DOI 10.1007/s10527-021-10031-z
Biomedical Engineering, Vol. 54, No. 5, January, 2021, pp. 323-326. Translated from Meditsinskaya Tekhnika, Vol. 54, No. 5, Sep.-Oct., 2020, pp. 19-21.
Original article submitted March 2, 2020.

Monitoring the Frequency and Amplitude Parameters of Ventricular Fibrillation during Artificial Perfusion of the Heart

M. I. Gurianov[1]* and P. K. Yablonsky[1,2]

A method for monitoring the frequency and amplitude parameters of ventricular fibrillation (VF) during artificial perfusion of the heart is described. The method is based on spectral analysis of VF cardiosignal at 30 frequencies of 0.5 Hz width in the frequency range of 0.5-15 Hz and determining the frequency, amplitude, and relative weight of the 1st-3rd highest amplitude oscillations. The method can be used for monitoring the frequency and amplitude parameters of VF during long-term artificial perfusion of the heart.

Introduction

Cardioplegic arrest and artificial circulation have been used for decades in cardiothoracic surgery [1, 2]. The heart is not perfused when in a state of total ischemia under cardioplegia, which is detrimental for the heart [3]. Reperfusion is performed to recover cardiac activity after a period of cardioplegia and ischemia. However, reperfusion leads to reperfusion complications, including myocardial damage/necrosis and depression of contractility [1-5]. Ischemic and reperfusion complications cannot be avoided in the case of cardiothoracic surgery under cardioplegia.

The use of ventricular fibrillation (VF) and artificial perfusion of the heart during cardiothoracic surgery is an alternative to cardioplegia. It allows complications of cardioplegia associated with myocardial ischemia and reperfusion to be avoided. The fibrillating myocardium does not suffer from ischemia, and no reperfusion is needed during cardiothoracic surgery under artificial perfusion of the heart.

Monitoring of VF parameters is needed during cardiothoracic surgery under VF and long-term artificial perfusion of the heart. Monitoring makes it possible to perform online control of the functional state of the heart. We have not found any works in the available literature devoted to monitoring the parameters of VF during cardiothoracic surgery under artificial perfusion of the fibrillating heart.

The aim of the work was to test a method for monitoring the frequency and amplitude parameters of VF during artificial perfusion of the heart.

The method is based on Fast Fourier Transform (FFT) of VF cardiosignal in the frequency range of 0.5-15 Hz. FFT has proved its efficiency. It allows the frequency and amplitude of VF oscillations to be determined in an automated regime [6-8]. The novelty of the method is that we have made FFT analysis of VF cardiosignal at 30 frequencies of 0.5 Hz width (0.5, 1, 1.5, ..., 15 Hz) and determined the frequency, amplitude, and relative weight of the 1st-3rd highest amplitude oscillations of VF.

Methods

Ventricular electrogram was recorded in four experiments on the isolated canine heart perfused with the blood of a supporting dog using the standard technique [9]. The experiments were carried out in compliance with the requirements of the USSR Ministry of Higher and Secondary Professional Education Order No. 742 of November 13, 1984 "Regulations for carrying out studies using experimental animals" and the European Convention for the Protection of Vertebrate Animals used

[1] Saint Petersburg State University, St. Petersburg, Russia; E-mail: mgurianov@yandex.ru
[2] Saint Petersburg Research Institute of Phthisiopulmonology, Ministry of Health of the Russian Federation, St. Petersburg, Russia.
* To whom correspondence should be addressed.

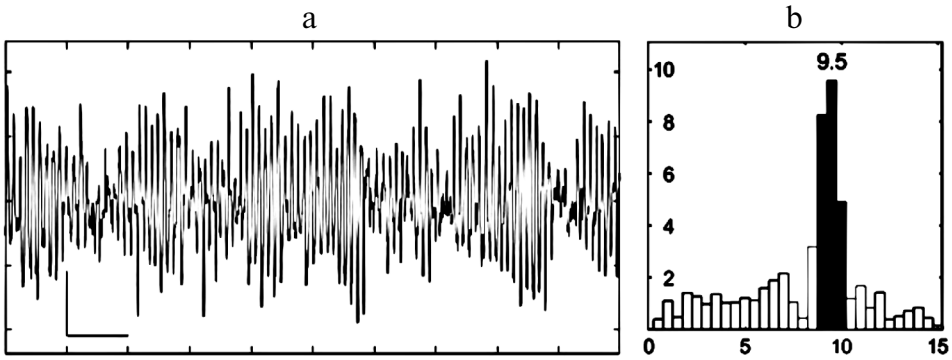

Fig. 1. Ten-second segment of ventricular electrogram (a) and spectrogram of the first one-second segment of electrogram (b) of the canine heart during perfusion in ventricular fibrillation. Calibration of the electrogram: 2 mV; 1 s. In the spectrogram: the abscissa — frequency (Hz); the ordinate — amplitude (mV).

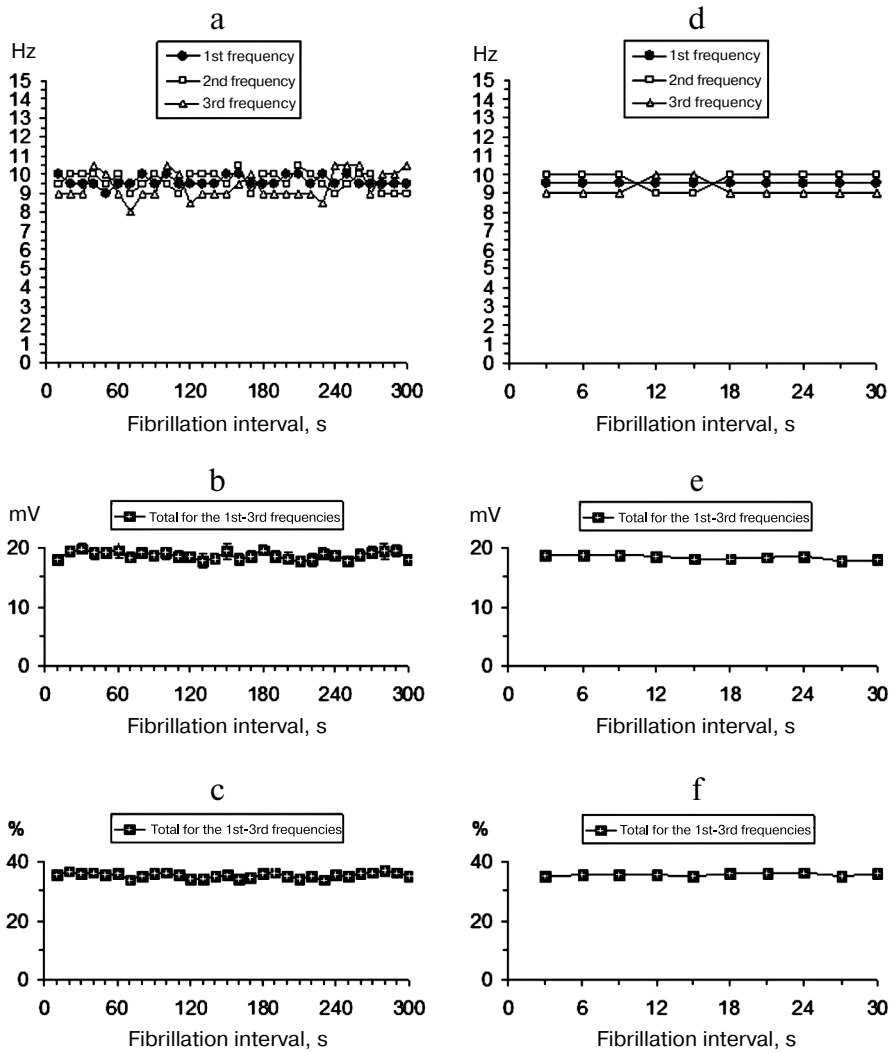

Fig. 2. Frequency (Hz), amplitude (mV), and relative weight (%) of the 1st-3rd highest amplitude oscillations in 10-second (a-c) and 3-minute (d-f) intervals of ventricular fibrillation during perfusion of the canine heart: mode (a, d); $M \pm m$ (b, c, e, f); $n = 40$ (a-c); $n = 720$ (d-f); $p > 0.05$ when comparing pairs of values of the amplitude (b, e) and relative weight (c, f).

for Experimental and Other Scientific Purposes (Strasbourg, March 18, 1986).

Ventricular electrogram was recorded from electrodes inserted into the right and left ventricles using a Cardiotechnika-ECG-8 cardiograph (Inkart, Russia) at a sampling rate of 1000 Hz. VF was induced by electric stimuli with a frequency of 10 Hz and an amplitude of 10 mA. We performed spectral analysis of one-second segments of ventricular electrogram during VF using FFT analysis at 30 frequencies of 0.5 Hz width in the range of 0.5-15 Hz: 0.5, 1, 1.5, ..., 15 Hz.

The frequency (Hz) and amplitude (mV) of the 1st, 2nd, and 3rd highest amplitude oscillations of VF were determined as shown in Fig. 1. The spectrogram shows that oscillations of 9.5, 9, and 10 Hz generate the first, second and third highest spectral power; the 1st-3rd highest amplitude oscillations dominate in the frequency structure of VF.

After that, the frequency (Hz), amplitude (mV), and relative weight (%) of the 1st, 2nd, and 3rd highest amplitude oscillations were determined at 10-second intervals (n = 40) and 3-minute intervals (n = 720) of VF under perfusion of four fibrillating canine hearts (frequency – mode; amplitude, weight – $M \pm m$).

The suggested method for spectral analysis of VF cardiosignal is original. It was developed by our team on the basis of our previous studies of VF [10, 11]. Statistical analysis was performed in the R Project for Statistical Computing [12] using Welch's t-test [13].

Results

The results obtained are shown in Fig. 2. Analysis of 10-second intervals of VF reveals a stable frequency band containing the 1st, 2nd, and 3rd highest amplitude oscillation frequencies: the 1st frequency (with the highest spectral power) has the values of 9-10 Hz, and the 2nd and 3rd frequencies are 0.5-1 Hz above or below the 1st frequency (Fig. 2a).

The sum amplitude of the 1st-3rd highest amplitude oscillations is 18-19 mV, and the small amplitude differences in 10-second intervals of VF are not significant (Fig. 2b). The 1st-3rd frequency oscillations occupy together 1/10 of the frequency range of 0.5-15 Hz, having 35-36% of the total spectral power and dominating in the frequency structure of VF (Fig. 2c). The dominant frequency and amplitude structure is virtually stable during 30-minute perfusion in VF, as evidenced by the constant frequency (9-10 Hz), amplitude (18-19 mV), and relative weight (35-36%) of dominating oscillations of the 1st, 2nd, and 3rd frequencies (Fig. 2d-f).

Conclusions

A method for monitoring the parameters of VF during artificial heart perfusion has been described. The method is based on FFT analysis of canine ventricular electrogram in the frequency range of 0.5-15 Hz. The novelty of the method is that spectral analysis is carried out at 30 frequencies of 0.5 Hz width in the range of 0.5-15 Hz, and the frequency, amplitude, and relative weight of the 1st, 2nd, and 3rd highest amplitude oscillations of VF are determined. Analysis of the 1st-3rd highest amplitude oscillation frequencies has revealed the dominant frequency and amplitude structure of VF. The frequency, amplitude, and relative weight of dominating oscillations of the 1st, 2nd, and 3rd frequencies were virtually stable during artificial perfusion of the heart in VF.

A method for determining the frequency and amplitude of the 1st, 2nd, and 3rd highest amplitude oscillation frequencies can be used for automatic monitoring of ECG or ventricular electrogram during long-term artificial perfusion of the fibrillating heart under cardiothoracic surgery. The functional state of the fibrillating myocardium is stable during perfusion, as evidenced by the stability of the frequency, amplitude, and relative weight of dominating oscillations of the 1st, 2nd, and 3rd highest amplitude frequencies of VF. The VF frequency of the canine heart is close to that of the human heart [14, 15], and the spectral content of the ECG in VF is close to that of the ventricular electrogram in VF [8].

REFERENCES

1. Valooran, G. J., Nair, S. K., Chandrasekharan, K., Rahul, S., and Dominic, C., "Del Nido cardioplegia in adult cardiac surgery – Scopes and concerns," Perfusion, **31**, No. 1, 6-14 (2016).
2. Yamamoto, H. and Yamamoto, F., "Myocardial protection in cardiac surgery: A historical review from the beginning to the current topics," Gen. Thorac. Cardiovasc. Surg., **61**, 485-496 (2013).
3. Gebhard, M.-M., Bretschneider, H. J., and Schnabel, P. A., "Cardioplegia principles and problems," in: Physiology and Pathophysiology of the Heart (N. Sperelakis, ed.), Kluwer, Boston (1989), pp. 655-668.
4. Aass, T., Stangeland, L., Moen, C. A., et al., "Left ventricular dysfunction after two hours of polarizing or depolarizing cardioplegic arrest in a porcine model," Perfusion, **34**, No. 1, 67-75 (2019).
5. Jennings, R. B., "Historical perspective on the pathology of myocardial ischemia/reperfusion injury," Circ. Res., **113**, 428-438 (2013).
6. Pandit, S. V. and Jalife, J., "Rotors and the dynamics of cardiac fibrillation," Circ. Res., **112**, 849-862 (2013).
7. Bazaev, N. A. and Telyshev, D. V., "A complex algorithm of automatic fibrillation detection," Biomed. Eng., No. 2, 71-74 (2009).
8. Huizar, J. F., Warren, M. D., Shvedko, A. G., et al., "Three distinct phases of VF during global ischemia in the isolated blood-perfused pig heart," Am. J. Physiol., **293**, H1617-H1628 (2007).

9. Janse, M. J., The Effect of Changes in Heart Rate on the Refractory Period of the Heart, Mondeel-Offsetdrukkerij, Amsterdam (1971).
10. Gurianov, M. I., "Organized structure of ventricular fibrillation in canine heart," Ross. Fiziol. Zh. im. I. M. Sechenova, **102**, No. 3, 297-306 (2016).
11. Gurianov, M. I., "Organized frequency structure of electrocardiogram during long-duration ventricular fibrillation under experimental conditions," Sovr. Tekh. Med., **8**, No. 3, 37-48 (2016).
12. The R Project for Statistical Computing, https://www.r-project.org/ (accessed February 28, 2020).
13. Kobzar', A. I., Applied Mathematical Statistics. For Engineers and Scientists [in Russian], Fizmatlit, Moscow (2006).
14. Ivanov, G. G. and Vostricow, V. A., "Ventricular fibrillation and ventricular tachicardia – base position and diagnostic criteria," Vestn. RUDN Ser. Med., No. 1, 75-80 (2009).
15. Noujaim, S. F., Berenfeld, O., and Kalifa, J., "Universal scaling law of electrical turbulence in the mammalian heart," Proc. Natl. Acad. Sci., **104**, 20985-20989 (2007).