudinal half-axis of the ellipse (in mm).

A local Ethical Committee had approved the research project. Prior to being placed into the project, each patient signed an Informed Consent Form.

The average breathing volume at spontaneous breathing was 630.6±129.3 ml (Mean ± SD); the average breathing frequency was 16.0±1.97 respirations per minute. The average breathing volume at deep breathing was 2665.6±620.6 ml, whilst the average breathing frequency was 6.3±0.18 respirations per minute. The average area of the ellipse in the XYt graph at spontaneous breathing was 80.36±92.0 mm^2, whilst at the deep breathing it was 1256.0±692.1 mm^2. In comparison with breathing at rest, a significant increase of heart rate and heart rate oscillations (internal free area of XYt graphs) was recorded in connection with an increase of atrial filling pressure in case of deep breathing ($p<0.001$ paired T-test).

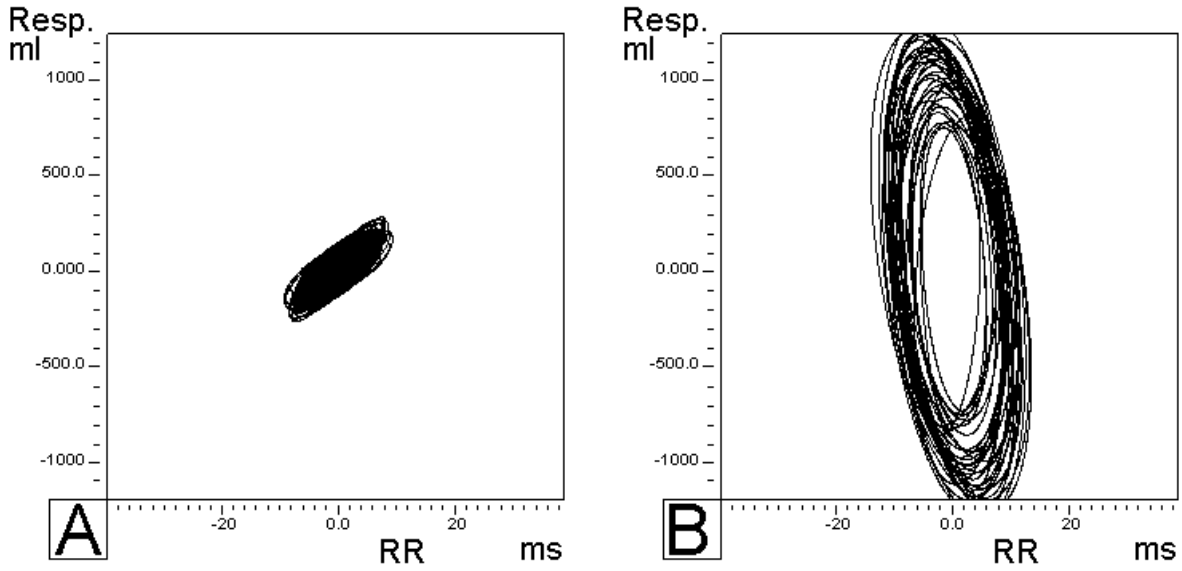

Fig. 1. *Typical findings of HR dependence on the changes of atrial filling pressure (AFP) in patients less than 90 days after heart transplantation. The X-axis represents the relative heart rate changes (in ms). RR = heart intervals. The Y-axis represents the relative breathing volume changes (in ml) and the t-axis represents the time (in s). Due to the two-dimensionality of the Figure, the t-axis is absent here. A: result of rest recording; B: result of deep breathing recording.*

Since the heart shortly after transplantation is totally without vegetative innervation (eight patients were less than 90 days after the heart transplantation (Fig. 1), the above described changes of the heart rate cannot be determined by a change of sympathetic tonus. Moreover, the reaction of HR to the change of the atrial filling pressure (Palatini and Julius 1997) began immediately so that it was not transmitted in a humoral manner. Thus the change of HR was intrinsic to the heart itself. It is possible that the increase in HR was caused by the increased mechanical dilatation of cells in the sinoatrial nodus.

References

ATTUBATO MJ, KATZ ES, FEIT F, BERNSTEIN N, SCHWARTZMAN D, KRONZON I: Venous changes occurring during the Valsalva maneuver: evaluation by intravascular ultrasound. *Am J Cardiol* **74**: 408-410, 1994.

FRITSCH-YELLE JM, CONVERTINO VA, SCHLEGEL TT: Acute manipulation of plasma volume alter arterial pressure response during Valsalva maneuvers. *J Appl Physiol* **86**: 1852-1857, 1999.

JULIUS S: Effect of sympathetic overactivity on cardiovascular prognosis in hypertension. *Eur Heart J* **19** (Suppl F): F14-F18, 1998.

KÁRA T, JURÁK P, HALÁMEK J: A spirometer ANNA 1, depth of breathing and autonomic nervous system. *PACE* **6:** A79, 1999a.

KÁRA T, JURÁK P, SOUČEK M, HALÁMEK J, NOVÁK M, ŠUMBERA J, TOMAN J, ŠTEJFA M, NOVÁKOVÁ Z, ŘIHÁČEK I: Evaluation of autonomic nervous system dysfunction by phase shift and XYt graph methods. *Am J Hypertens* **12**: A182, 1999b.

MANCIA G: The sympathetic nervous system in hypertension. *J Hypertens* **15**: 1553-1565, 1997.

PALATINI P, JULIUS S: Association of tachycardia with morbidity and mortality. *J Hum Hypertens* **11**: 374-381, 1997.

ZUANETTI G, MANTINI L, HERNÁNDEZ-BERNAL F, BARLERA S, DI GREGORIO D, LATINI R, MAGGIONI AP: Relevance of heart rate as a prognostic factor in patients with acute myocardial infarction: insights from the GISSI-2 study. *Eur Heart J* **19** (Suppl F): F19-F26, 1998.

Reprint requests

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