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HEMODYNAMIC SIGNIFICANCE OF VENTRICULAR ECTOPIC BEATS: THE IMPACT OF COUPLING INTERVALS

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The aim of the study was to evaluate the effect the impact of the coupling interval (CI) of ventricular ectopic beats (VEB) on their hemodynamic properties.

Methods. The hemodynamic properties of VEBs were studied using the example of ventricular parasystoles with typical manifestations. The hemodynamic properties of VEB were studied using the example of ventricular parasystoles with typical manifestations (significant differences in CI, “multiplicity,” presence of “fusion” QRS complexes) in two female patients without structural heart abnormalities, each having more than 10000 monomorphic VEB per day. The research method involved measuring blood pressure (BP) with each heartbeat. The duration of the study, over the course of which systolic BP (SBP), diastolic BP (DBP), and pulse BP (PBP) were recorded, was 15 minutes.

Results. The hemodynamic properties of VEB were determined by assessing the correlation between the duration of the CI and the SBP, DBP, and PBP of the VEB. The SBP, DBP, and PBP values showed a highly significant correlation with the CI of the VEB: the shorter the CI, the lower the SBP and PBP, and the higher the DBP. The DBP was more strongly dependent on the CI than the SBP, and the PBP was even more dependent. The relationship between the DBP and CI of the VEB was linear, whereas the relationship between the SBP and PBP with the CI of the VEB was nonlinear: it was more pronounced with short (decreased BP) and long CIs (increased BP). There was also a highly significant correlation between the PBP and SBP of the VEB, as well as between the PBP and DBP of the VEB: the PBP of the VEB was influenced by both the decrease in SBP and the increase in DBP, but more so by the decrease in SBP.

Conclusions. As the CI of VEB shortens, its SBP decreases and DBP increases. The relationship between DBP and CI is linear, whereas the relationships between SBP and PBP with CI are nonlinear: they are more pronounced with short (decreased BP) and long (increased BP) CIs. The PBP of VEB depends on both the decrease in SBP and the increase in DBP, but it is more strongly associated with SBP.

Key words: ventricular extrasystole; parasystole; coupling interval; arrhythmia-associated cardiomyopathy; “beat-to-beat” method; measurement of blood pressure at each heartbeat; hemodynamic effectiveness.

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Ventricular premature beats (VPB) are one of the most commonly encountered arrhythmias, which can be detected in patients with cardiovascular and other diseases, as well as in healthy individuals. Their primary clinical significance is their ability to provoke life-threatening ventricular arrhythmias and, as a consequence, sudden cardiac death. This is especially relevant for patients with various organic heart diseases and genetically determined heart conditions, including channelopathies and cardiomyopathies. However, even in the absence of the aforementioned pathology, idiopathic VPBs, including frequent ones, are not rare. These VPBs are not associated with sudden cardiac death. However, like other arrhythmias, such as various supraventricular tachyarrhythmias, they have different clinical significance.

Firstly, these are the symptoms and decreased quality of life. Secondly, they have the potential to form cardiomyopathies associated with arrhythmia (CAA). In contrast to tachyarrhythmias, where CAA is due to the high heart rate and the duration of the rhythm disturbance, in the case of VPBs, CAA is primarily linked to the number of ventricular ectopies. According to literature, when the number of VPBs exceeds 20% of the total number of heartbeats in a 24-hour ECG monitoring period, it is strongly correlated with an increased chamber size and decreased heart pump function. However, while the number of VPBs is an extremely important factor in determining their hemodynamic significance, it is likely not the only one. A clinical case was previously presented where a burden of ventricular ectopics exceeding 50% of heartbeats per day (including non-sustained and paroxysmal ventricular tachycardia) over 30 years of observation did not lead to the formation of CAA.

In the draft recommendations of the Ministry of Health of the Russian Federation for 2025 «Ventricular Arrhythmias. Sudden Cardiac Death,» it is indicated that the risk of developing CAA, in addition to the proportion of ectopic heartbeats, may be associated with the width of the ectopic QRS complexes. In several publications, alongside this characteristic, the possible significance of the morphology of QRS complexes, the index of premature beats, polymorphism, and several others are also discussed. However, the possible contribution of each of these characteristics to the hemodynamic incompetence of VPBs, which, in turn, leads to the formation of CAA, remains not fully understood.

It is not difficult to assume that the hemodynamic incompetence of premature heartbeats should be related to a decrease in systolic blood pressure (SBP) and an increase in diastolic blood pressure (DBP). The integral parameter – pulse blood pressure (PBP) – should decrease even further. It seems quite a complex task to evaluate the independent influence of each of the aforementioned characteristics on the hemodynamic properties of VPBs. The subject of this study was selected as a typical frequent monomorphic ventricular parasystole, where the only variable parameter was the coupling interval (CI). All VPBs were from a single source, with the same morphology (except for «fusion» beats) and QRS complex width. Thus, we had the opportunity to study the impact of the coupling interval on the hemodynamic characteristics of ectopic beats. To do this, the «beat-to-beat» blood pressure measurement method was used, which has been repeatedly described in previous studies. This method involves continuous registration of the volume of the finger arteries via a photoplethysmographic signal and a monitoring electro-pneumatic system that creates pressure, preventing changes in the diameter of the arteries under the cuff. At the same time, blood pressure is measured routinely on the other arm. The continuous blood pressure signal corresponds to Korotkoff sounds through the application of a special calculation formula. This method allows for the measurement of SBP and DBP during each individual heartbeat: both sinus and ectopic.

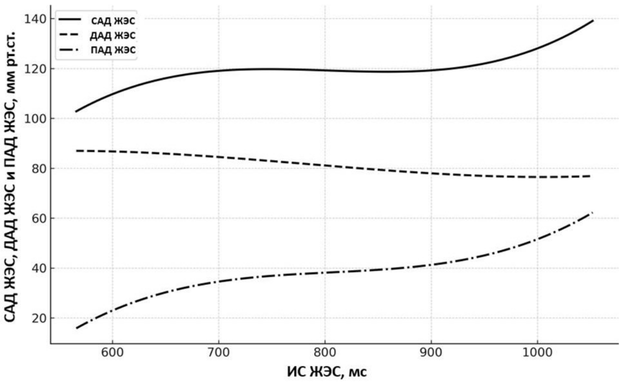

Fig. 1. Patient O. The relationship between SBP, DBP, and PBP of VPBs with the CI of VPBs.

The aim of the study was to assess the impact of the coupling interval of premature ventricular ectopic beats on their hemodynamic propertie.

METHODS

The clinical study adhered to Good Clinical Practice standards and the principles of the Helsinki Declaration and was approved by the local ethics committee of the cardiology clinic «North-West Center for the Diagnosis and Treatment of Arrhythmias» (Saint Petersburg, Russia). Written informed consent was obtained from the patients to participate in the study.

The hemodynamic properties of VPBs were studied using the example of clear (typical) ventricular parasystole (significant differences in CI, «multiplicity,» presence of «fusion» QRS complexes) in two female patients, each having more than 10,000 monomorphic VPBs according to Holter electrocardiogram monitoring. They did not have ventricular ectopic beats of other morphologies. Both patients showed no structural heart abnormalities according to echocardiographic data.

The primary method of the study involved measuring blood pressure («beat to beat») using the «Cardiotekhnika-SAKR» device (NAO «Inkart,» Saint Petersburg, Russia, patents for inventions N RU 2694737 C1, V.V. Pivovarov et al. and RU 2698447 C1, V.V. Pivovarov et al.). The duration of the study, during which SBP, DBP, and PBP were determined for sinus beats and VPBs at each heartbeat, was 15 minutes.

Statistical analysis

For statistical analysis, the SPSS software package was used. The means and standard errors of the mean (M±m) were calculated for each of the four variables (CI of VPB, SBP of VPB, DBP of VPB, and PBP of VPB). Pearson's correlation coefficient (r) was used to assess the linear relationship between two quantitative variables. To evaluate the influence of the independent variable (CI of VPB) on multiple dependent variables (SBP of VPB, DBP of VPB, and PBP of VPB), third-order polynomial regression (cubic regression) was employed. Multiple linear regression was used to assess the influence of multiple independent variables (SBP of VPB and DBP of VPB) on the dependent variable (PBP of VPB). A p-value of <0.05 was considered the threshold for statistical significance.

RESULTS

Patient O., 35 years old. The total number of VPBs during the 15-minute study was 256. The CI of VPBs ranged from 568 to 1052 ms (797.61±27.03 ms). The SBP of VPBs ranged from 93 to 144 mmHg (114.66±0.53 mmHg), DBP ranged from 67 to 96 mmHg (86.10±0.34 mmHg), and PBP ranged from 3 to 44 mmHg (34.63±2.10 mmHg). The SBP of sinus beats ranged from 111 to 129 mmHg (120.23±0.40 mmHg), DBP from 70 to 84 mmHg (78.18±0.31 mmHg), and PBP from 36 to 49 mmHg (42.04±0.26 mmHg). It is evident that VPBs are hemodynamically significant and significantly inferior in efficiency to sinus beats, manifested by a decrease in SBP and an increase in DBP. As an integral parameter, PBP naturally decreases.

The correlation between the hemodynamic properties of VPBs and their CI was determined by assessing the correlation between the CI duration of VPBs and SBP, DBP, and PBP of VPBs. It turned out that the values of SBP, DBP, and PBP of VPBs were closely and highly significantly correlated with the CI of VPBs: the shorter the CI, the lower the SBP and PBP, and the higher the DBP. The coefficients of correlation (r) were 0.78 for SBP, -0.85 for DBP, and 0.87 for PBP. Thus, according to the correlation coefficients, DBP depends on the CI more than SBP, and PBP, as a calculated integral parameter (the difference between SBP and DBP), depends on the CI to an even greater extent. All three correlations were highly significant ($p < 0.001$). The graphical representation of the correlation between SBP, DBP, and PBP of VPBs with CI of VPBs is shown in Figure 1.

From the graph, constructed using third-order polynomial regression (cubic regression), it is evident that the relationship between DBP of VPBs and CI is almost linear, whereas the relationships between SBP and PBP with CI of VPBs are nonlinear: they are more pronounced with short (decreased BP) and long (increased BP) CIs.

The analysis of the correlation between PBP and SBP of VPBs, as well as between PBP and DBP of VPBs, showed that there is a close and highly significant correlation in both cases: between PBP and SBP ($r = 0.98$, $p < 0.001$), and between PBP and DBP ($r = -0.70$, $p < 0.001$). Thus, PBP of VPBs depends both on the decrease in SBP of VPBs and the increase in DBP of VPBs, but more strongly on the decrease in SBP. This correlation is clearly demonstrated in Figure 2.

Patient E., 67 years old. The total number of VPBs during the 15-minute study was 72. The CI of VPBs ranged from 606 to 1156 ms (820.40±26.98 ms). The results obtained for Patient E. were similar to those for Patient O. The SBP of VPBs ranged from 85 to 133 mmHg (117.75±1.33 mmHg), DBP ranged from 79 to 99 mmHg (86.50±0.54 mmHg), and PBP ranged from 0 to 50 mmHg (31.06±1.60 mmHg). The SBP of sinus beats ranged from 123 to 140 mmHg (130.21±0.40 mmHg), DBP from 71 to 87 mmHg (78.07±0.35 mmHg), and PBP from 45 to 61 mmHg (52.14±0.37 mmHg). Thus, in this case, VPBs are also hemodynamically significant, manifested by a decrease in SBP and an increase in DBP. As with Patient O., PBP, as the difference between SBP and DBP, decreases significantly. Notably, these changes are more pronounced in this case.

The correlation between the hemodynamic properties of VPBs and their CI was determined by assessing the correlation between the CI duration of VPBs and SBP, DBP, and PBP of VPBs. It turned out that the values of SBP, DBP, and PBP of VPBs were closely and highly significantly correlated with the CI of VPBs: the shorter the CI, the lower the SBP and PBP, and the higher the DBP. The results for Patient E. followed the same patterns as for Patient O. However, the correlation between the CI duration of VPBs and SBP, DBP, and PBP was somewhat less tight. The coefficients of correlation (r) were 0.45 for SBP, -0.65 for DBP, and 0.76 for PBP. For Patient E., according to the correlation coefficients, DBP depends more on the CI than SBP, and PBP as an integral parameter depends even more. All three correlations were highly significant ($p < 0.001$). The graphical representation (graph constructed using third-order polynomial regression) showed that the relationship between SBP, DBP, and PBP of VPBs with CI of VPBs was identical to that of Patient O. Therefore, it is unnecessary to reproduce the figure. In this case, the relationship between DBP of VPBs and CI of VPBs is linear, and the relationship between SBP and PBP of VPBs with CI of VPBs is nonlinear, being more pronounced with CIs of 600-700 ms and 1100-1150 ms.

The analysis of the correlation between PBP and SBP of VPBs, as well as between PBP and DBP of VPBs, for Patient E. again showed a close and highly significant correlation: between PBP and SBP ($r = 0.85$, $p < 0.001$) and between PBP and DBP ($r = -0.40$, $p < 0.001$). Thus, as in Patient O., PBP of VPBs depends on both the decrease in SBP and the increase in DBP, but more so on the decrease in SBP.

DISCUSSION

The primary cause of CAA in patients with VPBs is commonly considered to be a high frequency of hemodynamically ineffective ectopic ventricular contractions. Much of the scientific literature focuses on the number of VPBs per day that can lead to heart chamber dilation and reduced pump function. However, considerably less attention is given to the characteristics of the VPBs themselves. According to a recent survey conducted by the EHRA among arrhythmologists, 72% of respondents consider the number of VPBs as an important factor in the development of CAA, while 44% mention the source of VPBs and 29% refer to the width of the QRS complex. Other characteristics are not mentioned [37].

As noted earlier, literature suggests that the hemodynamic significance of VPBs, in addition to the factors mentioned above, can also be related to features such as QRS complex fragmentation, morphology, CI, and polymorphism. However, the direct relationship of these features to the localization of the arrhythmogenic substrate is still unclear. Evaluating the contribution of each of these characteristics to the hemodynamic incompetence of VPBs is a complex task, as they are closely interconnected. For this study, we chose ventricular parasystole with its obvious features, such as varying CIs, «multiplicity,» and «fusion» ventricular contractions. The characteristics of this type of VPB imply the presence of only one variable: the CI. All other characteristics are constant. This allowed us

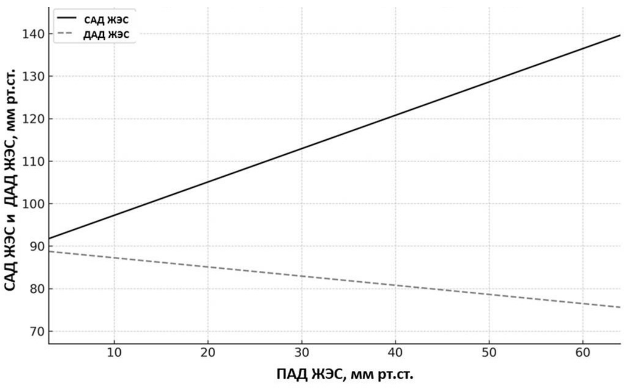

Fig. 2. Patient O. The relationship between PBP and SBP of VPBs, PBP and DBP of VPBs.

to assess the impact of the CI on the hemodynamic properties of VPBs.

For this purpose, we used the «beat to beat» method of blood pressure measurement. The study demonstrated that, as expected, there is a close, highly significant relationship between the CI of VPBs and their hemodynamic incompetence. Shortening of the CI leads to a decrease in SBP and an increase in DBP for VPBs. Comparison of the correlation coefficients showed that DBP depends more on the CI than SBP. At the same time, it was found that the relationship between DBP and CI of VPBs is almost linear, whereas the relationship between SBP and CI is nonlinear: it is more pronounced with short CIs (decreased SBP) and long CIs (increased SBP). The integral parameter, pulse blood pressure (PBP), was strongly associated with both decreased SBP and increased DBP, but, according to the correlation coefficients, it is more strongly correlated with SBP. The relationship between PBP and CI is similarly nonlinear.

It is important to note that this study is a pilot study, based on the analysis of VPBs from just two patients. One limitation of the study is the wide range of CIs for VPBs, which ranged from approximately 570 to 1160 ms. However, as is well known, the CI of VPBs typically falls within the range of approximately 500-600 ms.

CONCLUSION

The findings of the study can be summarized in the following conclusions: as the CI of ventricular premature beats shortens, its systolic blood pressure decreases, and its diastolic blood pressure increases. Moreover, DBP is more strongly correlated with the CI than SBP. The relationship between DBP and CI of VPBs is linear, whereas the relationship between SBP and CI is nonlinear. This relationship is more pronounced at shorter CIs (resulting in decreased blood pressure) and at longer CIs (leading to increased blood pressure). Pulse blood pressure of VPBs depends on both the decrease in SBP and the increase in DBP. However, it is more strongly correlated with SBP. The relationship between PBP and CI is nonlinear, similar to the relationship between SBP and CI.

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