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Functioning of the Human Heart in the Pron-Position

Aim To study intracardiac hemodynamics in healthy men in supine and prone positions.

Material and Methods This echocardiography study included 14 apparently healthy men at a mean age of 38 years.

Results In a prone position, the heart configuration and location in the chest changed, the heart rate increased by 7.3%, and the transaortic flow velocity decreased by 13.7%. Also, early and late right ventricular diastolic filling velocities and the pulmonary artery flow velocity were increased by 31.7, 11.4, and 5.6%, respectively. In the intact tricuspid valve, the velocity and regurgitation pressure gradient were reduced by 7% and 14.2%, respectively.

Conclusion In a prone position, spatial changes in the location of the heart and its structures influence velocities of intracardiac blood flow, which may initiate the development of heart failure if the prone position is long-lasting.

Keywords Prone position; echocardiography; systemic and intracardiac hemodynamics

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Introduction

Changes in posture affect the performance of the heart, which ensures its effective function by changing intracardiac hemodynamics [1]. Clinical assessment of the heart performance is based on the examination of linear and functional parameters using Doppler echocardiography [2]. The COVID-19 pandemic has made significant changes to echocardiographic examination. These patients require echocardiographic monitoring to determine functional changes in the heart [3]. Prone positioning is used to improve pulmonary ventilation in moderate-to-severe pneumonia. It is effective for rapid improvement of blood oxygenation in patients with COVID-19-related pneumonia. There is evidence that prone positioning reduces mortality in moderate-to-severe acute respiratory distress syndrome [4], improves blood oxygenation, and reduces right ventricular (RV) dysfunction. By relieving the load on the RV, prone positioning helps to improve the heart performance [5]. It increases the cardiac index in patients with preload reserve, which stresses the important role of preload in the hemodynamic effects of prone positioning [6]. There is ample evidence in favor of prone positioning in severe hypoxic respiratory failure and acute respiratory distress syndrome [7, 8].

However, prone positioning makes it difficult to scan the heart from the parasternal view. Echocardiography techniques proposed by various authors for patients in the prone position are conducted from the right lateral and left lateral apical views [9, 10]. Parameters measured for two-dimensional calculations of left ventricular ejection fraction (LVEF) may be erroneous and do not allow adequate interpretation of the findings, since the LV configuration changes in the prone position, which can affect the heart performance. The M-mode cannot virtually be used in the prone position to calculate LVEF, since there is no optimal access to obtain the parasternal view. Moreover, the M-mode data obtained for the calculation of LVEF provide unfortunately only information on contractility of the basal LV region [2]. However, as informative as LVEF is, it alone is not enough to characterize intracardiac hemodynamics. LVEF is a variable indicator and significantly depends on preload and post-load, which is why it cannot be decisive in evaluating the heart performance, especially in patients positioned prone. It should be appreciated that the echocardiographic parameters recorded in prone positioning approximate the normative values obtained in healthy people in standard postures: supine or left lateral positions.

The available literature data recorded in prone positioning using transthoracic [6] and transesophageal echocardiography [11] were obtained mainly in patients with acute respiratory distress syndrome during COVID-19. There are only single studies of the heart performance assessed by echocardiography in healthy individuals after changing their posture to the

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prone position [12]. It is of particular interest to study the effect of prone positioning on the intracardiac hemodynamic parameters in healthy people.

Aim

To study the intracardiac hemodynamics in prone positioning in healthy men.

Material and methods

Studies with a change in the posture to the prone position were conducted in the same group of male patients (n = 14) with mean age of 38±3.6 years, body length of 175.7±4.4 cm, and weight of 80.2±12.4 kg. The subjects did not have acute and chronic diseases and did not complain when they were examined by a physician during the study. Male patients were residents of the European North of Russia (Syktyvkar, 62° N). The cardiovascular examination was performed at a room temperature of 21±1.0 °C and relative humidity of 58%. The experiment was carried out in a relaxed atmosphere, patients were fasted. When the heart rate stabilized in the supine position, the blood pressure was measured twice. Doppler ultrasound was used to study intracardiac hemodynamics. Then the subjects turned on their stomachs and lay so that the ultrasound examination of the heart remained possible, for which a special medical bed with an access hole for heart examination was used. The subjects remained in this posture for 3 minutes, after which blood pressure and intracardiac hemodynamics were measured in steps. The examinations were performed in compliance with the Declaration of Helsinki and the European Directives and approved by the local ethical committee of the Komi Institute of Physiology, the Ural Branch of the Russian Academy of Sciences. The subjects had been informed about the goals, tasks, methods of examination, that they could refuse to participate at any stage of the study. The subjects signed the voluntary consent to participate in the study.

The cardiovascular parameters were registered based on the data obtained using verified devices: semiautomatic pressure gauge OMRON-M1 Plus, ultrasound scanner MyLab Class C. The pressure gauge was used to measure systolic blood pressure (SBP) and diastolic blood pressure (DBP). Ultrasound Doppler echocardiography was performed via transthoracic approach from apical and parasternal views using a 2–5 MHz cardiac probe to examine intracardiac hemodynamics of the subjects lying in the supine position and on the stomach.

Early diastolic transtricuspid velocity (VEtr), late diastolic transtricuspid velocity (VAtr), aortic root velocity (VAo), and pulmonary root velocity (Vpr) were measured in the pulse mode. Tricuspid valve regurgitation velocity (VTr-reg) was measured in the continuous wave Doppler mode. Tricuspid valve regurgitation pressure gradient (Rreg-tr) was automatically calculated by the embedded program. The VEtr/VAtr ratio was additionally calculated, heart rate (HR) was calculated by the cardiac complexes on the echocardiogram.

Changes in the configuration and location of the heart in the chest cavity during prone positioning are clearly demonstrated by computed tomography (CT) images obtained in the supine position (background) and in the prone position using the Toshiba Aquilion 64 scanner.

Statistical analysis

The data obtained were analyzed using BIOSTAT 4.03. The Student's t-test and non-parametric Mann-Whitney test were used. The data are presented as M±m, where M is the arithmetic mean of the values obtained and m is the standard error of the mean. The differences were significant with $p<0.05$.

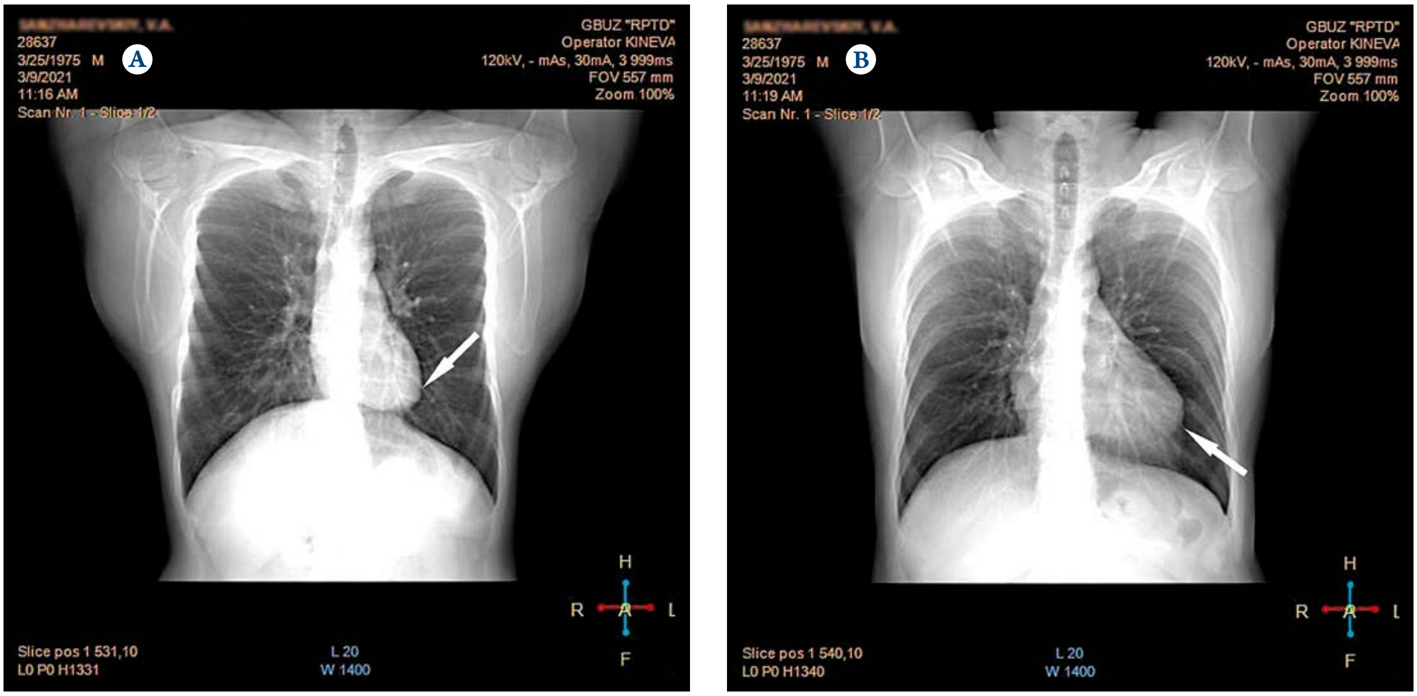
Results

On the supine chest X-rays (Figure 1, A), the heart border is vertical, and the apex silhouette is medial to the midclavicular line. In prone positioning (Figure 1, B), the diaphragm is displaced cranially, likely due to higher intra-abdominal pressure, and the apex of the heart is shifted laterally to the midclavicular line and closer to the anterior axillary line.

The long axis of the heart is displaced horizontally against the background. In the frontal images and axial CT slices (Figure 2), the heart silhouette is more adjacent to the anterior chest, its axis changes position and turns clockwise, when in the prone position.

In prone positioning, the adjacent lungs are hypoventilated in the anterior part and relatively more pneumatized in the posterior part. Since the anterior chest is more mobile than the posterior chest, the anteroposterior size of the chest decreases in the prone position relative to the same level measured in the supine position. The heart is displaced anteriorly and more leftward and changes its configuration relative to its original position, as if sprawling, and its shape become more spherical. This may be due to the LV overhanging the right ventricle (RV) and the displacement of the LV anterior and lateral walls anteriorly. The apex of the heart naturally limited in movement shifts likewise to the anterior chest wall, and its contours are smoothed out.

Figure 1. Chest X-ray in supine positioning (A) and prone positioning (B)

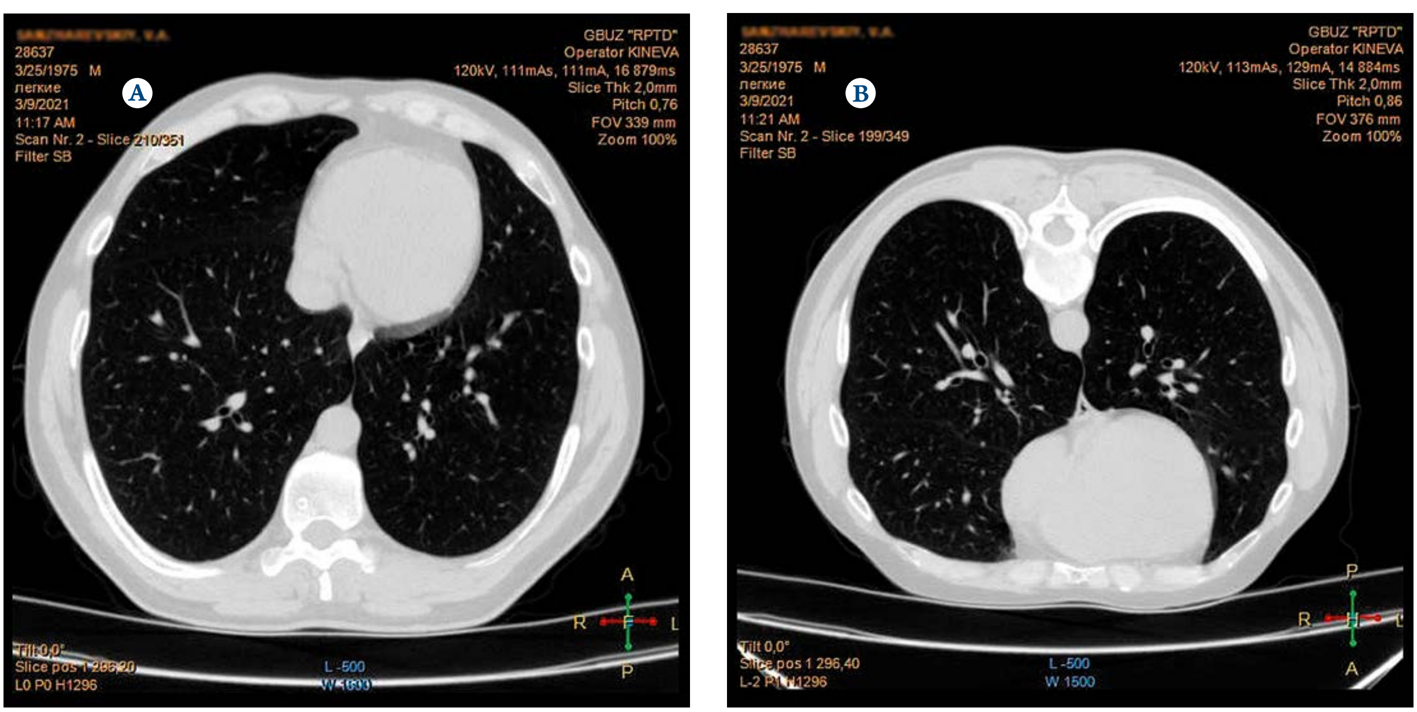


The arrow indicates the location of the apex of the heart. Explanation is provided in the text.

Changes in the spatial locations of the heart structures in the chest cavity leads to the increased mechanical load on the basal parts of the LV and the interventricular septum (IVS).

The movement of blood masses caused by changes in posture is due to the volume of venous return to the heart and the degree of the hemodynamic resistance [13]. Due to the complex anatomical structure of the RV and its changed location, visual assessment of the free wall motion is challenged. Changes in the spatial locations of the heart structures in the chest cavity leads to the increased mechanical load on the basal parts of the LV and IVS. The biomechanics of the tricuspid annulus also changes [12]. When the

Figure 2. Chest computed tomography image in supine positioning (A) and prone positioning (B). Axial slice



Explanation is provided in the text.

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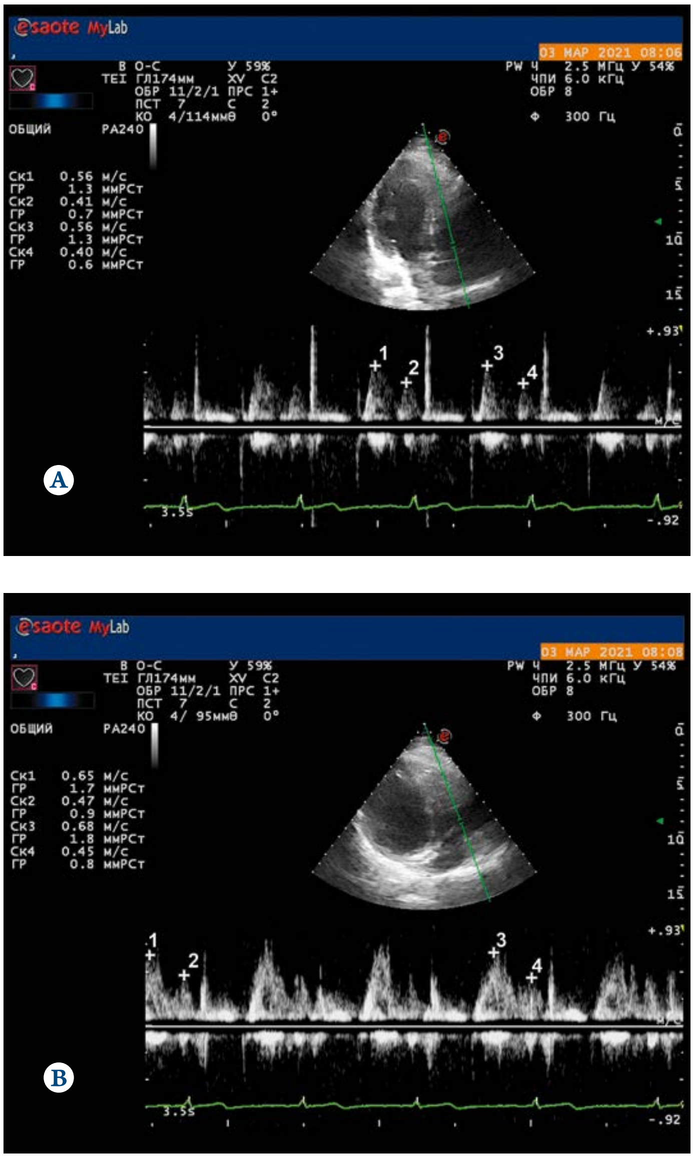
configuration of the heart changes, the physiological pathways of blood inflow and outflow in the RV and LV are likely to transform, which causes changes in the intracardiac flow velocities. Thus, we used indirect indicators of blood flow velocities to assess the activity of the myocardium.

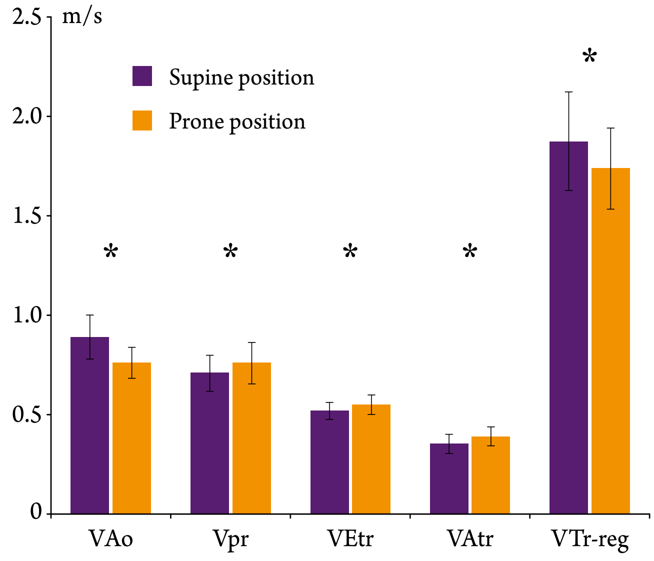
Initially, the subjects in the supine position had normal-to-high SBP of 131.64±10.48 mm Hg. In prone positioning, SBP did not differ significantly from the initial position and amounted to 130.93±10.5 mm Hg. At the same time, DBP increased mildly from 79.14±7.97 mm Hg to 81.00±8.45 mm Hg. The latter may be due to higher volemic load and increased

Figure 3. Two-dimensional and pulsed wave Doppler modes of transtricuspid blood flow in supine positioning (A) and prone positioning (B)



The Doppler image shows above the isoline a higher peak 1, 3 of early right ventricular diastolic blood filling and a lower peak 2, 4 of late right ventricular diastolic blood filling. Explanation is provided in the text.

Figure 4. Hemodynamic parameters of the heart in supine and prone positioning (m/s)



VAo is the velocity of the systolic blood ejected to the aorta by the left ventricle through the aortic valve; Vpr is the velocity of the systolic blood flow in the pulmonary artery; VEtr is the velocity of the blood flow through the tricuspid valve during early diastolic filling of the right ventricle; VAtr is the velocity of the systolic blood flow to the atrial systole through the tricuspid orifice; Vtr-reg is the velocity of the reverse blood flow in the intact tricuspid valve. Significance of differences in cardiohemodynamic parameters in prone positioning: *p<0.05 compared to the values in supine positioning.

pressure in the LV with a spatial reconfiguration of the heart.

HR increased from 69.57±9.35 bpm in the supine position to 74.71±10.41 bpm in the prone position, which is likely to be due to regulatory reactions of the body to a different posture through an growing influence of the sympathetic nervous system in the myogenic autoregulation of the heart in response to increased venous return to the heart [14]. Velocity of the systolic blood flow to the aorta ejected by the LV through the aortic valve (VAo) decreased from 0.88±0.11 m/s in the supine position to 0.76±0.08 m/s in the prone position ($p<0.05$; Figure 3, Figure 4).

Discussion

Decreased Vao is likely to due to the partial deposition of the blood in the pulmonary vessels, on the one hand, and a decrease in the LV pumping function when the heart configuration is altered in the supine position, on the other hand. In prone positioning, the velocity of the blood flow through the tricuspid valve during early diastolic filling of the RV (VEtr.) increases from 0.41±0.05 m/s to 0.54±0.05 m/s ($p<0.05$). The velocity of systolic blood flow in atrial systole through the tricuspid orifice (VAtr) also increases from 0.35±0.05 m/s to 0.39±0.05 m/s. It is suggested that this may be due to increased venous return to the heart. Increased systolic blood flow velocity in the pulmonary artery from 0.71±0.08 m/s to 0.75±0.10 m/s ($p<0.05$), decreased reverse blood flow (VTr-reg) from 1.86±0.25 m/s to 1.73±0.05 m/s, and reduced pressure gradient of the reverse blood flow on the intact tricuspid valve (Rtr-reg) from 14.15±3.67 mm Hg to 12.12±2.87 mm Hg ($p<0.05$) may be indicative of a decrease in the RV afterload. It is assumed that IVS plays an essential role in maintaining the best possible RV wall motion. In prone positioning, it is likely to be more actively involved in the ejection of blood from the RV to the pulmonary artery. In this setting, due to the improved lungs ventilation perfusion ratios, pulmonary vascular resistance seems to decrease, which may contribute to an increase in the central blood reserve and reduce the volumetric load on the left heart [15–17].

Conclusion

Thus, a change in the spatial position of the heart and its structures in the prone position of the body affects the intracardiac blood flow velocities, which can provoke heart failure in long-term prone positioning.

In prone positioning, the heart rate increases and transaortic flow velocity decreases, the velocities of early and late diastolic right ventricular filling and pulmonary artery systolic velocity increase.

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