

**CHARACTERISTICS OF VARIABLE CARDIOINTERVALOMETRY INDICATORS
IN THE EARLY POSTCOMPRESSION PERIOD OF CRUSH SYNDROME****I. Horbachevsky Ternopil National Medical University Ministry of Health of Ukraine (Ternopil, Ukraine)**
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Heart rate variability reflects the body's adaptive capacity in response to changes in living conditions and is underpinned by the interaction of regulatory systems capable of maintaining homeostasis and adaptation. The aim of our study was to determine the characteristics of cardiointervalometry parameters in the early postcompression period of crush syndrome in an experiment. The results of the study indicate that the Mo index in the early postcompression period of crush syndrome decreases by 5% ($p < 0.05$) 1 day after decompression, and by 18.9% ($p < 0.001$) 3 days later, this indicates an increase in adrenergic influence on the myocardium via humoral pathways. The ΔX index decreased slightly 1 day after the study, but 3 days after the experimental animals were released from compression, it was 1.8 times ($p < 0.01$) lower than that in intact animals. The AMO index, as observed during the postcompression period of crush syndrome in laboratory rats, increased by 26.7% ($p < 0.01$) 1 day after decompression. The increase in AMO continued 3 days into the experiment, when this index had risen by of 1.7 ($p < 0.001$). Heart rate increased by 5.3% ($p < 0.05$). Three days after the study, an increase in heart rate of 23.2% ($p < 0.001$) was recorded compared with intact animals. After 1 day of the study, SI showed a tendency to increase, although this was not statistically significant. After 3 days of the study, during the early postcompression period of crush syndrome, the indicator under analysis increased fourfold ($p < 0.001$).

Key words: cardiointervalography, crush syndrome, rats, experiment.

Connection of the publication with planned research work.

This experimental study was carried out as part of the comprehensive research project "Investigation of the pathogenetic mechanisms underlying the development of post-traumatic and inflammatory-degenerative damage to organs and systems, and their correction" (state registration number 0124U000154).

Introduction.

Crush syndrome (CS) remains a pressing issue in modern medicine due to the large number of armed conflicts, man-made disasters and road traffic accidents [1]. According to a number of authors, mortality rates in situations where CS ranges from 20–48% and one of the causes of mortality in the early postcompression period is cardiac complications. Hypoxia resulting from tissue compression leads to the development of intracellular acidosis, which triggers mechanisms of cell membrane depolarisation, promotes the release of K^+ ions into the vascular space, as well as the entry of Ca^{2+} and Na^+ ions into the cell, and leads to hyperkalaemia, the adverse effects of which manifest in the early postcompression period as arrhythmias, ventricular fibrillation and asystole [2, 3]. The decompression period is particularly dangerous, as it involves tissue reperfusion, which causes the systemic circulation to become saturated with toxic metabolites, potentially leading to sudden arrhythmias and cardiac death [2, 4]. The basis of reperfusion injury to the heart is the so-called "oxygen paradox", which manifests as ischaemia of cardiomyocytes against a background of high concentrations of reactive oxygen species, triggering processes of lipid peroxidation and acidosis [3, 5]. Variational cardiointervalography is one of the non-invasive methods for investigating the mechanisms regulating cardiac activity. In the literature available to us, we found no studies dedicated to investigating changes in heart rhythm under conditions of CS therefore, monitor-

ing heart rate variability (HRV) in the postcompression period of CS is important in terms of studying the body's adaptive capacity to pathological factors and changes in the external and internal environment, as well as the timely correction of electrolyte imbalances, and is critically important for improving the prognosis of patients [5, 6, 7].

The aim of the study.

To find out the characteristics of cardiointervalometry parameters in the early postcompression period of CS in the experiment.

Object and research methods.

The study was conducted on 36 white laboratory rats weighing 240–270 grams. The experimental animals were divided into two groups of 12 animals each, which were withdrawn from the experiment after 1 and 3 days. The control group consisted of 12 intact male rats. CS was simulated by compressing the soft tissues of the right hind limb in a device designed by us for 6 hours. The compression area was 5 cm², and the compression force was 7 kg/cm² [8]. For analgesia, the experimental animals were administered ketamine hydrochloride intraperitoneally at a dose of 100 mg/kg body weight. Electrocardiographic examination was performed in standard lead II using the "CardioLab CE" computer system (Ukraine) after the experimental animals had been administered a solution of sodium thiopental at a dose of 40 mg•kg⁻¹ intraperitoneally, 3–5 minutes after falling asleep. Changes in heart rhythm were analysed over 1,000 consecutive R-R intervals using the software for the aforementioned device, with an accuracy of 0.001 seconds. The following parameters were determined: heart rate (HR, beats per minute), mode value (M, s) – the duration of the R-R interval that occurred most frequently in the studied segment of the electrocardiogram, and the amplitude of the mode (AMo, %) – the frequency of R-R intervals defining the mode, expressed as

a percentage of the total number of analysed R-R intervals; and the variation range of R-R intervals (ΔX , s) – the difference between the maximum and minimum values of R-R duration in the sample, stress index (SI, conventional units) – is calculated using the formula $SI = AMo / (2 \times \Delta X \times Mo)$ and indicates the degree of centralisation of heart rate control. Electrocardiograms were recorded between 11.00 and 13.00 in a specially designated room at a temperature of 20–22°C, relative humidity of 40–60 per cent and illuminance of 250 lx.

For the statistical analysis of the results, a licensed version of the BioStat software programme (AnalystSoft Inc., version 6, USA) was used. The Newman–Keuls parametric test was applied, and the arithmetic mean (M) and standard error of the mean (m) were determined. The research results were considered statistically significant at $p < 0.05$ [9].

Following the recording of the cardiointervalograms, the experimental animals were removed from the experiment by bloodletting. The experimental studies and the euthanasia of the experimental animals were carried out in accordance with the requirements of the “General Ethical Principles for Animal Experimentation”, adopted by the First National Congress on Bioethics (Kyiv, 2001), the “European Convention for the Protection of Vertebrate Animals used for Experimental and other Scientific Purposes”, and the Law of Ukraine “On the Protection of Animals from Cruel Treatment” (dated 21 February 2006).

Research results and their discussion.

Analysis HRV It is a method for assessing the state of the body's regulatory mechanisms, in particular the neurohumoral regulation of cardiac activity and the interaction between the sympathetic and parasympathetic divisions of the autonomic nervous system. HRV analysis reflects the integrated response of the heart rate to central and peripheral neurohumoral influences, enabling a more in-depth assessment of the body's functional state and adaptive capacity compared with standard heart rate recording [10]. Mathematical analysis of HRV using the method of variational cardiointervalometry enables an assessment of the relationship between the activity of the parasympathetic and sympathetic branches of the autonomic nervous system and the heart's adaptive capacity in experimental animals under conditions of experimental CS. The results of the mathematical analysis of HRV in the early postcompression period of CS are presented in **table**.

Following experimental reproduction of CS the Mo index decreased during the early postcompression period of CS. Thus, 1 day after the experimental rats were released from compression, the Mo index decreased by a statistically significant 5% ($p < 0.05$), and after 3 days – by 18.9% ($p < 0.001$). Given that the Mo index reflects

the functioning of the sinus node, it can be concluded that there is a reduction in the autonomy of its function, which is caused by the activation of influences from the autonomic nervous system.

The AMO index increased by 26.7% ($p < 0.01$) one day after decompression and showed an upward trend three days into the experiment, when the AMO index had risen 1.7 times ($p < 0.001$). This indicated significant strain on the mechanisms of autonomic regulation of cardiac activity. According to O.P. Mincer et al. (2022), AMO is an indicator of the kinetic energy expended by the body to adapt to various environmental stressors, or the “cost of adaptation”.

The ΔX index had decreased slightly after 1 day of the study, but 3 days after the test animals were released from compression, it was 1.8 times ($p < 0.01$) lower than that in intact animals. Such changes in ΔX indicate a reduction in the organism's adaptive and compensatory capabilities and a decrease in heart rate variability, which is a consequence of the decompression of the test animals.

The dynamics of heart rate during the postcompression period of CS we observed a slight but statistically significant increase in HR of 5.3% ($p < 0.05$). Three days after the study, the HR had increased by 23.2% ($p < 0.001$) compared with intact animals. One day after the start of the experiment, the HR had increased by 5.3% ($p < 0.05$). Three days into the study, an increase in HR of 23.2% ($p < 0.001$) was recorded compared with the control group.

SI unlike the previous indicators, this is an integral measure and reflects the degree of centralisation of heart rate control. Normally, at rest, the heart rate is predominantly regulated by the heart's own pacemaker and by regulatory mechanisms acting via the sympathetic and parasympathetic ganglia, as well as via the humoral system, in particular through the release of adrenaline. In stressful situations and certain pathological conditions involving the heart (angina pectoris, ischaemic heart disease), more highly organised structures of the brain – the brainstem and the cerebral cortex – become involved in regulating the heart rate. At the same time, the SI increases significantly [10]. In our study, one day after decompression, the SI rise from 25,904 conventional units to 40,080 conventional units; however, despite the fairly large difference in absolute values, no statistically significant changes were detected. Three days into the experiment, the SI had increased fourfold and stood at 103,817 conventional units ($p < 0.001$).

E.T. Mouchtouri and colleagues [11] investigated VSR in their work, in which they induced stress in laboratory rats by immobilising them in a tubular restraint device with a diameter of 8.25 cm. Nine minutes later, stress was induced for three minutes using a jet of air, consisting of 18 pulses at eight-second intervals, during which air was delivered at a rate of 10 l/min to the forehead using a pump (BDINF20C, Black & Decker, Towson, Maryland, USA). Restraint was maintained for a further 20 minutes, after which the rats were returned to their cages under continuous ECG monitoring for two hours. The researchers observed marked sympathetic activation throughout the study period, as evidenced by a significant increase

Table – Mathematical analysis of the heart rate of laboratory rats in the early postcompression period of CS, (M $\pm$ m)

Indicator	Intact animals	Duration of the postcompression period CS	
		After 1 day	After 3 day's
Mo, s	0.1418 $\pm$ 0.0023	0.1348 $\pm$ 0.0015*	0.1150 $\pm$ 0.0006***
AMo, %	30.0 $\pm$ 1.7	38.0 $\pm$ 1.8*	51.9 $\pm$ 1.9***
ΔX , s	0.0041 $\pm$ 0.0001	0.0039 $\pm$ 0.0004	0.0023 $\pm$ 0.0002**
HR, hits/minute	423.1 $\pm$ 6.4	445.6 $\pm$ 5.1*	521.5 $\pm$ 2.9***
SI, conventional units	25904 $\pm$ 1765	40080 $\pm$ 6018	103817 $\pm$ 8020***

Notes: * – $p < 0.05$; ** – $p < 0.01$; *** – $p < 0.001$

SI. The authors recommend using the Stress Index (SI) not in isolation, but in combination with other HRV parameters for a detailed assessment of autonomic responses, particularly when investigating arrhythmogenesis. A thorough study of the importance of the stress index (SI) was conducted by J.D. Huizinga et al. [12]. They demonstrated that, under stress, there is an increase in AMO against a background of a decrease in ΔX and an increase in the SI. This may indicate a reduction in heart rate variability and a reduction in the activity of the autonomic regulatory mechanisms of the sympathetic branch of the autonomic nervous system.

Conclusions.

1. Mathematical analysis of heart rate variability using the method of variational cardiointervalometry showed that 3 days after decompression in the early

postcompression period, activation of the sympathetic branch of the autonomic nervous system predominates in the regulation of cardiac contractile function.

2. The maximum reduction in the Mo index after three days, a four-fold increase in IN, a decrease in ΔX , and a maximum increase in AMO indicate that this period is the most critical for the experimental animals due to excessive centralisation in heart rate regulation, maximum activation of the sympathetic branch and a reduction in the protective properties of the parasympathetic branch of the autonomic nervous system.

Prospects for further research.

To investigate the characteristics of cardiointervalometry parameters in the intermediate and late post-compression periods of CS.

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ОСОБЛИВОСТІ ПОКАЗНИКІВ ВАРІАЦІЙНОЇ КАРДІОІНТЕРВАЛОМЕТРІЇ В РАНЬОМУ ПОСТКОМПРЕСІЙНОМУ ПЕРІОДІ СИНДРОМУ ТРИВАЛОГО СТИСНЕННЯ

Юрик Я. І.

Резюме. Дослідження варіабельності серцевого ритму дає змогу з'ясувати співвідношення між активністю парасимпатичної і симпатичної ланок автономної нервової системи та дослідити адаптаційні резерви серця у піддослідних тварин за умов експериментального СТС.

Метою дослідження було встановити особливості показників кардіоінтервалометрії в ранньому посткомпресійному періоді СТС.

Дослідження виконано на 36 білих лабораторних щурах-самцях вагою 240–270 грам. Піддослідних тварин було розділено на 2 групи по 12 особин у кожній, яких виводили з експерименту через 1 та 3 доби. Контрольна група становила 12 інтактних тварин. СТС моделювали шляхом стискання м'яких тканини стегна правої тазової кінцівки протягом 6 годин. Площа стискання становила 5 см², сила компресії – 7 кг/см². Для знеболення вводили внутрішньо-очеревинно кетаміну гідрохлорид з розрахунку 100 мг/кг маси тіла. Електрокардіографічне дослідження проводили в II стандартному відведенні за допомогою комп'ютерного комплексу «Cardio-Lab CE» (Україна) після введенням щуром розчину тіопенталу натрію в дозі 40 мг·кг⁻¹ внутрішньо-очеревинно через 3–5 хвилин після засинання. Аналізували зміни серцевого ритму на 1000 послідовно розташованих інтервалах R-R з точністю до 0,001секунди. Проведено визначення таких показників: частоту серцевих скорочень (ЧСС, хв⁻¹), величину моди (Mo, с), амплітуду моди (AMo, %), варіаційний розмах кардіоінтервалів (ΔX , с), індекс напруження (IN, ум. од.). Для проведення статистичної оцінки отриманих результатів використовували ліцензійну версію комп'ютерної програми BioStat, AnalystSoft Inc., версія 6 (США). Використовували параметричний критерій Ньюмана-Кейлса, визначали середнє арифметичне (M), стандартну похибку середнього арифметичного (m). Результати досліджень вважали статистично достовірними при $p < 0,05$.

Отримані результати дослідження свідчать про те, що показник Mo у ранньому посткомпресійному періоді СТС знижується через 1 добу після декомпресії на 5% ($p < 0,05$), а через 3 доби – на 18,9% ($p < 0,001$), що свідчить про зростання адренергічного впливу на міокард по гуморальних каналах. Показник ΔX через 1 добу до-

слідження знизився незначно, але через 3 доби був у 1,8 раза ($p < 0,01$) нижчим від такого у інтактних тварин. Показник АМо через 1 добу після декомпресії зріс на 26,7% ($p < 0,01$), а через 3 доби експерименту – у 1,7 раза ($p < 0,001$). ЧСС через 1 добу після початку експерименту зросла на 5,3% ($p < 0,05$). Через 3 доби дослідження реєстрували збільшення ЧСС на 23,2% ($p < 0,001$). Через 1 добу дослідження показник ІН мав тенденцію до зростання, яке не було достовірним. Через 3 доби дослідження аналізований показник зріс у 4 рази ($p < 0,001$).

Ключові слова: кардіоінтервалографія, синдром тривалого стиснення, щури, експеримент.

CHARACTERISTICS OF VARIABLE CARDIOINTERVALOMETRY INDICATORS IN THE EARLY POSTCOMPRESSION PERIOD OF CRUSH SYNDROME

Yuryk Ya. I.

Abstract. The study of heart rate variability makes it possible to determine the relationship between the activity of the parasympathetic and sympathetic branches of the autonomic nervous system and to investigate the heart's adaptive reserves in experimental animals under experimental CS.

The aim of the study was to determine the characteristics of cardiointervalometry parameters in the early post-compression period of CS.

The study was conducted on 36 white laboratory male rats weighing 240–270 grams. The experimental animals were divided into two groups of 12 animals each, which were removed from the experiment after 1 and 3 days. The control group consisted of 12 intact animals. CS was modelled by compressing the soft tissues of the right hind limb of 6 hours. The compression area was 5 cm², and the compression force was 7 kg/cm². For analgesia were administered ketamine hydrochloride intraperitoneally at a dose of 100 mg/kg body weight. Electrocardiographic examination was carried out in standard lead II using the "CardioLab CE" computer system (Ukraine) after rats were administered a solution of sodium thiopental at a dose of 40 mg•kg⁻¹ intraperitoneally, 3–5 minutes after they had fallen asleep. Changes in heart rate were analysed across 1,000 consecutive R-R intervals with an accuracy of 0.001 seconds. The following parameters were determined: heart rate (HR, beats per minute), mode (Mo, s), mode amplitude (AMo, %), variation range of R-R intervals (ΔX , s), stress index (SI, conventional units). For the statistical analysis of the results, the licensed version of the BioStat software programme, AnalystSoft Inc., version 6 (USA), was used. The Newman–Kales parametric test was used to determine the arithmetic mean (M) and the standard error of the arithmetic mean (m). The study results were considered statistically significant at $p < 0.05$.

The results of the study indicate that the Mo index in the early post-compression period of CS decreases by 5% ($p < 0.05$) one day after decompression, and by 18,9% ($p < 0.001$) three days later, this indicates an increase in adrenergic influence on the myocardium via humoral pathways. The ΔX index decreased slightly 1 day into the study, but 3 days after the experimental animals were released from compression, it was 1.8 times ($p < 0.01$) lower than that in intact animals. The AMo index increased by 26,7% ($p < 0.01$) one day after decompression, and by of 1.7 ($p < 0.001$) three days into the experiment. Heart rate increased by 5.3% ($p < 0.05$) one day after the start of the experiment. Three days into the study, a 23.2% increase in heart rate ($p < 0.001$) was recorded. One day into the study, the SI index showed a tendency to increase, although this was not statistically significant. Three days into the study the index under analysis increased fourfold ($p < 0.001$).

Key words: cardiointervalography, crush syndrome, rats, experiment.

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A – Work concept and design, **B** – Data collection and analysis, **C** – Responsibility for statistical analysis, **D** – Writing the article, **E** – Critical review, **F** – Final approval of the article.

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