



## Autonomic regulation of heart rate in sows during the farrowing period

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**Abstract.** Contemporary research demonstrates the significant influence of the autonomic nervous system on the adaptation and productivity of farm animals. The farrowing period in sows is particularly critical, as changes in autonomic tone determine the course of parturition stress and the rate of recovery. The aim of the study was to investigate the dynamics of variational pulsometry

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parameters in sows with normotonic, sympathotonic and vagotonic autonomic nervous system tone before farrowing, as well as one day and five days after parturition stress. The experiment was conducted on fifteen sows of the Large White breed, divided into three groups according to the level of the stress index. For each animal, one day before farrowing, and on the first and fifth days after farrowing, one hundred consecutive intervals between heartbeats were recorded using an electrocardiograph. The mean interval duration, interval mode, mode amplitude, range of variation, vegetative balance index and stress index were calculated. It was found that prior to farrowing, vagotonic animals exhibited the highest heart rate variability, whilst sympathotonic animals exhibited the lowest. One day after parturition stress, a decrease in the mean duration of intervals and an increase in the stress index were noted in all groups; however, the fastest recovery of parameters was observed in vagotonic sows. On the fifth day after farrowing, the parameters in sows of the normotonic group approached baseline values, whereas in animals with increased sympathetic tone, the stress response persisted. Thus, the use of variational pulse wave analysis to assess the tone of the autonomic nervous system prior to farrowing allows for the identification of the most stress-resistant sows and the implementation of targeted supportive measures in the first days after farrowing. This approach will contribute to improving piglet survival, shortening the recovery period for sows and increasing the economic efficiency of pig farming

**Keywords:** variational pulsometry; autonomic nervous system; parturition stress; adaptive mechanisms; pigs

## Introduction

Under conditions of the intensification of pig production and increased requirements for animal productivity and welfare, the study of physiological mechanisms of adaptation in sows during critical periods of ontogenesis has become particularly relevant. Farrowing represents one of the most stressogenic stages of the reproductive cycle, accompanied by considerable neuroendocrine load and capable of significantly affecting both the condition of the maternal organism and the viability of the offspring. Individual differences in the functional state of the autonomic nervous system determine the variability of responses to parturition stress and the rate of post-farrowing recovery; however, these aspects remain insufficiently considered in livestock practice. Thus, the application of methods for assessing autonomic regulation of heart rhythm may allow the prediction of stress resistance in sows

and the optimisation of management decisions aimed at improving the efficiency and sustainability of production.

The autonomic nervous system (ANS) plays a decisive role in the formation of adaptive responses in the organism of sows under various stress factors, particularly during farrowing. The ANS consists of two antagonistic branches – the sympathetic and the parasympathetic nervous systems – which, through neuroendocrine interactions, respond rapidly to external and internal stimuli. K. Steierová *et al.* (2025) noted that under resting conditions parasympathetic tone predominates, maintaining a lower heart rate and promoting energy conservation. L. Stovbetska *et al.* (2021) reported that with the onset of stress, particularly acute pain or emotional stress during labour contractions, the sympathetic nervous system becomes activated:

the secretion of catecholamines (adrenaline and noradrenaline) increases and cortisol is released into the bloodstream. M.E. Lago-da *et al.* (2022) and N. Manu *et al.* (2021) indicated that this mechanism mobilises energy resources, increases heart rate and arterial pressure; however, an excessively pronounced sympathetic response may be accompanied by impaired uterine perfusion, prolonged labour and even acute foetal hypoxia. R. Lemery (2024), in a historical review of the development of the concept of cardiac autonomic regulation, demonstrated how ideas about sympathetic and parasympathetic interaction evolved gradually from early anatomical studies to modern multidisciplinary approaches.

Analysis of heart rate variability (HRV) is a widely accepted non-invasive method for assessing the state of the ANS in animals and is recognised as one of the most informative approaches for determining indicators of the functional state of the ANS in farm animals (Ishaque *et al.*, 2021). A decrease in HRV indicators within the low-frequency (LF) and high-frequency (HF) spectra indicates the predominance of sympathetic activity, whereas the predominance of parasympathetic activity is reflected in an increase in the HF component and in the overall SDNN index (standard deviation of NN intervals) (Tiwari *et al.*, 2021). Considering that parturition stress in sows is accompanied by abrupt changes in autonomic tone and may significantly influence piglet survival and the economic efficiency of production (Von Borell & Raoult, 2024), further investigation of these processes is necessary. According to J. Calderón-Amor *et al.* (2024), chronic stress during pregnancy in sows, resulting from unfavourable microclimatic conditions or hierarchical interactions, is associated with suppression of HRV and elevated cortisol concentrations long before farrowing, which negatively affects subsequent reproductive performance.

Complicated farrowing may prolong labour due to impaired coordination of uterine contractions: high levels of catecholamines reduce the effectiveness of oxytocin and hinder the movement of piglets through the birth canal (Buckley *et al.*, 2023). Existing studies by Ukrainian researchers are mainly focused on investigations of young pigs (Todoryuk *et al.*, 2023). However, issues related specifically to comparative analysis during the farrowing period remain insufficiently studied. Despite numerous investigations conducted in different animal species, information concerning sows with different baseline ANS tone in the context of parturition stress and post-farrowing recovery remains limited. It is therefore necessary to determine how differences in the initial ANS tone (normotonia, sympathicotonia and vagotonia) influence the recovery of animals.

Thus, based on the analysis of the available literature, there was a need to conduct studies comparing the dynamics of HRV in sows with normotonic, vagotonic and sympathicotonic ANS tone during critical periods of pregnancy and after farrowing. Such research will allow the development of scientifically substantiated methods for the selection and management of animals with the highest potential for stress resistance. The aim of the study was to determine the characteristics of the dynamics of key indicators of variational pulsometry in sows with different baseline ANS tone before farrowing, as well as on the first and fifth days after parturition stress.

## **Materials and Methods**

The study was conducted during 2024-2025 at the Department of Vertebrate Physiology and Pharmacology of the National University of Life and Environmental Sciences of Ukraine. Experimental procedures involving animals were carried out in accordance with the fundamental principles of bioethics and complied

with Law of Ukraine No. 3447-IV (2006), the European Convention for the Protection of Vertebrate Animals Used for Experimental and Scientific Purposes (1986), Directive 2010/63/EU (2010), Law of Ukraine No. 249 (2012), and the ARRIVE (n.d.) guidelines for reporting experiments involving live animals.

The research was carried out on 15 Large White sows (second-third farrowing, aged 2.5-3.5 years, body weight 180-210 kg), selected from a total of 40 animals using a preliminary analysis of the stress index (SI) according to Baevsky's method modified for animals (Todoruk *et al.*, 2023). The selected animals were divided into three groups (n = 5): normotonic – NT (SI 80-100 conventional units), sympathicotonic – ST (SI > 150 conventional units) and vagotonic – VT (SI < 50 conventional units).

The study material consisted of short-term electrocardiogram recordings (up to 5 min) obtained one day before farrowing and on the first and fifth days after farrowing, using a Heaco 300G MDT electrocardiograph (manufacturer: HEACO, UK) with a tape speed of 50 mm/s. Key indicators of heart rate variability were calculated based on the filtered intervals: Mean RR (mean R-R interval), Mo (mode), AMo (amplitude of mode), variability range ( $\Delta x$ ), and the vegetative balance index (VBI):

$$VBI = AMo/\Delta x, \quad (1)$$

where AMo – the mode amplitude;  $\Delta x$  – the difference between the maximum and minimum mode values (s).

And also the SI stress index:

$$SI = AMo/(2 \times Mo \times \Delta x), \quad (2)$$

where AMo – mode amplitude; Mo – a variational pulsometry parameter;  $\Delta x$  – the difference between the maximum and minimum values of the mode (s).

Statistical analysis of the results was performed using MS Excel. For each parameter, the mean and standard deviation were calculated, and the results were presented as  $M \pm SD$ . Prior to conducting a comparative analysis, the distribution of the samples was assessed for conformity to a normal distribution. The significance of differences between the mean values in the experimental and control groups was determined using Student's t-test for independent samples. A difference was considered statistically significant at levels:  $P < 0.05$ ,  $P < 0.01$ , and  $P < 0.001$ .

## Results and Discussion

Summary indicators of variational pulse rate in sows with different baseline autonomic nervous system tone were determined prior to farrowing, as well as on the first and fifth days following parturition stress. The results of the study presented in Table 1 made it possible to analyse both the baseline intergroup differences in the autonomic regulation of heart rate and the dynamics of the autonomic nervous system's response to farrowing and subsequent recovery. Analysis of the table indicates significant changes in the integral indices of stress and autonomic balance in the early post-farrowing period, as well as varying rates of normalisation of these indices depending on the animals' initial autonomic status.

**Table 1.** Indicators of variational pulsometry in sows ( $M \pm SD$ ; n = 5)

Indicators HRV	ANS Tone		
	Normotonic	Vagotonic	Sympathicotonic
	Before farrowing		
Mean RR (s)	0.81 ± 0.01	1.02 ± 0.01 <sup>^^^</sup>	0.68 ± 0.01 <sup>^^^</sup>

Table 1. Continued

Indicators HRV	ANS Tone		
	Normotonic	Vagotonic	Sympathicotonic
Before farrowing			
Mo	0.81 ± 0.01	1.03 ± 0.01 <sup>^^^</sup>	0.68 ± 0.01 <sup>^^^</sup>
AMo	27.2 ± 2.2	17.4 ± 0.6 <sup>^^^</sup>	40.6 ± 1.4 <sup>^^^</sup>
Δx (s)	0.19 ± 0.01	0.25 ± 0.01 <sup>^^^</sup>	0.09 ± 0.01 <sup>^^^</sup>
VBI (a.u.)	140.1 ± 10.0	68.5 ± 0.8 <sup>^^^</sup>	466.0 ± 27.5 <sup>^^^</sup>
SI (a.u.)	86.6 ± 6.7	33.4 ± 0.5 <sup>^^^</sup>	343.2 ± 23.0 <sup>^^^</sup>
1 day after farrowing			
Mean RR (s)	0.76 ± 0.01 <sup>***</sup>	0.80 ± 0.01 <sup>***^^^</sup>	0.62 ± 0.01 <sup>***^^^</sup>
Mo	0.76 ± 0.01 <sup>***</sup>	0.80 ± 0.01 <sup>***^^^</sup>	0.62 ± 0.01 <sup>***^^^</sup>
AMo	37.8 ± 1.3 <sup>***</sup>	38.8 ± 2.5 <sup>***</sup>	49.0 ± 0.9 <sup>***^^^</sup>
Δx (s)	0.10 ± 0.01 <sup>***</sup>	0.13 ± 0.01 <sup>***^^^</sup>	0.08 ± 0.01 <sup>^^</sup>
VBI (a.u.)	389.0 ± 44.3 <sup>***</sup>	296.4 ± 22.0 <sup>***^</sup>	660.8 ± 57.4 <sup>***^^^</sup>
SI (a.u.)	257.3 ± 29.7 <sup>***</sup>	185.5 ± 14.8 <sup>***^</sup>	533.3 ± 46.9 <sup>***^^^</sup>
5 days after farrowing			
Mean RR (s)	0.79 ± 0.01 <sup>*</sup>	0.85 ± 0.01 <sup>***^^^</sup>	0.665 ± 0.005 <sup>^^^</sup>
Mo	0.79 ± 0.01 <sup>*</sup>	0.86 ± 0.01 <sup>***^^^</sup>	0.666 ± 0.006 <sup>^^^</sup>
AMo	34.0 ± 1.5 <sup>**</sup>	35 ± 2.2 <sup>***</sup>	42.0 ± 1.1 <sup>^^^</sup>
Δx (s)	0.16 ± 0.01 <sup>***</sup>	0.17 ± 0.01 <sup>***</sup>	0.11 ± 0.01 <sup>^^^</sup>
VBI (a.u.)	213.7 ± 13.1 <sup>***</sup>	210.1 ± 16.4 <sup>***</sup>	414.7 ± 49.7 <sup>^^^</sup>
SI (a.u.)	135.2 ± 7.8 <sup>***</sup>	122.9 ± 10.0 <sup>***</sup>	311.0 ± 36.6 <sup>^^^</sup>

**Note:** 1. Mean RR – mean R-R interval duration (s); Mo – mode; AMo – amplitude of the mode; Δx – difference between the maximum and minimum values of the mode (s); VBI – vegetative balance index (units); SI – stress index (units). 2. Statistically significant differences compared with the previous study period: \*\*\* –  $P < 0.001$ ; \*\* –  $P < 0.01$ ; \* –  $P < 0.05$ . 3. Statistically significant differences compared with pigs with normotension: ^^ –  $P < 0.001$ ; ^^ –  $P < 0.01$ ; ^ –  $P < 0.05$

**Source:** authors' own work

Table 1 shows that in sows with balanced sympathetic and parasympathetic regulation of heart rhythm (normotonia, NT) before farrowing, the mean values of the following indicators – R-R intervals (Mean RR), R-R mode (Mo), mode amplitude (AMo), R-R mode range (Δx), vegetative balance index (VBI) and stress index (SI) – indicated the absence of signs of excessive autonomic load. In vagotonic sows (VT) before farrowing, Mean RR increased by 26.0% ( $P < 0.001$ ) compared with NT animals. This

indicates a slowing of heart rhythm under the influence of increased parasympathetic activity. At the same time, Mo increased by 27.2% ( $P < 0.001$ ) compared with NT animals, confirming a shift of the most frequent R-R interval towards prolongation. In contrast, AMo decreased by 36.0% ( $P < 0.001$ ) compared with NT animals, indicating a wider distribution of intervals and increased variability. Δx increased by 31.6% ( $P < 0.001$ ) compared with NT animals, suggesting greater diversity of cardiac rhythms. VBI decreased by

51.1% ( $P < 0.001$ ) compared with NT animals, indicating the predominance of parasympathetic tone. SI decreased by 61.4% ( $P < 0.001$ ) compared with NT animals, reflecting a substantial reduction in autonomic stress at rest.

In sows of the ST group before farrowing, Mean RR decreased by 16.2% ( $P < 0.001$ ) compared with NT animals. Mo also decreased by 16.0% ( $P < 0.001$ ) compared with NT animals. However, AMo increased by 49.3% ( $P < 0.001$ ) compared with NT animals, indicating a narrowed distribution of intervals and predominance of a single mode.  $\Delta x$  decreased by 52.6% ( $P < 0.001$ ) compared with NT animals, reflecting lower diversity of R-R intervals. VBI increased by 232.7% ( $P < 0.001$ ) and SI by 296.8% ( $P < 0.001$ ) compared with NT animals, indicating pronounced sympathetic load and a high level of autonomic stress at rest. In sows of the NT group one day after farrowing, Mean RR decreased by 6.2% ( $P < 0.001$ ) compared with the pre-farrowing value, indicating an acceleration of heart rhythm due to activation of the sympathetic nervous system. Mo also decreased by 6.2% ( $P < 0.001$ ) compared with pre-farrowing values, confirming a shift of the modal R-R interval towards shortening. AMo increased by 39.0% ( $P < 0.001$ ) compared with pre-farrowing values, indicating strengthening of the dominant interval and reduced diversity of rhythms.  $\Delta x$  decreased by 47.4% ( $P < 0.001$ ) compared with pre-farrowing values, demonstrating a reduction in the overall variability of intervals. VBI increased by 177.6% ( $P < 0.001$ ) and SI by 197.2% ( $P < 0.001$ ) compared with pre-farrowing values, indicating a shift in autonomic balance towards sympathetic tone and reflecting a high level of autonomic stress.

In sows of the VT group one day after farrowing, Mean RR decreased by 21.6% ( $P < 0.001$ ) and Mo by 22.3% ( $P < 0.001$ ) compared with pre-farrowing values, confirming a shift of the most frequent R-R interval towards shortening. AMo doubled, indicating the strengthening of

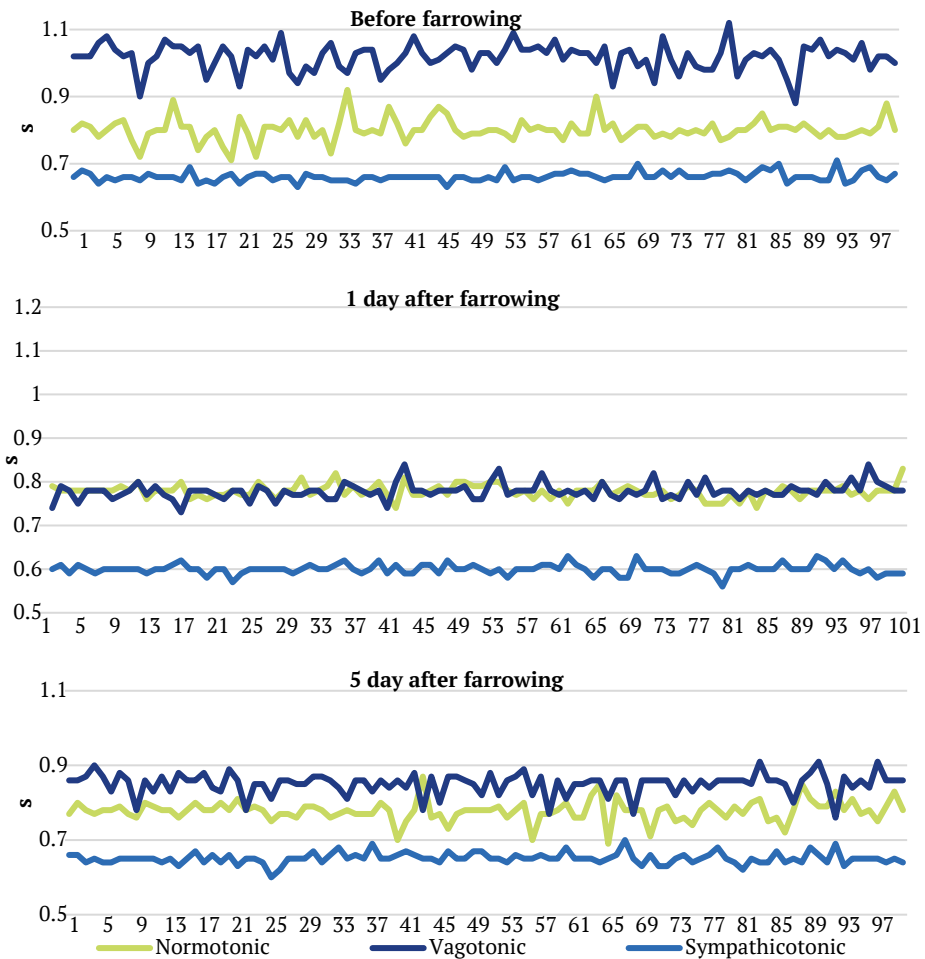
one dominant interval and reduced diversity.  $\Delta x$  decreased by 48.0% ( $P < 0.001$ ) compared with pre-farrowing values, demonstrating a reduction in the overall variability of R-R intervals. VBI increased fourfold ( $P < 0.001$ ) and SI increased fivefold ( $P < 0.001$ ) compared with pre-farrowing values, indicating a shift in autonomic balance towards the dominance of the sympathetic nervous system. In sows of the ST group one day after farrowing, Mean RR and Mo decreased by 8.8% ( $P < 0.05$ ) compared with the pre-farrowing values. In contrast, AMo increased by 20.7% ( $P < 0.001$ ) compared with the pre-farrowing values, reflecting an increased contribution of the modal interval and a simultaneous narrowing of the variability spectrum.  $\Delta x$  decreased by 11.1% compared with the pre-farrowing values, indicating reduced diversity of intervals. VBI increased by 41.8% ( $P < 0.01$ ) and SI by 55.4% ( $P < 0.001$ ) compared with the pre-farrowing values, indicating predominant activation of the sympathetic branch of the autonomic nervous system during the first day after farrowing.

From the first to the fifth day after farrowing in the NT group, Mean RR increased by 4% ( $P < 0.05$ ), indicating partial recovery of the initial heart rate. At the same time, AMo decreased by 10% ( $P < 0.01$ ) and  $\Delta x$  increased by 60% ( $P < 0.001$ ), reflecting an increase in variability. Meanwhile, VBI decreased by 45% ( $P < 0.001$ ) and SI by 47% ( $P < 0.001$ ). In sows of the VT group, Mean RR increased by 6% ( $P < 0.001$ ) and  $\Delta x$  by 31% ( $P < 0.001$ ). However, AMo decreased by 10% ( $P < 0.001$ ), indicating greater diversity of intervals. VBI decreased by 29% ( $P < 0.001$ ) and SI by 34% ( $P < 0.001$ ). In sows of the ST group, Mean RR increased by 7%, indicating a gradual reduction of excessive sympathetic activity. AMo decreased by 14%, while  $\Delta x$  increased by 38%. VBI decreased by 37% and SI by 42%, indicating a gradual reduction of sympathetic dominance.

Thus, a similar pattern of variational pulsometry dynamics was observed in all studied

groups of sows during parturition stress and recovery after farrowing: before farrowing, ANS tone determined the baseline levels of variability (lowest stress in VT, moderate in NT, and highest in ST). After farrowing (day 1), all groups demonstrated a sharp increase in SI and VBI indices together with a decrease in  $\Delta x$  and Mean RR, indicating activation of the sympathetic branch and a high level of autonomic stress. By the fifth day, heart rate variability began to recover

gradually: Mean RR and  $\Delta x$  approached their initial values, AMo decreased, and SI and VBI declined, reflecting restoration of autonomic balance and a reduction in the stress response to a level closer to the baseline. Figure 1 presents measurements of 100 consecutive R-R intervals (in seconds) for one sow in each group (normotonic – blue, vagotonic – green, sympathicotonic – red) at three time points: before farrowing, on the first day, and on the fifth day after farrowing.



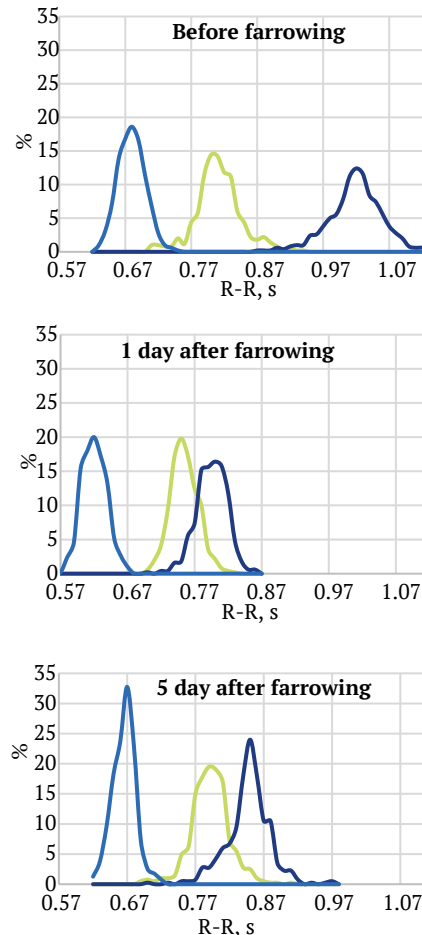
**Figure 1.** Cardiointervalogram of sows with different parameters of autonomic regulation, R-R, s (n = 1)

Source: authors' own work

Before farrowing, sows in the VT group showed wide fluctuations around 1.00 s (peaks up to 1.10 s and a minimum of about 0.90 s), indicating high interbeat variability under the influence of parasympathetic dominance. In sows of the NT group, moderate fluctuations were observed around 0.80 s (range approximately 0.75-0.90 s), whereas in sows of the ST group a narrow clustering of intervals within 0.65-0.70 s was detected, indicating low variability associated with the predominance of sympathetic tone. On the first day after farrowing, shifts towards shorter intervals were observed in all three curves. In ST sows, the interval remained the most “compressed” (approximately 0.60-0.65 s), whereas in sows of the NT and VT groups the curves converged around 0.75-0.80 s with smaller fluctuations, demonstrating acute sympathetic activation in all groups. On the fifth day after farrowing, the cardiointervalogram curve of VT sows expanded again to 0.85-0.95 s, indicating recovery of parasympathetic activity. In NT sows, fluctuations partially recovered (approximately 0.70-0.85 s), whereas in ST sows the intervals remained relatively “compressed” (0.60-0.70 s), indicating a slower return to baseline variability. These cardiointervalograms illustrate the influence of the initial tone of the autonomic nervous system on the level of heart rate variability and on the rate of its recovery after farrowing stress.

Figure 2 presents the distribution of R-R intervals in sows of the three experimental groups with different ANS tones before farrowing: vagotonic – the green curve – show a peak interval frequency around 1.02 s with a wide distribution “tail” (maximum  $\approx 12\%$ ), indicating high variability due to dominant parasympathetic influence; normotonic – the blue curve – demonstrate an average interval of approximately 0.78 s with a smoother and more symmetrical distribution (maximum  $\approx 14\%$ ), reflecting balanced sympathetic-parasympathetic regulation; sympathicotonic – the

red curve – are characterised by a narrow peak around 0.67 s with the highest recurrence percentage ( $\approx 18\%$ ), indicating rigid “clustered” interval grouping and low variability under sympathetic dominance.



**Figure 2.** Variation graph of R-R interval repetition (s) in pigs with different ANS tone (M; n=5)

**Note:** yellow line – normotonic; dark blue line – vagotonic; light blue line – sympathicotonic

**Source:** authors' own work

On the graph of the R-R interval distribution on the first day after farrowing, the red curve (ST sows) was narrowly concentrated around  $\sim 0.62$  s with a peak of about 20%, indicating the

persistence of rigid “clustered” interval contraction under dominant sympathetic activity. The blue curve (NT sows) had a peak value of approximately 0.76 s with a peak of about 20% and a slightly wider yet fairly symmetrical distribution, reflecting moderate variability during the acute stress response. The green curve (VT sows) was shifted towards approximately 0.80 s with a peak of about 16% and showed the most extended distribution among all groups, indicating relatively high R-R interval variability even in the presence of enhanced autonomic activation following parturition stress.

The fifth day after farrowing was characterised by a further shift and widening of the R-R interval distributions in sows of all groups. In sympathicotonic animals, the intervals remained narrowly clustered around ~0.665 s with the highest peak percentage (~32%), indicating persistent rigid sympathetic tone. In normotonic sows, the peak interval was approximately 0.79 s with a more uniform but still relatively narrow distribution (~19%), reflecting moderate variability during the recovery period. In vagotonic animals, the widest distribution was observed, with a maximum around 0.85 s (~24%), indicating a well-expressed parasympathetic recovery response and a gradual restoration of high heart rate variability.

Analysis of the R-R interval distributions in sows with different ANS tones showed that the baseline autonomic status determines the initial level of variability: vagotonic animals had the widest distribution and the longest intervals, normotonic animals had intermediate values, and sympathicotonic animals had the narrowest distribution. On the first day after farrowing, sows in all experimental groups demonstrated a shift of the peaks towards shorter R-R intervals and a sharp “clustered” contraction of the distributions, reflecting activation of the sympathetic branch and high autonomic stress. By the fifth day after farrowing,

the distributions gradually widened and approached their initial values: the greatest variability was again observed in vagotonic sows, moderate variability in normotonic animals, whereas sympathicotonic sows still retained a relatively rigid “clustered” interval structure. Such dynamics demonstrate a universal response to parturition stress, followed by a gradual reduction of sympathetic load and restoration of autonomic balance in sows during the first five days after farrowing.

Thus, this study presents the first comprehensive analysis of variational pulsometry in sows with different baseline tones of the autonomic nervous system during the periods before and after farrowing. The obtained results revealed a clear correlation between the baseline balance of sympathetic and parasympathetic tone and the cardiovascular response to parturition stress, supporting hypotheses regarding the role of autonomic regulation in post-parturition recovery.

Firstly, the baseline HRV indicators reflect the classical distribution according to autonomic tone: in VT sows, an increased mean duration of R-R intervals and wide variability were observed, correlating with enhanced parasympathetic activity (Todoryuk *et al.*, 2023). In NT sows, a balance between both branches of the ANS was maintained, whereas in ST sows the sympathetic branch predominated, with a rigidly “compressed” spectrum of R-R intervals corresponding to lower adaptive flexibility, as reported by A. Youssef *et al.* (2020). These findings are consistent with the work of C.J. Byrd *et al.* (2020), which indicated that high sympathetic activity is associated with a reduced range of variability in mammals during stress.

Secondly, on the first day after farrowing, sows in all groups demonstrated a significant increase in the stress index (SI) and the vegetative balance index (VBI), as well as a decrease in Mean RR and  $\Delta x$ , indicating activation of the

sympathetic branch and a high level of stress response. Such rapid changes correspond to the phenomena of “parturition shock” in mammals described by F.T. Spradley (2019), in which sympathetic predominance promotes mobilisation of physiological resources and thermoregulation. Similar observations were reported in the studies of W. Sipos *et al.* (2013), where in pigs during parturition stress the stress index and vegetative balance index increased almost two-fold within the first 12 hours after farrowing. According to L. Stovbetska *et al.* (2021), acute pain stress and hormonal changes during farrowing cause a sharp shift towards sympathetic dominance: sows exhibit tachycardia, reduced heart rate variability, and elevated levels of adrenocorticotrophic hormone and cortisol.

Thirdly, by the fifth day after farrowing, HRV indicators partially returned towards baseline levels: Mean RR and  $\Delta x$  approached their initial values, while AMo decreased, indicating recovery of parasympathetic activity. According to C.J. Byrd *et al.* (2020), after farrowing the intensity of sympathetic activity gradually declines and the parasympathetic nervous system becomes capable of regulating homeostasis: in sows respiratory rate and cardiac intervals normalise, uterine perfusion improves, and milk let-down becomes more efficient. However, in the present study, sympathicotonic sows showed the greatest delay in recovery, with VBI and SI values remaining markedly elevated compared with NT and VT animals even on the fifth day. This finding is consistent with the concept that a baseline sympathicotonic tone reduces adaptive capacity to repeated stress stimuli (Lipsitz *et al.*, 1997). As noted by L. Stovbetska *et al.* (2021), insufficient transition to parasympathetic recovery may lead to complications such as delayed uterine involution, increased risk of postpartum metritis, and deterioration in milk quality. Conversely, facilitating a rapid

shift towards parasympathetic dominance correlates with a better onset of lactation and improved survival of newborn piglets.

In veterinary science, ANS tone is regarded as a key factor determining stress resistance and productivity in animals. Scientific literature describes in detail the anatomical and functional relationships between the ANS and central brain structures and their influence on cardiac regulation (Ten Donkelaar *et al.*, 2020). V. Todoryuk *et al.* (2023), in experiments on piglets, found that vagotonic individuals adapt better to environmental changes during early ontogenesis, whereas sympathicotonic animals demonstrate increased levels of stress reactions. V.O. Danchuk *et al.* (2024) also drew attention to changes in biochemical markers (total protein and its fractions) in sows with different ANS tones during pregnancy and farrowing, emphasising the influence of autonomic status on the physiological condition of animals during critical periods.

As the results of the present study demonstrated, assessment of adaptive changes in the ANS of sows during farrowing should include HRV monitoring both before and directly during parturition. This conclusion is supported by C.J. Byrd *et al.* (2020), who indicated that data collection using ECG telemetry enables the determination of spectral indicators such as LF and HF, the LF/HF ratio, and, shortly after farrowing, the RMSSD (root mean square of successive differences). A decrease in RMSSD and HF during the contraction phase indicates intense sympathetic activation, which can be moderated by the administration of antispasmodics and analgesics to reduce pain load. M.D. Ghezzi *et al.* (2024) emphasised the importance of combining HRV analysis with infrared thermography to record real-time changes in ANS tone and to predict physiological stress before visible clinical signs appear. K.E. Speer *et al.* (2024) also noted that the inclusion of

hormonal markers, particularly cortisol, provides a deeper understanding of the mechanisms of adaptation in homeothermic organisms. Furthermore, the authors emphasised that most responses arising in animals under the influence of stress factors are mediated by the autonomic nervous system, and that a comprehensive assessment of HRV parameters combined with thermographic and endocrine markers increases the accuracy of early stress diagnostics. Such a multidisciplinary approach creates a basis for the development of predictive models for assessing stress reactivity and for the timely implementation of corrective measures under production conditions.

Thus, determination of ANS tone using variational pulsometry, as demonstrated in the present study, may serve as a practical indicator of stress resistance in sows prior to farrowing and may help predict their ability to recover rapidly afterward. This is particularly important for highly intensified livestock production systems, where reducing the recovery period after farrowing contributes to increased piglet survival and improved sow productivity. Farrowing stress in sows is accompanied by a universal activation of the sympathetic branch of the autonomic nervous system, resulting in pronounced changes in variational pulsometry parameters regardless of the initial autonomic status. At the same time, the type of autonomic regulation influences both the magnitude of the stress response and the rate of post-farrowing recovery of cardiovascular regulation, which was reflected in different dynamics of the stress index and vegetative balance indicators.

The greatest adaptive potential was demonstrated by vagotonic sows, whereas sympathicotonic animals exhibited prolonged autonomic tension. The obtained data confirm the feasibility of using variational pulsometry as an integral tool for assessing stress resistance and predicting adaptive capacity in sows during the farrowing

period. The expected outcome of such studies will be the development of validated predictive models for evaluating stress resistance in pigs, which will improve the accuracy of early diagnosis of maladaptive conditions, optimise housing and management technologies, and enhance productive performance during different physiological periods.

## **Conclusions**

According to the obtained results, a clear temporal dynamics of variational pulsometry parameters was identified in Large White sows with different baseline tones of the autonomic nervous system during the pre-farrowing period and the early post-farrowing period. A step-by-step analysis of heart rate variability was conducted in normotonic, vagotonic and sympathicotonic animals one day before farrowing, as well as on the first and fifth days after parturition stress using the method of variational pulsometry. It was established that the baseline autonomic status determines the initial level of heart rate variability, the intensity of the stress response to farrowing, and the subsequent rate of recovery.

The highest adaptive potential was demonstrated by vagotonic sows, whereas sympathicotonic animals were characterised by a prolonged persistence of autonomic tension. On the first day after farrowing, a pronounced activation of the sympathetic branch of the autonomic nervous system was recorded in all groups, accompanied by an increase in the stress index and the vegetative balance index, reflecting the mobilisation of the organism's regulatory resources. In particular, in normotonic sows the VBI increased by 177.6% ( $P < 0.001$ ) and the SI by 197.2% ( $P < 0.001$ ), while in vagotonic animals the VBI increased fourfold and the SI fivefold ( $P < 0.001$ ), indicating acute sympathetic activation regardless of the initial autonomic tone. By the fifth day after farrowing, partial restoration of autonomic balance was observed, the degree of which depended on the type of

autonomic regulation: in normotonic sows the SI decreased by 47% ( $P < 0.001$ ) and the VBI by 45% ( $P < 0.001$ ) compared with the first day, whereas in sympathicotonic animals, even after a 42% decrease, the SI remained at the level of  $311.0 \pm 36.6$  conventional units, indicating a slower normalisation of regulatory mechanisms.

The obtained data allow heart rate variability to be considered an integral indicator of stress resistance and adaptive capacity in sows during the critical period of farrowing and early post-farrowing recovery. The limitations of the study are associated with the small sample size ( $n = 5$  in each group) and the absence of long-term monitoring beyond the fifth day, which may affect the assessment of longer-term

adaptive processes. A promising direction for further research is the integration of heart rate variability indicators with hormonal, behavioural and productivity markers in order to develop comprehensive predictive models of stress resistance in pigs during different physiological periods.

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## Conflict of Interest

None.

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**Анотація.** Сучасні дослідження демонструють значний вплив вегетативної нервової системи на адаптацію та продуктивність сільськогосподарських тварин. Особливо критичним є період опоросу в свиноматок, коли зміни вегетативного тону детермінують перебіг родового стресу та швидкість відновлення. Метою дослідження було вивчити особливості динаміки параметрів варіаційної пульсометрії у свиноматок із нормотонічним, симпатикотонічним та ваготонічним тонусом вегетативної нервової системи до опоросу, а також через добу та п'ять діб після родового стресу. Експеримент проведено на п'ятнадцяти свиноматках великої білої породи, розподілених на три групи за рівнем індексу напруги. Для кожної тварини за одну добу до опоросу, на першу та п'яту добу після опоросу реєстрували сто послідовних інтервалів між серцевими скороченнями за допомогою електрокардіографа. Розраховували середню тривалість інтервалів, моду інтервалів, амплітуду моди, варіаційний розмах, індекс вегетативного балансу та індекс напруги. Встановлено, що до опоросу ваготонічні тварини мали максимальну варіабельність серцевих інтервалів, симпатикотонічні – найнижчу. Через добу після родового стресу в усіх групах відзначено зменшення середньої тривалості інтервалів та збільшення індексу

напруги, однак найшвидше відновлення параметрів спостерігалось у ваготонічних свиноматок. На п'ятий день після опоросу показники у свиноматок нормотонічної групи наблизились до вихідних значень, тоді як у тварин з підвищеним симпатичним тонусом стресова реакція зберігалася. Отже, використання варіаційної пульсометрії для оцінки тону вегетативної нервової системи перед опоросом дозволяє виявити найбільш стресостійких свиноматок і запровадити цільові підтримуючі заходи у перші доби після опоросу. Такий підхід сприятиме підвищенню виживаності поросят, скороченню періоду відновлення свиноматок та підвищенню економічної ефективності свинарства

**Ключові слова:** варіаційна пульсометрія; вегетативна нервова система; родовий стрес; адаптивні механізми; свині