UDC 616.136.1/.16:616.26:616.36-008.5
https://doi.org/10.31612/2616-4868.7.2025.06

FEATURES OF STRUCTURAL RECONSTRUCTION OF ARTERIES AND MICROVASCULAR BED OF THE MUSCULAR PART OF THE DIAPHRAGM IN JAUNDICE

Ihor Ya. Dzyubanovsky[1], Myroslav Yu. Kritsak[1], Yurii M. Hupalo[2]

[1]I. Horbachevsky Ternopil National Medical University of the Ministry of Health of Ukraine, Ternopil, Ukraine
[2]State Institution of Science «Center of innovative healthcare technologies» State Administrative Department, Kyiv, Ukraine

Abstract

Aim. To evaluate changes in morphometric parameters of the muscular part of the diaphragm in an experimental model of obstructive jaundice.
Materials and methods. Twenty-five animals were divided into two groups. The control group included ten healthy subjects, while the experimental group included fifteen rats that underwent induction of obstructive jaundice by isolation and ligation of the common bile duct. On day 7, the diaphragm was harvested for examination.
Results. The arterial walls showed signs of thickening, and the lumens exhibited narrowing. The outer (zonal) diameter of the arteries increased significantly ($p < 0.05$) by 5.72%. Concurrently, the inner diameter decreased by 5.11%. The thickness of the media also increased, reaching 12.08 ± 0.44 μm, which represents a 4.72% increase. Consequently, the Vogenward index increased by 1.8%. The difference in the relative volume of damaged endothelial cells in the arteries of the lumbar region between the control and jaundiced groups was highly significant ($p < 0.001$), with the experimental group showing a 1.91-fold higher volume. Examination of the microvasculature of the microvascular bed revealed an increase in the diameters of arterioles and precapillary arterioles. Additionally, changes in the venous vessels were observed, manifested by increased venous congestion. In the control group, the density of the capillary bed in the costal region was 3809.78 ± 50.67 per 1 mm^2, and in the lumbar region, it was 3818.90 ± 43.29 per 1 mm^2. In jaundiced animals, the corresponding values were 3790.88 ± 35.56 and 3795.00 ± 57.50 per 1 mm^2, respectively. The mean difference between the control and experimental groups was 0.5% and 0.67%, respectively, indicating a decrease in capillary density in the costal and lumbar regions in animals with jaundice.
Conclusions. Hemodynamic changes in obstructive jaundice lead to significant structural alterations in the small-caliber arteries of the costal and lumbar regions of the diaphragm. These changes are characterized by thickening of arterial walls, narrowing of lumens, an increase in the Vogenward index, reduced vascular capacity, and endothelial damage and dysfunction.

Keywords: **obstructive jaundice, diaphragm, rats, experiment, histology**

INTRODUCTION

Diaphragmatic weakness, a consequence of diaphragmatic dysfunction and atrophy, is a common occurrence in the ICU and is associated with serious clinical consequences. The use of ultrasound to assess the diaphragm's structure (thickness, thickening) and mobility (caudal displacement) is feasible and reproducible, but large-scale 'real-world' studies remain unavailable [1, 2, 3].

Obstructive jaundice (OJ) is a prevalent pathological syndrome in the field of hepatobiliary surgery. Recent studies have shown that impairment of the intestinal mucosal barrier function and dysfunction of hepatic reticular endothelial cells are two pivotal contributors to bacterial and endotoxin migration, which may lead to multiple organ dysfunction following OJ [4, 5, 6].

In such cases, bile outflow into the intestines is impeded due to bile duct obstruction. Consequently, bile accumulates in the liver cells and bile ducts [6]. An increase in bile acids and bilirubin levels in serum has been shown to cause damage to various internal organs [6, 7, 8]. It can also lead to conditions such as cardiovascular disease, renal failure, delayed wound healing, gastrointestinal bleeding, bacterial translocation, sepsis, multiple organ dysfunction, and death [7, 9].

It has been shown that tissue damage associated with mechanical jaundice and endotoxemia leads to increased formation of non-toxic oxygen free radicals [10]. These compounds damage cell membranes and cause multiorgan and multisystem morphological and functional changes in the body, significantly increasing perioperative morbidity and mortality [11, 12].

As shown in earlier research, alterations in intestinal barrier function due to OJ lead to the migration of bacteria and endotoxins to various organs and systems [13]. In animal models, the presence of these molecules has been observed to increase the amount of lipid peroxidation products. The effect on non-hepatic tissues, such as the kidneys, lungs, brain, and others, is significant.

In routine clinical practice, delayed surgical intervention in patients with OJ, without ensuring adequate bile drainage, has been associated with increased morbidity and mortality rates. Importantly, end-organ damage becomes irreversible if the period of obstruction is prolonged. However, data from electron microscopy on functional changes due to obstructive injury, the pathophysiology of reversibility, and the healing process remain incomplete. The key unresolved question concerns whether a reversibility period exists and what ultrastructural changes ultimately result in cell death.

AIM

The aim of this experimental study was to evaluate changes in morphometric parameters of the muscular part of the diaphragm in an experimental model of obstructive jaundice in rats.

MATERIALS AND METHODS

All animal experiments in this study were conducted in compliance with the guidelines of the Bioethics Committee at I. Horbachevsky Ternopil National Medical University.

Animals were housed in an accredited university vivarium in standard cages. Ambient temperature was maintained at 22 °C, with relative humidity between 60% and 80%, and a 12-hour light/dark cycle. Food and water were provided *ad libitum*. Animals were 5-6 months old, weighing 210-230 g. A total of 25 rats were randomly divided into two groups: control (CG, n = 10) and experimental (EG, n = 15) groups. Control animals were healthy and served as physiological references, while EG underwent obstructive jaundice (OJ) induction.

OJ was induced by the same experimenter under standardized conditions. Food and water were withheld for 6 h before anesthesia. Anesthesia was induced by intramuscular injection of 10 mg/kg xylazine and 90 mg/kg ketamine. The abdominal fur was shaved, rats were placed supine on a dissection table, and the surgical field disinfected with 10% povidone-iodine, sparing limbs and neck. A midline incision (~ 3 cm) was made from the xiphoid process. After isolating the duodenum and pyloric stomach, the common bile duct was identified and ligated with silk 4-0 ligatures (Fig. 1).

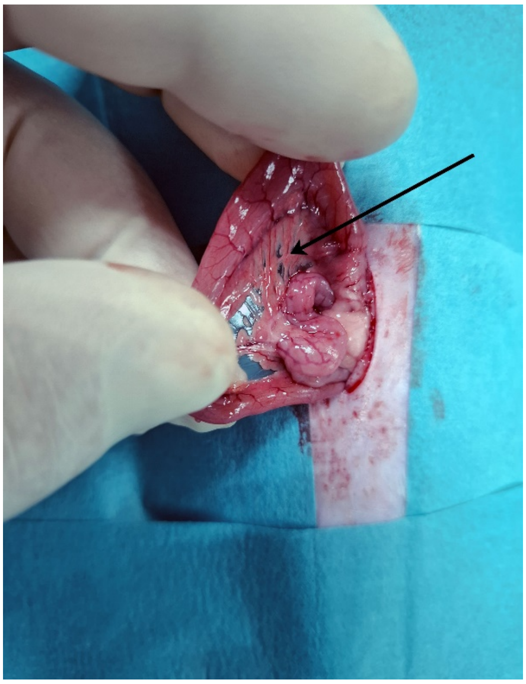

Figure 1. Common bile duct (shown by an arrow).

Post-procedure, clinical signs of OJ – such as jaundice of ears, mucosa, dark urine – were observed from day 3. By postoperative day 7, all surviving rats exhibited yellowing of ears, eyes, tail, and internal organs (Fig. 2), dilated proximal bile ducts, and moderate hepatic firmness. Two rats died on days 5 and 6 and were excluded (cause: OJ-related multiorgan failure).

Euthanasia was performed on day 7 by intraperitoneal injection of Thiopental sodium 75 mg/kg. Costal (CP) and lumbar (LP) diaphragm parts (Fig. 3) were fixed in 10% neutral-buffered formalin, progressively dehydrated in ethanol, embedded in paraffin, sectioned at 5-7 μm, deparaffinized, and H&E stained.

Diaphragms were harvested per Work Certificate No. 126059 dated April 29, 2024. With regard to the macro preparation of the diaphragm (Fig. 3), the costal (CP) and lumbar (LP) parts were separated and placed in a 10% solution of neutral formalin. Following fixation, the material was dehydrated in ethyl alcohols of increasing concentration and embedded in paraffin. Histological sections of 5-7 μm thickness were prepared from each paraffin block on a microtome, following deparaffinisation, and stained with hematoxylin and eosin.

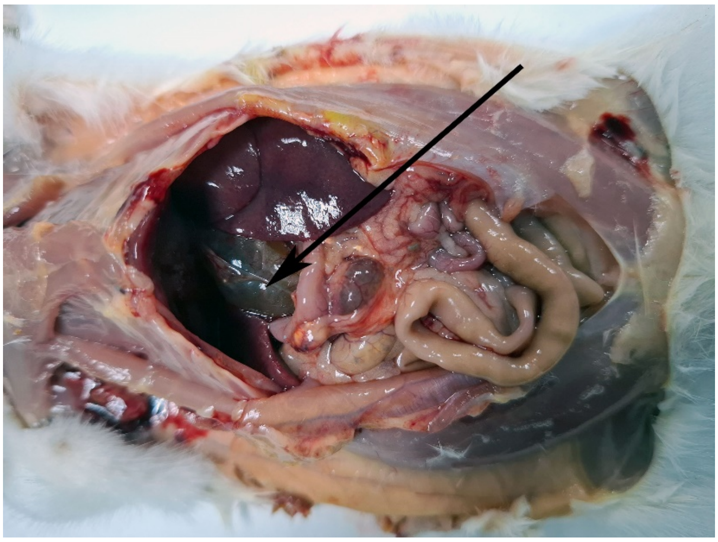

Figure 2. Dilated common bile duct on day 7 of mechanical jaundice (shown by an arrow).

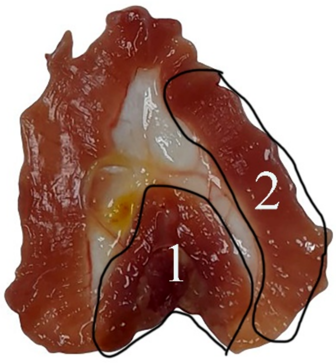

Figure 3. Selected rat diaphragm: 1 – lumbar part; 2 – costal part.

Morphometric data were analyzed using Microsoft Excel and STATISTICA 5.5 (StatSoft, USA) employing parametric statistical methods.

RESULTS

The obtained morphometric parameters of small-calibre arteries of the muscular part of the diaphragm of both groups are presented in Table 1. No statistically significant differences were found when comparing the parameters in the CG between the studied parts of the CP and LP diaphragms ($p > 0{,}05$). Consequently, the outer diameter (OD) of the LP increased by only 0.4%. Consequently, the outer diameter (OD) of the LP increased by a mere 0.4%. The inner diameter (ID) exhibited a 1.6% decrease in the LP. Consequently, the

Vogenworth Index (VI) demonstrated an increase of merely 0.6% within the LP. It was observed that the media thickness (MT) increased by a mere 2.3% in LP. The results of the study demonstrated that endothelial cell height (ECH) and endothelial cell nuclei diameter (ECND) increased by 0.2% and 1.7%, respectively, in CP and LP. The relative volume of damaged endothelial cells (RVDEC) exhibited an increase of 2.4% in LP.

A comparison of the values obtained in the EG with those in the CG revealed a number of morphometric parameters that differed significantly. Thus, the OD of small-calibre arteries of the CP diaphragm increased by 2.47% (from (34.45 ± 0.14) to (35.30 ± 0.29) μm) ($p < 0.05$), and the ID decreased by 5.26% (from (12.35 ± 0.14) to (11.70 ± 0.25) μm) ($p < 0.05$). VI increased by 1.97% (785.24 ± 3.36), ($p < 0.01$), while MT increased statistically significantly ($p < 0.05$) by 3.76%. The RVDEC increased by 38.25% in comparison with the animals not administered OJ (from (2.05 ± 0.25) to (3.32 ± 0.24) %), ($p < 0.01$). In addition, a statistically insignificant ($p > 0,05$) increase was observed in the values of EHC, ECND and nuclear-to-cytoplasmic ratio of endothelial cells (NCREC), with respective increases of 0.52%, 3.28% and 10.36%.

Table 1

Morphometric Parameters of Small-Calibre Arteries of the Diaphragm

Indicator	Observation groups			
	Control group		Experimental group	
	Costal part	Lumbar part	Costal part	Lumbar part
Outer diameter, μm	34,45 ± 0,14	34,61 ± 0,15	35,30 ± 0,29*	36,71 ± 0,34*
Inner diameter, μm	12,35 ± 0,14	12,15 ± 0,23	11,70 ± 0,25*	11,53 ± 0,29
Vogenworth index, %	769,80 ± 1,22	774,50 ± 4,67	785,20 ± 3,36**	788,70 ± 3,48*
Media thickness, μm	11,25 ± 0,28	11,51 ± 0,27	11,89 ± 0,31*	12,08 ± 0,44
Endothelial cell height, μm	5,78 ± 0,20	5,77 ± 0,24	5,81± 0,18	5,84 ± 0,18
Endothelial cell nuclei diameter, μm	2,95 ± 0,25	3,00 ± 0,23	3,05 ± 0,25	3,12 ± 0,19
Nuclear-to-cytoplasmic ratio of endothelial cells	0,251 ± 0,041	0,263 ± 0,039	0,280 ± 0,035	0,288 ± 0,017
Relative volume of damaged endothelial cells, %	2,05 ± 0,25	2,10 ± 0,24	3,32 ± 0,24**	4,03 ± 0,11***

Note: * – $p < 0,05$, ** – $p < 0,01$, *** – $p < 0,001$ compared to the control group.

The values of morphometric parameters of small-calibre arteries of the LP of the diaphragm in the EG increased in comparison with analogous parameters in the CG. It was found that OD of arteries was statistically significantly ($p < 0.05$) increased by 5.72%. Concurrently, the ID exhibited a 5.11% decrease. Furthermore, an increase in MT was observed, reaching 12.08 ± 0.44 μm, which corresponds to an increase of 4.72%. Consequently, the value of VI increased by 1.8%. A discrepancy was identified in the values of RVDEC in the small-calibre arteries of the LP diaphragm between the CG and OJ animals, with a high degree of reliability ($p < 0.001$). The RVDEC value in the EG was found to be 1.91 times higher than that observed in the CG and OJ animals. This increase in the index was due to an increase in the number of apoptotic and dystrophically altered endothelial epithelial cells. The height of endothelial cells in the studied arteries increased by only 1.2%, the diameter of nuclei by 3.85%, and the nuclear-to-cytoplasmic ratio by 8.68% ($p > 0.05$).

The morphometric parameters of the hemomicrocirculatory bed of the CP and LP diaphragm of the CG and EG diaphragms are presented in Table 2. The diameter of arterioles (DA) in the CP of the CG diaphragm was (16.74 ± 0.33) μm. The same indicator in the LP was slightly higher by 0.36% ($p > 0.05$). In OJ rats, analogous values were found to be statistically significantly higher ($p < 0.05$) by 1.59% and 1.64%, respectively, in the CP and LP diaphragms. Concurrently, the discrepancy between the values recorded in the cruses of diaphragm (17.08 ± 0.32) μm and it's muscle part (17.01 ± 0.25) μm was 0.41% ($p > 0.05$).

Table 2

Morphometric Parameters of the Diaphragmatic Microvascular Bed

Indicator	Observation groups			
	Control group		Experimental group	
	Costal part	Lumbar part	Costal part	Lumbar part
Diameter of arterioles, μm	16,74 ± 0,33	16,80 ± 0,31	17,01 ± 0,25*	17,08 ± 0,32*
Diameter of precapillary arterioles, μm	10,06 ± 0,37	10,08 ± 0,36	10,15 ± 0,40	10,20 ± 0,35*
Hemocapillary diameter, μm	5,25 ± 0,16	5,27 ± 0,16	5,30 ± 0,16*	5,38 ± 0,16*
Diameter of the postcapillary venules, μm	11,80 ± 0,35	11,82 ± 0,34	11,87 ± 0,36*	11,91 ± 0,33*
Diameter of venules, μm	27,12 ± 0,30	27,15 ± 0,37	27,40 ± 0,34*	27,45 ± 0,40*
Capillary bed density, in 1 mm^2	3809,78 ± 50,67	3818,90 ± 43,29	3790,88 ± 35,56*	3795,00 ± 57,50*

Note: * – $p < 0.05$ compared to the control group.

The diameter of the precapillary arterioles (DPA) in the CG was found to be equivalent to (10.06 ± 0.37) µm in the CP diaphragm and (10.08 ± 0.36) µm in the LP diaphragm ($p > 0.05$). The DPA indices in the EG exceeded those in the CG by 0.89% in the CP diaphragm and by 1.18% in the LP. The mean difference between the two groups was 0.49% ($p > 0.05$).

The morphometric parameter of hemocapillary diameter (HD) in the CP diaphragm was (5.25 ± 0.16) µm, and with high statistical significance ($p < 0.001$), was 3.2 times less than that of DA and 1.9 times less than that of DPA. In animals with OJ, the morphometric parameters of the HD were (5.30 ± 0.16) µm in the CP and (5.38 ± 0.16) µm in the LP of the diaphragm, and these also exceeded the same quantitative parameters of arterioles and precapillary arterioles by 3.2 times ($p < 0.001$).

The mean diameter of the postcapillary venules (DPV) in the CG was found to be statistically significantly ($p < 0.001$) higher than the diameter of the hemocapillaries in the CP diaphragm and LP, by 2.2 times and (11.80 ± 0.35) µm and (11.82 ± 0.34) µm, respectively. In animals with OJ, the correlation of morphometric parameters with hemocapillary sizes was similar. Within the group, the DPV in the LP of the diaphragm exceeded that in its CP by 0.34% ($p > 0.05$). The value of the indicator in the CP of the diaphragm was (11.87 ± 0.36) µm and (11.91 ± 0.33) µm in the LP, and was statistically unreliable ($p > 0.05$). It exceeded it in the CG by 0.59% and 0.76%, respectively.

The mean diameter of the venules (DV) in the CP diaphragm of the CG was found to be (27.12 ± 0.30) µm, and in the LP diaphragm, it was (27.15 ± 0.37) µm. The aforementioned parameters exceeded the value of the DPV by 2.3 times in both groups ($p < 0.001$). In the experimental group, the DV parameters were found to be equal to (27.40 ± 0.34) µm in the CP and (27.45 ± 0.40) µm in the LP of the diaphragm, which also exceeded the corresponding values of the DPV by 2.3 times ($p < 0.001$). The values obtained for these groups were 1.02% and 1.10% higher than those recorded for the CG animals.

In the present study, the capillary bed density (CBD) of the CP was found to be (3809.78 ± 50.67), and in the LP (3818.90 ± 43.29) per 1 mm^2. In the OJ condition, the CBD was equal to (3790.88 ± 35.56) in the CP and (3795.00 ± 57.50) per 1 mm^2 in the LP of the diaphragm. Concurrently, the disparity between the CP diaphragm indices in CG and EG was 0.5%, and between the measurements of the LP diaphragm – 0.67% in the direction of their decrease in animals with OJ.

DISCUSSION

Animals such as rats are widely used in experimental research due to their small size, low cost, high vitality and short reproduction cycle. In experimental studies, rats are used to model OJ and reproduce various treatments. There are two main ways to build a model of biliary obstruction: crossing the common bile duct with subsequent ligation and simple ligation with suture material [8].

In this study, a rat model of OJ was prepared by isolating and ligating the common bile duct. Following a three-day period of modelling, the presence of typical signs of OJ was observed, including the yellowing of the cornea, the skin of the ears and urine, and a decrease in appetite. The typical external signs mentioned above are considered a success of the modelling.

A significant body of research has been dedicated to investigating the underlying mechanisms of liver damage and the pathophysiological changes associated with bile duct obstruction. As demonstrated by these investigations, the administration of OJ to rats resulted in the identification of pathological damage to the liver and other abdominal organs [6, 7]. The changes in morphometric parameters observed in this study also confirmed the pathological damage to the muscular part of the diaphragm after biliary obstruction.

The morphometric data presented demonstrate a congruence with the findings of morphometric examinations of the diaphragm documented in scientific publications. These studies have indicated the presence of circulatory disorders within the system of microcirculatory beds and medium-sized vessels. Capillaries, venules and arterioles were found to be full-blooded, exhibiting all indications of rheohemodynamic disorders, including blood stasis, erythrocyte sludge and adhesion to the vessel walls. The arterioles exhibited signs of thickening, indicative of plasma saturation. The endothelium underwent a process of modification, resulting in the appearance of rounded cells with vacuolated cytoplasm. It was observed that a proportion of the subjects had undergone exfoliation. The vessel walls exhibited signs of both oedema and smooth muscle dystrophy. Perivascular spaces were observed to be expanded due to stromal oedema. In addition, the presence of minor lymphocytic infiltrates was detected within the endo- and perimysium [14]. This is particularly evident in the rise of RVDEC, as demonstrated in our research, attributable to an increase in the number of apoptotic and dystrophically altered endothelial epithelial cells [15].

The thickening of the arterial wall, narrowing of the lumen, and increase in the Vogenworth index are indicative of a marked decrease in the capacity for blood flow of the studied vessels and deterioration of blood supply to the organ. This is consistent with the morphological data [14]. It should be noted that greater changes were detected in the LP diaphragm, which we attribute to the fact that it is more functionally loaded compared to the CP [15, 16].

The pronounced structural changes of small-calibre arteries in both studied parts of the diaphragm in OG are indicative of their special functional activity in redistribution of blood flow in OJ. The thickening of the vessel walls and narrowing of the lumens were due to oedema and dystrophy of the smooth muscle cells. Concurrently, an augmentation in the tone of the lateral branches of the arterial vessels was also observed. Damage to a significant number of endothelial cells can result in a number of adverse outcomes, including the following: dysfunction of the endothelial cells; blockade of nitric oxide synthase; reduction of nitric oxide synthesis; activation of its degradation; and increased synthesis of vasoconstrictors, including endothelin, angiotensin-II, thromboxane, and prostaglandin, which can increase spasm and vasoconstriction [5, 6]. The structural changes described in the literature pertaining to small-calibre arteries significantly affected the regulation of blood flow in OJ, thereby ensuring optimal blood supply to the organ under these pathological conditions.

From a practical and clinical standpoint, the diaphragm is a significant tendinous-muscular structure that plays a crucial role in respiration. A comprehensive understanding of pathomorphological alterations facilitates enhanced anaesthetic support, given that surgical intervention constitutes the primary treatment modality [10, 11, 17]. The present study aims to expand the indications for laparoscopic methods of treating OJ by adding another pathological factor, pneumoperitoneum, which creates intra-abdominal pressure. During surgical procedures, the anatomy must be carefully considered in order to minimise trauma to this important organ [1, 10]. The rhythmic contraction of this muscle is instrumental in facilitating continuous pulmonary ventilation, a process essential for sustaining life. It is imperative to ensure sufficient blood flow to the diaphragm to enable the continuous maintenance of its contractile function. Imbalances in nutrient supply and absorption can result in diaphragmatic insufficiency, which can lead to significant morbidity and mortality [1, 3]. It is evident that the supply of oxygen to the diaphragm is crucial for its function, therefore, it is unsurprising that there has been a surge in research focusing on the diaphragm in recent animal studies. This work has advanced our understanding of the morphometric alterations in the CT and LP. However, due to the relative inaccessibility of the diaphragm, similar studies in humans are not possible. Consequently, the present corpus of knowledge is predicated exclusively on the findings of animal studies.

CONCLUSIONS

The isolation and ligation of the common bile duct in experimental animals is complicated by the latter's dilation and the subsequent development of obstructive jaundice. It is evident that hemodynamic changes result in a significant structural restructuring of the small-calibre arteries of the costal and lumbar parts of the diaphragm. This structural restructuring is characterised by thickening of the arterial walls, narrowing of the lumen, an increase in the Vogenworth index, a decrease in vascular capacity, endothelial cell damage, endothelial dysfunction, deterioration of the organ's blood supply, hypoxia, and dystrophy. The alterations in the vessels of the haemomicrocirculatory bed manifested through an augmentation in the diameter of arterioles and precapillary arterioles, accompanied by an increase in venous fullness, and a reduction in microvascular density.

Perspectives for further research. The data from this study form the basis of a series of investigations into the effects of pneumoperitoneum created by carbon dioxide, a technique similar to that employed in laparoscopic treatment of obstructive jaundice, on various parts of the diaphragm. The investigations will examine the effects of different durations of standard and low intra-abdominal pressure.

COMPLIANCE WITH ETHICAL REQUIREMENTS

The experimental studies were conducted in full compliance with the current national and international regulations: The Law of Ukraine 'On Protection of Animals from Cruelty' No. 3477-IV of 21.02.2006 (as amended); Order of the Ministry of Education and Science, Youth and Sports of Ukraine 'On Approval of the Procedure for Conducting Experiments and Experiments on Animals by Scientific Institutions' No. 249 of 01.03.2012; General Ethical Principles for Animal Experiments, adopted by the First National Congress of Ukraine on Bioethics (Kyiv, 2001); Directive 2010/63/EU of the European Parliament and of the Council of the European Union on the Protection of Animals Used for Scientific Purposes (Brussels, 2010); European Convention for the Protection of Vertebrate Animals Used for Research and Other Scientific Purposes (Strasbourg, 1986).

FUNDING AND CONFLICT OF INTEREST

The authors declare no conflicts of interest that could have influenced the objectivity or outcomes of this study. The authors received no financial support for the research, authorship, or publication of this article. The authors do not have any financial interest and did not receive any financial benefit from this research.

AUTHOR CONTRIBUTIONS

Dzyubanovsky I. Ya.[A, C, E, F]

Kritsak M. Yu.[B, D, F]

Hupalo Yu. M.[E, F]

REFERENCES

1. Dres, M., & Demoule, A. (2020). Monitoring diaphragm function in the ICU. Current opinion in critical care, 26(1), 18-25. https://doi.org/10.1097/MCC.0000000000000682
2. Tasnim, S., Bribriesco, A. C., & Sudarshan, M. (2024). Surgical Diaphragm: Anatomy and Physiology. Thoracic surgery clinics, 34(2), 111-118. https://doi.org/10.1016/j.thorsurg.2024.01.002
3. Jain, R., Gupta, A., Kandasamy, D., & Jana, M. (2022). Imaging in Pediatric Obstructive Jaundice. Indian journal of pediatrics, 89(9), 899-907. https://doi.org/10.1007/s12098-022-04171-7
4. Minami, T., Manzoor, K., & McCool, F. D. (2018). Assessing Diaphragm Function in Chest Wall and Neuromuscular Diseases. Clinics in chest medicine, 39(2), 335-344. https://doi.org/10.1016/j.ccm.2018.01.01
5. Zhang, C. X., Shu, C. M., Zhang, X. Y., Lin, X. T., Guan, Q. H., Zhang, F., & Zhi, X. T. (2021). Effect and mechanism of omega-3 polyunsaturated fatty acids on intestinal injury in rats with obstructive jaundice. European review for medical and pharmacological sciences, 25(19), 6077-6092. https://doi.org/10.26355/eurrev_202110_26886
6. Angelis, A., Kostakis, I. D., Lilimpakis, K., Kalaitzopoulou, E., Papadea, P., Skipitari, M., Georgiou, C. D., & Vagianos, C. (2023). Time-Related Evidence of Intestinal Oxidative Stress in Obstructive Jaundice-Induced Rats. European surgical research. Europaische chirurgische Forschung. Recherches chirurgicales europeennes, 64(3), 323-333. https://doi.org/10.1159/000530087
7. Kilavuz, H., Turan, U., Yoldas, A., Tolun, F. I., Tanriverdi, B., Yaylali, A., Yaman, A., Yener, M. K., & Irkorucu, O. (2021). The effect of Farnesoid X receptor agonist tropifexor on liver damage in rats with experimental obstructive jaundice. Acta cirurgica brasileira, 36(9), e360902. https://doi.org/10.1590/ACB360902
8. Zhang, X., Peng, B., Zhang, Y., Zhang, Y., Lu, X., & Cao, Y. (2022). Biliary Drainage Reduces Intestinal Barrier Damage in Obstructive Jaundice by Regulating Autophagy. Contrast media & molecular imaging, 2022, 3301330. https://doi.org/10.1155/2022/3301330
9. Shi, L., Guo, C., Xie, Y., Liu, Y., & Wu, F. (2019). Dexmedetomidine Attenuates Lung Injury in Obstructive Jaundice Rats Through PI3K/Akt/HIF-1α Signaling Pathway. Archives of medical research, 50(5), 233-240. https://doi.org/10.1016/j.arcmed.2019.08.006
10. Savdan, M., Çakır, M., Vatansev, H., Küçükkartallar, T., Tekin, A., & Tavlı, Ş. (2017). Preventing oxygen free radical damage by proanthocyanidin in obstructive jaundice. Turkish journal of surgery, 33(2), 62-68. https://doi.org/10.5152/turkjsurg.2017.3337
11. Dilektasli, E., Ozmen, M. M., Gundogdu, E., Dizen, H., Besler, H. T., & Ozogul, C. (2016). The effects of obstructive jaundice on the brain: An experimental study. Asian journal of surgery, 39(3), 155-163. https://doi.org/10.1016/j.asjsur.2015.03.014
12. Lv, Y., Yue, J., Gong, X., Han, X., Wu, H., Deng, J., & Li, Y. (2018). Spontaneous remission of obstructive jaundice in rats: Selection of experimental models. Experimental and therapeutic medicine, 15(6), 5295-5301. https://doi.org/10.3892/etm.2018.6119
13. Pavlidis, E. T., & Pavlidis, T. E. (2018). Pathophysiological consequences of obstructive jaundice and perioperative management. Hepatobiliary & pancreatic diseases international: HBPD INT, 17(1), 17-21. https://doi.org/10.1016/j.hbpd.2018.01.008
14. Kritsak, M. Y., Dzyubanovsky, I. Y., Golovata, T. K., Gargula, T. I., Yasinovskyi, O. B., & Palamar, S. A. (2025). Structural changes in the diaphragm under conditions of obstructive jaundice (an experimental study). Reports of Morphology, 31(1), 22-29. https://doi.org/10.31393/morphology-journal-2025-31(1)-03
15. Kocjan, J., Adamek, M., Gzik-Zroska, B., Czyżewski, D., & Rydel, M. (2017). Network of breathing. Multifunctional role of the diaphragm: a review. Advances in respiratory medicine, 85(4), 224-232. https://doi.org/10.5603/ARM.2017.0037
16. Lessa, T. B., de Abreu, D. K., Bertassoli, B. M., & Ambrósio, C. E. (2016). Diaphragm: A vital respiratory muscle in mammals. Annals of anatomy = Anatomischer Anzeiger: official organ of the Anatomische Gesellschaft, 205, 122-127. https://doi.org/10.1016/j.aanat.2016.03.008
17. Abbey-Mensah, G. N., Waite, S., Reede, D., Hassani, C., & Legasto, A. (2017). Diaphragm Appearance: A Clue to the Diagnosis of Pulmonary and Extrapulmonary Pathology. Current problems in diagnostic radiology, 46(1), 47-62. https://doi.org/10.1067/j.cpradiol.2015.07.010

Резюме

ОСОБЛИВОСТІ СТРУКТУРНОЇ ПЕРЕБУДОВИ АРТЕРІЙ ТА ГЕМОМІКРОЦИРКУЛЯТОРНОГО РУСЛА М'ЯЗОВОЇ ЧАСТИНИ ДІАФРАГМИ ПРИ НАЯВНОСТІ ЖОВТЯНИЦІ

Ігор Я. Дзюбановський[1], Мирослав Ю. Кріцак[1], Юрій М. Гупало[2]

[1]Тернопільський національний медичний університет імені І. Я. Горбачевського Міністерства охорони здоров'я України, м. Тернопіль, Україна

[2]Державна наукова установа «Центр інноваційних технологій охорони здоров'я» Державного управління справами, м. Київ, Україна

Мета. Оцінити зміни морфометричних параметри у м'язовій частині діафрагми на моделі механічна жовтяниця у експериментальних тварин.

Матеріали та методи. Для експерименту було обрано 25 тварин, поділених на дві групи. У групу контролю увійшли 10 абсолютно здорових особин, у дослідну групу увійшли 15 щурів, яким проводили моделювання obstructive jaundice, методом виділення та перев'язки загальної жовчної протоки. На 7-му добу відбирали діафрагму для дослідження. Цифровий матеріал піддавався статистичній обробці на комп'ютері з використанням програмного забезпечення «Excel» (Microsoft, США) та «STATISTICA» 5.5 (Statsoft, США) із застосуванням параметричних методів оцінки даних.

Результати. Встановлено потовщення стінки артерій, звуження їх просвіту. Зонішній діаметр артерій статистично достовірно ($p < 0,05$) збільшувався на 5,72%. При цьому на 5,11% зменшувався внутрішній діаметр. Товщина медії також збільшувалася і становила 12,08 ± 0,44 мкм, що ілюстрували збільшення на 4,72%. Відповідно на 1,8% зростав індекс Вогенворда. Між значеннями відносного об'єму пошкоджених епітеліоцитів в артеріях дрібного калібру поперекової частини контролю та жовтяниці встановлена різниця із високою достовірністю ($p < 0,001$), що становило у 1,91 раза більше у дослідній групі. При вивченні показників мікросудин гемомікроциркуляторного русла виявлено збільшення діаметру артеріол та прекапілярних артеріол. Зміни відбувались і у венозних судинах у вигляді венозного повнокров'я. У контрольній групі щільність капілярного русла реберної частини дорівнювала (3809,78 ± 50,67) у поперековій частині (3818,90 ± 43,29) на 1 мм^2. За умови жовтяниці показник становив (3790,88 ± 35,56) у реберній і (3795,00 ± 57,50) на 1 мм^2 у поперековій частині діафрагми. При цьому різниця між показниками в контрольній і дослідній групі становила 0,5% та 0,67% в сторону їх зменшення у тварин із жовтяницею відповідно у реберній та поперековій частині.

Висновки. Виділення та перев'язка загальної жовчної протоки у дослідних тварин ускладнюється розширенням останньої та розвитком obstructive jaundice. Зміни гемодинаміки при цьому призводять до вираженої структурної перебудови артерій дрібного калібру ребрової та поперекової частини діафрагми, яка характеризується потовщенням їх стінки, звуженням просвіту, зростанням індексу Вогенворта, зниженням пропускної спроможності судин, ураженням ендотеліоцитів, ендотеліальною дисфункцією.

Ключові слова: **механічна жовтяниця, діафрагма, щурі, експеримент, гістологія**

Received: 12.08.2025
Accepted: 15.10.2025