ORIGINAL ARTICLE

THE IMPACT OF CHRONIC HEART FAILURE ON BLOOD FLOW ENERGETICS IN CASE OF POLYTRAUMA

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Svitlana V. Lutska, Kostiantyn G. Mykhnevych, Yulia V. Volkova
KHARKIV NATIONAL MEDICAL UNIVERSITY, KHARKIV, UKRAINE

ABSTRACT

The aim: To study the influence of chronic heart failure of different origin on the energetics of blood circulation in case of polytrauma without myocardial damage.

Materials and methods: 32 patients with polytrauma without myocardial injury were examined that was assessed by the level of Troponin I not exceeding 0.3 ng/ml. The patients were divided into two groups: 1st group (n=15) without chronic heart failure (CHF), and the 2nd one — with CHF. The absence of CHF was proved by the level of NT-proBNP not exceeding 90 pg/ml. Circulatory reserve (CR) was an integral energy index. All measurements were made at the patients' admittance to the hospital, on the 3rd and the 7th day after admittance.

Results: During admittance, CR in the groups was low without a significant difference (in the 1st group – 117±44, in the 2nd group — 99±39 mW/m^2, p = 0.2). CR was increasing in the 1st group quicker than in the 2nd one; on the seventh day it reached 414±128 mW/m^2 growing out of dangerous values, while the 2nd group showed only up to 295±96 mW/m^2 (p = 0.005), which is lower than reference values.

Conclusions: A severer disorder occurs in patients with initial CHF. The treatment requires the improvement of myocardium metabolism. An important prognosis criterium of severity can be represented by the level of circulatory reserve; its value below 100-120 mW/m^2 is a worse outcome predictor.

KEY WORDS: blood flow power, NT-proBNP, circulatory reserve

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INTRODUCTION

Every year, the world witnesses from 8 to 12 million of injuries with lethal outcome, while injury as the reason of death has been occupying the 3rd place in the world for a long time [1]. 70% of injuries causing death are complex, in other words — polytrauma [2]. In recent years, mortality caused by injuries has been increasing; not less than 40,000 people in Ukraine every year die and 250,000 become disabled as the result of an injury [3].

At the same time, the rate of cardiac damage does not tend to decrease. Heart and vascular diseases have been the leading reason of death globally. In Ukraine, in not less than 68% cases, the reason of death is the diseases of blood circulation system present at 52.5% of adults, 37% of cases cover working-age population [4]. Cardiac failure greatly affects the cause of other pathological processes, making the diagnostics more difficult and disrupting reparation processes, which, in its turn, decreases treatment efficiency and can delay it [5].

Under such circumstances, it is natural that the majority of injured patients reveal cardiac medical history. According to different data, coronary heart disease, hypertensive disease, arrhythmia and heart failure are found in 44-62 % of patients in Ukraine. The structure of traffic, manufacturing and home traumatism mainly includes complex injuries; among them, the most severe cases are characterized by multiple system impairments followed by the occurrence of the state of shock, including patients with chronic heart failure (CHF) [5].

In case of polytrauma with chronic cardiac pathology, blood circulation failure is preconditioned by two factors: the decrease of myocardium contractility (MC) and circulating blood volume (CBV). Any blood circulation failure results in the decrease of tissue energy supply, which level defines to a great extent both the course and the outcome of traumatic disease [6].

THE AIM

The objective of the work is a study the influence of chronic heart failure of different origin on the energetics of blood circulation in case of polytrauma without myocardial injury.

MATERIALS AND METHODS

The functional state of blood circulation was studied in 32 patients with polytrauma but without myocardium damage. The absence of traumatic or other acute myocardium injury was revealed at admittance to polytrauma department by the level of TnI which did not exceed 0.3 ng/ml in all patients included into the study. All examined patients were divided into two groups depending on the presence or the absence of CHF proved by the concentration of NT-proBNP of more than 100 pg/ml. The first group included 15 patients with the level of NT-proBNP of not more

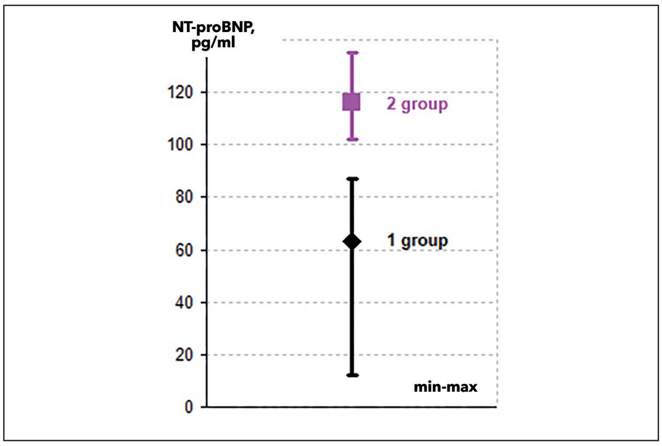

Fig. 1. NT-proBNP borderlines of the patient groups.

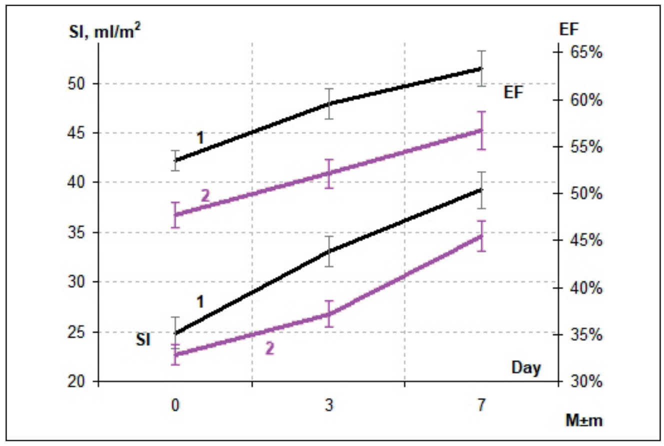

Fig. 2. SI and EF at the stages of the research.

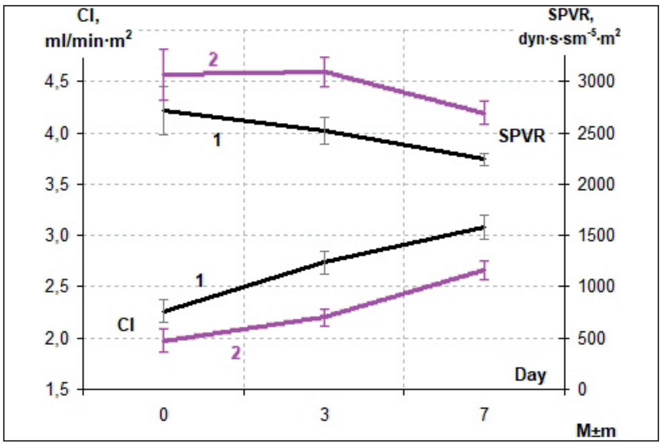

Fig. 3. CI and SPVR at the stages of the research.

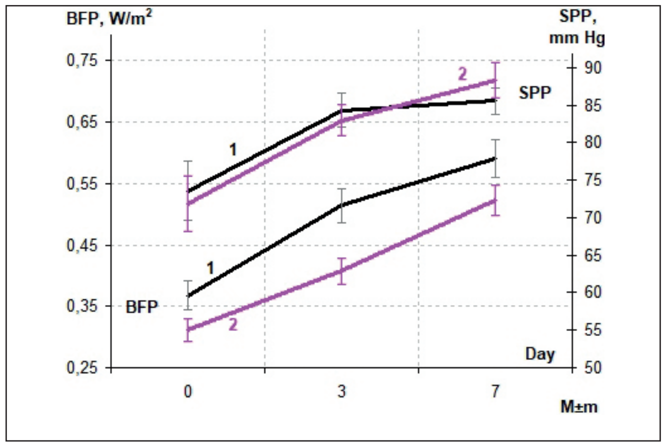

Fig. 4. Energy rate of blood circulation

than 90 pg/ml; the second group covered 17 patients with the NT-proBNP level exceeding 100 pg/ml. The patients whose NT-proBNP concentration ranged between 90 and 100 pg/ml were excluded from the research since this boarder level did not allow to definitely prove or decline the presence of chronic heart failure. The NT-proBNP borderline of two groups of patients is depicted in Fig. 1.

Initial data about the patients of two groups are represented in Table I.

According to the given indices, the patients of two groups did not reveal statistical difference, with exception of NT-proBNP level, which was explained by the principle of distribution into groups.

According to the diagnoses, the patients were divided as follows (Table II):

Besides, all the patients of the 2nd group showed coronary heart disease, cardiosclerosis, chronic heart failure of degree 2-A; 8 patients had hypertensive disease of stage 2.

Circulation was supported by infusion therapy and adrenomimetics if needed; in case of haemoglobin level lower than 90 g/l, concentrated red cells were administered.

Apart from the levels of TnI and NT-proBNP, the patients were examined for the indices of blood circulation system, oxygen budget, and lactate level.

Out of blood circulation indices, we directly measured end-diastolic and end-systolic volumes of the left ventricle with the help of ultrasonic equipment ULTIMA PA using a broadband sensors 3.5/2.7 MHz, S4, S8. Standard projections were used. Diastolic and systolic arterial blood pressure (DBP and SBP) were measured using noninvasive method, central venous pressure (CVP) — using Waldman apparatus through cava-catheter. Cardiac rate (CR) was also determined.

The apparatus ABL800 Flex Series 835 («Radiometer», Denmark) was used to measure the indices of oxygen budget: the saturation of haemoglobin of arterial and venous blood (S_{aO_2} and S_{vO_2}) with oxygen, oxygen pressure in arterial and venous blood (p_{aO_2} and p_{vO_2}). A routine method was used to examine the concentration of haemoglobin, heamatocrit, and lactate level.

Total body surface area was defined according to DuBois formula [7].

On the basis of the obtained results, we calculated the following indices:

1) kinetic blood circulation indices — stroke index and cardiac index (SI and CI), left ventricular ejection fraction (EF);

2) dynamic blood circulation indices — systemic perfusion pressure (SPP) as the difference between effective

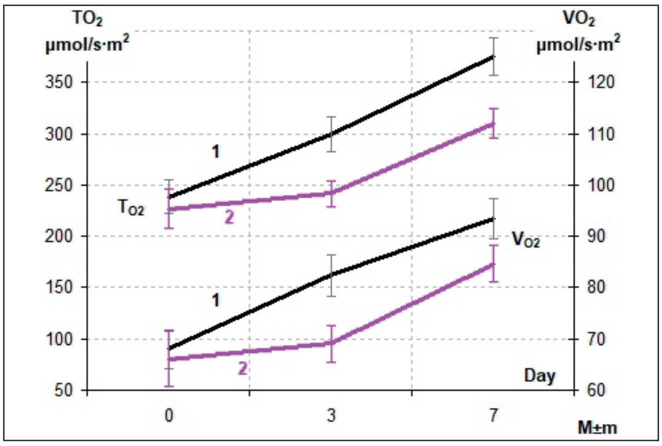

Fig. 5. Oxygen budget indices

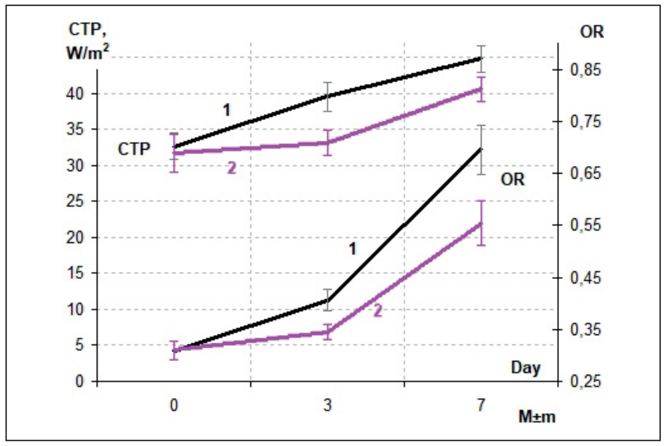

Fig. 6. Tissue energy consumption

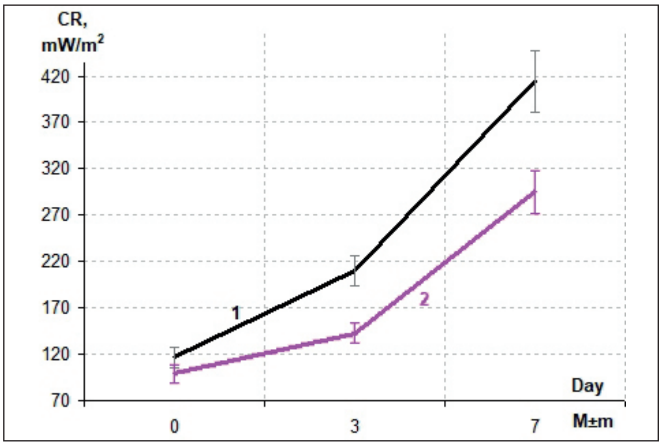

Fig. 7. Circulatory reserve depending on treatment day

arterial pressure and CVP, specific periphery vascular resistance (SPVR) [8];

3) energy rate of blood circulation — blood flow power (BFP);

4) oxygen budget indices — the content of oxygen in arterial and venous blood (C_{aO_2} and C_{vO_2}), arterial venous difference of oxygen content ($C_{(a\text{-}v)O_2}$), transport, consumption volume, and coefficient of oxygen extraction (T_{O_2}, V_{O_2} and E_{O_2});

5) energy budget of tissues — consuming tissue power (CTP), oxygen reserve (OR);

6) integral energy index — circulatory reserve (CR) [9].

All measurements were made at the time of the patients' admittance to the hospital, and on the 3rd and the 7th day after admittance.

The reliability of the differences was assessed using the Student's criterion, the differences were considered reliable at $p < 0.05$. The relationship between the indicators was assessed using the Pearson correlation coefficient. The relationship was considered significant at $r > 0.5$.

RESULTS

None of the admitted patients showed the TnI level higher than 0.29 ng/ml; it was the basis to exclude the possibility of traumatic or other acute myocardium damages. At the same time, the level of NT-proBNP ranged within wide limits.

Energy rate of blood circulation depended on kinetic and dynamic parameters. SI did not have any statistically relevant difference in the groups at admittance (24.9±6,0 and 22.7±4.3 ml/m^2 in the 1st и 2nd group respectively, p = 0.25), whereas EF differed greatly (respectively 53.5±4,3 and 47.7±5.4 %, p = 0.002, henceforward M±σ).

Further stages of the research proved the differences in the levels of SI and EF to be substantial and valid (Fig. 2). In the 1st group, SI level rose to 39.2±7.0 ml/m^2, EF increased to 63.3±7.3 %; in the 2nd group — to 34.6±6.3 ml/m^2 (p = 0.058) and 56.7±8.3 % (p = 0.02) respectively.

We did not notice relevant differences in SPVR at the admittance of the patients (for the 1st group — 2711±913, for the 2nd one — 3072±1009 dyn·s·sm^{-5}·m^2, p = 0.3); however, later the difference became obvious, moreover, on the 3rd day of the study, SPVR in the 2nd group hardly changed (3096±590 dyn·s·sm^{-5}·m^2), and the 1st group tended to show an inconsistent decrease (2520±485 dyn·s·sm^{-5}·m^2). By the seventh day, SPVR decreased accurately in both groups, although it remained relevantly higher in the 2nd group rather than in the 1st one (2696±437 vs. 2245±226 dyn·s·sm^{-5}·m^2, p = 0.001).

CI of the 1st group at admittance was as much as 2.26±0.42, and that of the 2nd group — 1.98±0,46 l/min·m^2, p = 0.08. Thereafter, during the whole study, CI of the 1st group of patients was relevantly higher than that of the second group; by the end of the research, it reached 3.08±0.45 and 2.66±0.38 l/min·m^2, p = 0.007 respectively (Fig. 3).

SPP index did not make a valid difference in both groups during the study. BFP in the first group was higher at admittance compared to the 2nd group: 368±91 and 311±75 mW/m^2, p = 0.05. On the 3rd day of the study, this index increased to 514±106 and 408±87 mW/m^2, p = 0.002 respectively. At the end of the study, BFP of the 1st group of patients reached 591±118 and that of the 2nd group – 523±102 mW/m^2, p = 0.09 (Fig. 4).

Oxygen budget indices at the admittance of the patients of the two groups did not show any significant difference

Table I. Distribution of patients into groups

Group	Age, years (M±σ)	Total body surface area, m^2 (M±σ)	TnI, ng/ml (M±σ)	NT-proBNP, pg/ml (M±σ)
1	56.4±12.0	2.06±0.21	0.17±0.08	63.3±19.6
2	60.2±11.7	2.10±0.19	0.21±0.06	116.4±8.2
p	0.4	0.6	0.2	$2.6 \cdot 10^{-11}$

Table II. Distribution of patients according to diagnoses

Group	First-listed diagnosis	n (%)
1	Closed chest injury and skeletal injury	4 (26.7±11.4)
	Closed brain and skeletal injury	4 (26.7±11.4)
	Closed brain and thoracal injury, skeletal injury	4 (26.7±11.4)
	Skeletal complex injury	3 (20.0±10.3)
2	Closed thoracal injury and skeletal injury	5 (29.4±11.1)
	Closed brain and skeletal injury	4 (23.5±10.3)
	Closed brain and thoracal injury, skeletal injury	4 (23.5±10.3)
	Skeletal complex injury	4 (23.5±10.3)

Table III. Correlation of NT-proBNP level with kinetic indices of blood circulation at admittance (r±m)

Index	1 group	2 group
EDI	–0.20±0.25	–0.29±0.22
SVI	–0.16±0.25	–0.50±0.18
EF	0.02±0.26	–0.43±0.20

(Fig. 5). Oxygen transport (T_{O_2}) in the 1st and 2nd group was 238.6±65.3 and 226.9±7.8 μmol/s·m², p = 0.7 respectively; oxygen consumption volume (V_{O_2}) — 68.0±14.9 and 66.1±22.5 μmol/s·m², p = 0.8 respectively. Thereafter, these indices were growing quicker in the 1st group. On the 3rd day, in the 1st and the 2nd group T_{O_2} was as much as 299.1±64.6 and 241.6±51.8 μmol/s·m², p = 0,009; V_{O_2} — 82.4±15.6 and 69.1±14.6 μmol/s·m², p = 0.02 respectively. By the end of the study, T_{O_2} of the first group was considerably higher than in the second one (374.8±70.5 и 310.1±59.8 μmol/s·m², p = 0.009; as for V_{O_2}, the differences between the groups disappeared (93.4±15.1 and 84.7±14.5 μmol/s·m², p = 0.1).

The dynamics of the studied indices described above defined the consuming tissue power (CTP). It was initially equal in both groups: 32.6±7.2 and 31.7±10.8 W/m² in the first and the second group respectively, p = 0.8 (Fig. 6). At the second stage of the study, CTP in the first group increased more considerably than in the second one: 39.5±7.5 and 33.1±7.0 W/m², p = 0.02. At the end of the study the difference disappeared again, CTP of the 1st and 2nd group reached 44.8±7.2 and 40.6±7.0 W/m², p = 0.1 respectively.

The adequacy of energy support of tissues was estimated according to oxygen reserve (OR). It was initially equally low in both groups (0.31±0.07 и 0.31±0.08); yet, it was rising quicker in the 1st group and reached the level of 0.70±0.18, whereas, for the 2nd group it was equal to 0.55±0.17 (p = 0.03).

A summarizing estimation of the adequacy of blood flow function was conducted with the help of the calculations of circulatory reserve (CR). It was initially at a dangerous level: in the 1st group 117±44, in the 2nd group — 99±39 mW/m², p = 0.2 (Fig. 7). On the third day, CR considerably increased in both groups, however, to a greater extend for the first group: 210±64 and 143±44 mW/m², p = 0.001. At the end of the study, this difference remained, in the 1st group CR rose to 414±128 mW/m² exceeding dangerous values, and in the 2nd group — only to 295±96 mW/m² (p = 0.005), which is also a not dangerous level, though it still remains lower than reference values.

Out of the patients included into the study, one patient from the first group died, and two patients — from the second one. Lethal outcomes occurred after the end of the study. A died patient of the first group had an initial CR level of 42 mW/m², by the end of the study it increased to 117 mW/m². One died patient from the 2nd group had an extremely low CR at admittance (26 mW/m^2), by the 7th day we managed to increase it to 49 mW/m^2; another died patient was admitted with CR of 121 mW/m2, by the 7th day it decreased to 77 mW/m^2. All died patients had chest injuries with haemothorax.

DISCUSSION

The indices of the body energy supply are greatly influenced by different kinetic and dynamic indices of blood flow, moreover, of different degree [6]. So, at admittance, SI did not reveal a statistical difference between the groups, whereas EF of the examined groups was initially different (Fig. 2). These results are associated with the fact that EF, as opposed to SI, is a nonlinear index, i.e., in case of the same SI, EF can appear different [9]. The obtained results testify to the fact that EF is an index reflecting myocardial contractility (MC). Besides, while the difference in end-diastolic index (EDI) between the groups was rather indefinite ($p = 0.7$), end-systolic index (ESI) was relevantly lower in the second group ($p = 0.04$). It was the linearity of SI that caused the absence of a valid difference in this index between the groups, while EF being a nonlinear index was considerably different in the groups. Another matter of concern is the power of correlation relationship of NT-proBNP concentrations with EDI, SVI, and EF (Table III). Moreover, it should be taken into account that because of hypovolemia developing as the result of complex injury, myocardium preload became lower than usual for a given patient.

The dependence of kinetic indices of blood circulation on NT-proBNP level in the 1st group was not noticed; in the 2nd group, the relationship was of a moderate force. It can be supposed that, this relationship was more apparent before hypovolemia development.

Vasoconstrictive response is the first natural reaction to circulatory hypoxia that can be of different origin [9]. The first group revealed only abrupt hypovolemic insufficiency. In the second group, acute hypovolemia appeared on the background of a previously existed CHF, that is why vasoconstrictive response of the patients of this group was more apparent, which was reflected on the value of SPVR.

Myocardium of the patients without existing cardiac pathology (1 group) had greater energy reserves and could overcome an increased vascular resistance to a greater extent, which was proved by the levels of CI (Fig. 3).

In order to overcome an increased total peripheral vascular resistance (TPVR), myocardium should supply a greater force of contractions, i.e., create higher SPP; however, in the patients of the second group, myocardium did not possess enough energy reserve to do it. Besides, it should be taken into account that SPP is energy necessary to transfer a unit volume of blood [10]. SPP during the whole study did not differ significantly in both groups, i.e., myocardium of the patients of both groups spent an equal amount of energy to transfer a unit volume of blood, but myocardium of the patients of the first group was quicker and more powerful (Fig. 4).

Since oxygen content in arterial blood did not differ, the dynamics of oxygen transport repeated CI dynamics; yet, oxygen consumption in the patients with a background CHF practically came up with the level of the 1st group by the end of the study. It presupposes the presence of some mechanisms contributing to oxygen consumption at a certain range of its transport.

The rate of oxygen consumption defines CTP which dynamics naturally matches the dynamics of oxygen consumption; however, the matter of concern is if CTP is sufficient for tissue demand. To solve this problem, OR is defined [9]. When CTP was practically the same in the two groups on the seventh day after admittance, OR in the 2nd group was considerably lower; it implies a greater energy demand of tissues of these patients. The reason of this phenomenon has not been revealed in this study.

Energy budget of a body depends on a great number of factors and their balance, which makes it more difficult to estimate their influence on energy exchange; yet, the total efficiency of the circulatory element of oxygen transport system can be estimated with the help of CR [6]. At the time of admittance, the patients' CR was at a low level, but while its reason in the patients of the 1st group was acute hypovolemia only, in the second group, acute hypovolemia was superimposed on a background CHF; that is why the recovery of circulating blood volume and the increase of blood oxygen capacity in the patients of this group did not lead to the same quick increase of CR as it was in the patients of the first group.

It should be noted that CR of all died patients was at a very low level at admittance (26.42 and 121 mW/m^2) and it did not increase by the end of the study. Low CR may be accompanied by irreversible changes in tissues as well as in the microcirculatory bloodstream.

CONCLUSIONS

1. Background CHF makes the course of acute hypovolemic failure associated with complex injuries not involving myocardium more severe.
2. A more severe course of polytrauma in patients with a background CHF is preconditioned by a decreased energy reserves of myocardium, i.e., its inconsistence to quickly transfer chemical energy of oxidation substrates to mechanical energy of contractions.
3. The treatment of patients with polytrauma in case of chronic heart failure requires the improvement of myocardium metabolism.
4. An important prognosis criterium of severity of the course of acute hypovolemic insufficiency can be represented by the level of circulatory reserve; its value below 100-120 mW/m^2 is a worse outcome predictor.

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ORCID and contributionship:
Svitlana V. Lutska: 0000-0002-0633-9801[A-E]
Kostiantyn G. Mykhnevych: 0000-0002-6135-7121 [F]
Yuliya V. Volkova: 0000-0001-8000-5802[F]

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CORRESPONDING AUTHOR
Svitlana V. Lutska
Kharkiv National Medical University
4 Nauki Avenu, 61000 Kharkiv, Ukraine
tel: +380673065985
e-mail: s.lutska@knmu.edu.ua

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