VO_2 v perioperační přípravě … čas na změnu paradigmatu?

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ARK

Fakultní nemocnice u sv. Anny v Brně

Konflikt zájmů

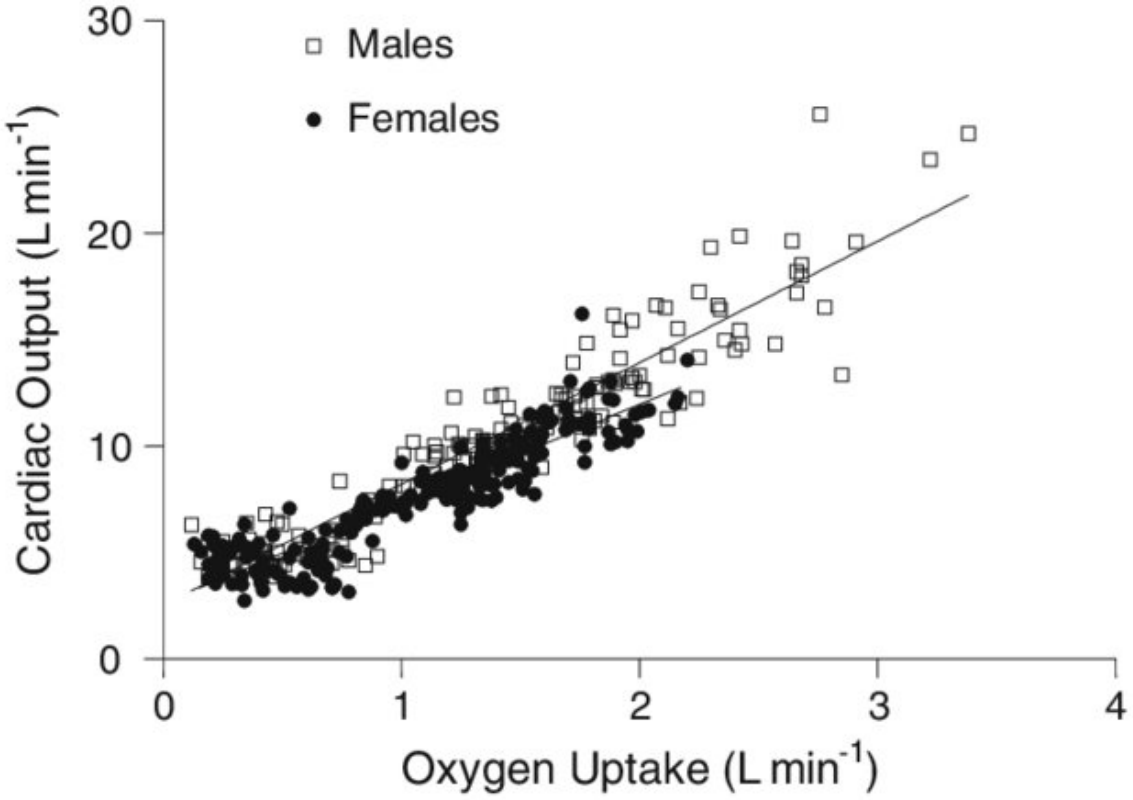
- Žádný

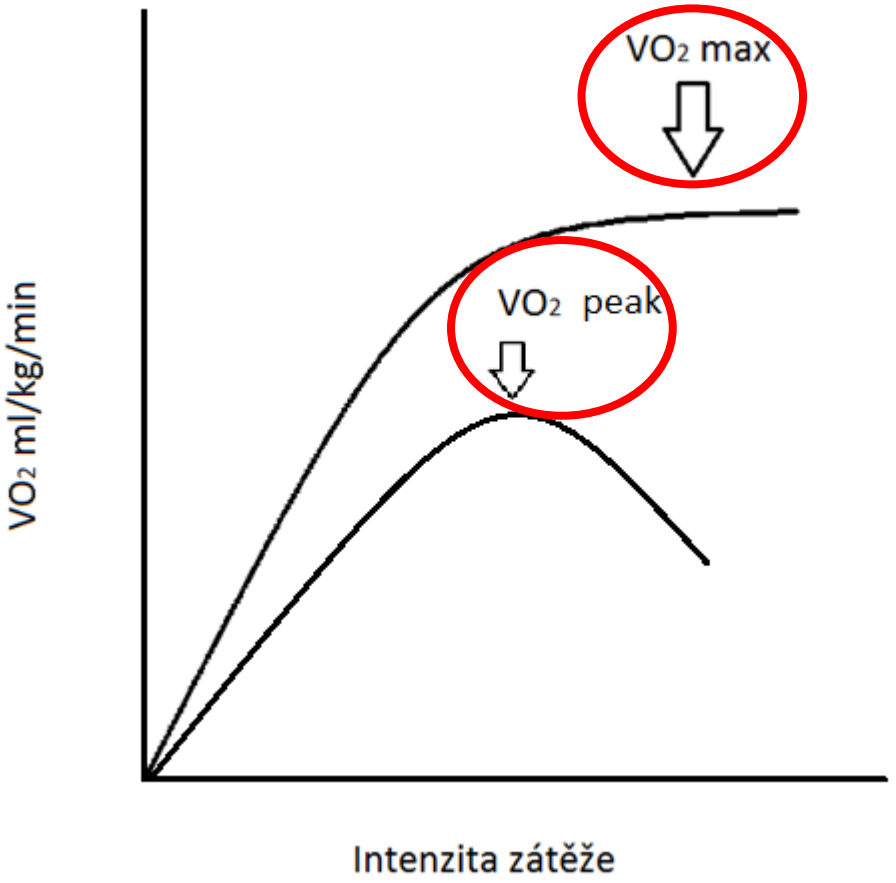
Spiroergometrie

- Dynamické, neinvazivní vyšetření
- Komplexní zhodnocení
  1. kardiovaskulárního
  2. plicního systému
- Schopnost vyrovnat se s metabolickými požadavky během zátěže (fyzické, trauma, chirurgie)
- VO_2, AT, V_E/VCO_2…

1. Konsumpce kyslíku - VO_2

$VO_2 = CO \times avO_2diff$

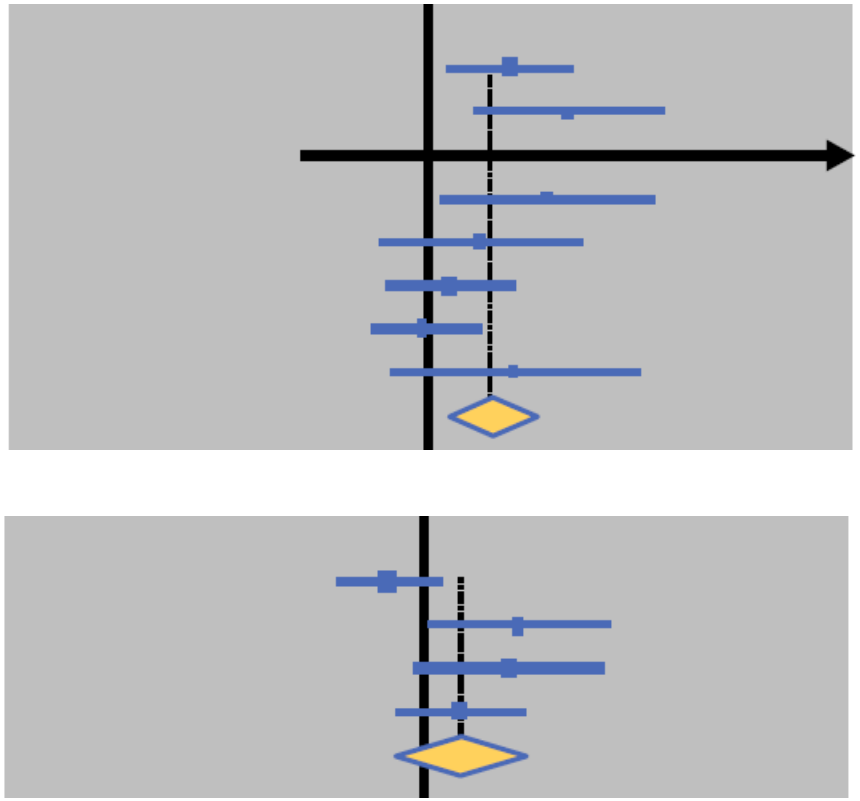




Paulo T. V. Farinatti; Eur J Appl Physiol; 2009

Peak VO_2 perioperačně

Author, year	Type of cancer	Mean difference (95%CI)	Weight (%)
No pulmonary complication vs Pulmonary complication			
Bayram, 2007	Lung	1.90 (0.41 to 3.39)	18.77
Bobbio, 2009	Lung	3.30 (1.03 to 5.57)	11.96
Brat, 2016	Lung	7.20 (-2.86 to 17.26)	0.92
Brunelli, 2009	Lung	2.80 (0.24 to 5.36)	10.19
Licker, 2011	Lung	1.20 (-1.23 to 3.63)	10.91
Brunelli, 2012	Lung	0.50 (-1.06 to 2.08)	17.99
Han, 2007	Lung	-0.10 (-1.39 to 1.19)	21.00
Morice, 1992	Lung	2.00 (-0.96 to 4.98)	8.25
Pooled effect (I^2=0%)		1.47 (0.49 to 2.45)	
No cardiopulmonary complication vs Cardiopulmonary complication			
Forshaw, 2008	Esophageal	-0.90 (-2.15 to 0.35)	30.65
Lam, 2019	Esophageal	2.20 (-0.01 to 4.41)	21.22
Moyes, 2013	Mixed	2.00 (-0.28 to 4.28)	20.62
Redrigues, 2016	Lung	0.85 (-0.71 to 2.41)	27.51
Pooled effect (I^2=0%)		0.84 (-0.63 to 2.35)	



Steffens et al.; Ann Surg Oncol (2021) 28:7120–7146

Peak VO_2 - Mortalita

Bayram 2007	Lung (55)	Peak VO_2 >15 (mL/Kg/min)	Peak VO_2 <15 (mL/Kg/min)	No mortality (30 days)	Mortality (30 days)	0.20 (0.01–5.7)	
Junejo 2014	Pancreatic (64)	Peak VO2 (mL/Kg/min)		No mortality (30 days)	Mortality (30 days)	1.03 (0.77–1.37)	
Junejo 2014	Pancreatic (64)	Peak VO_2 (mL/Kg/min)		No mortality (in–hospital)	Mortality (in–hospital)	1.32 (0.91–1.93)	
Begum 2016	Lung (1684)	Peak VO_2 >15 (mL/Kg/min)	Peak VO_2 <15 (mL/Kg/min)	No mortality (30 days)	Mortality (30 days)	0.60 (0.35–0.93)	

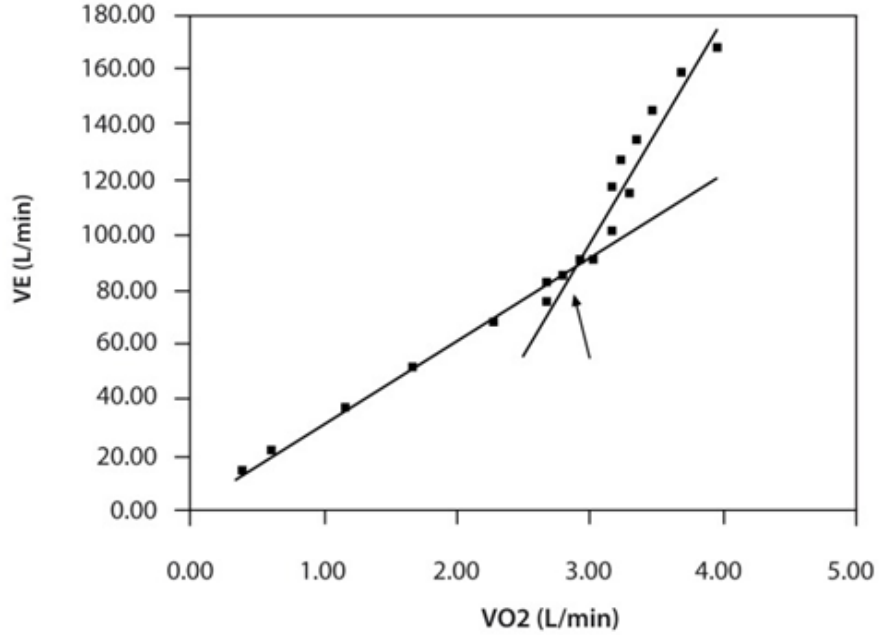
- Dobrý pro sportovce, ale méně pro naše nemocné
- Často nedosáhnout VO_2 max (nechtějí, nemohou) – záleží na vůli (motivaci)

- Snaha nalézt jiný vhodnější – submaximální

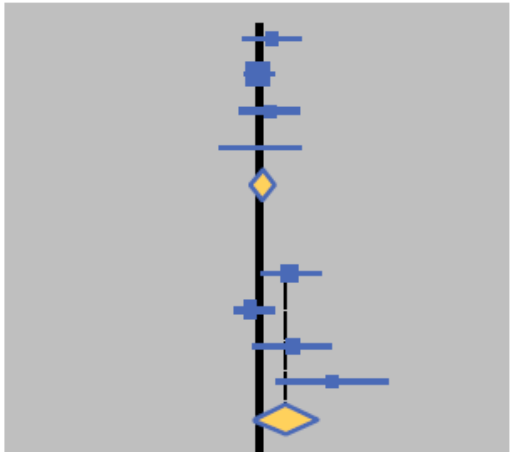
Steffens et al.; Ann Surg Oncol (2021) 28:7120–7146

2. Anaerobní práh

- Submaximální varianta VO_2
- Nezáleží na vůli, délce cvičení



Author, year	Type of cancer	Mean difference (95%CI)	Weight (%)
No complication vs Complication			
Brunelli, 2009	Lung	0.50 (-0.69 to 1.69)	15.46
Lam, 2019	Esophageal	0.00 (-0.60 to 0.60)	60.50
Yakal, 2018	Lung	0.43 (-0.74 to 1.60)	15.96
Prentis, 2013	Bladder	0.04 (-1.61 to 1.69)	8.08
Pooled effect (I^2=0%)		0.15 (-0.32 to 0.62)	
No cardiopulmonary complication vs Cardiopulmonary complication			
Forshaw, 2008	Esophageal	1.20 (-0.07 to 2.47)	27.01
Lam, 2019	Esophageal	-0.20 (-1.00 to 0.60)	32.87
Moyes, 2013	Mixed	1.30 (-0.28 to 2.88)	23.25
Nikolopoulos, 2015	Colorectal	2.89 (0.68 to 5.10)	16.88
Pooled effect (I^2=0%)		1.05 (-0.17 to 2.26)	

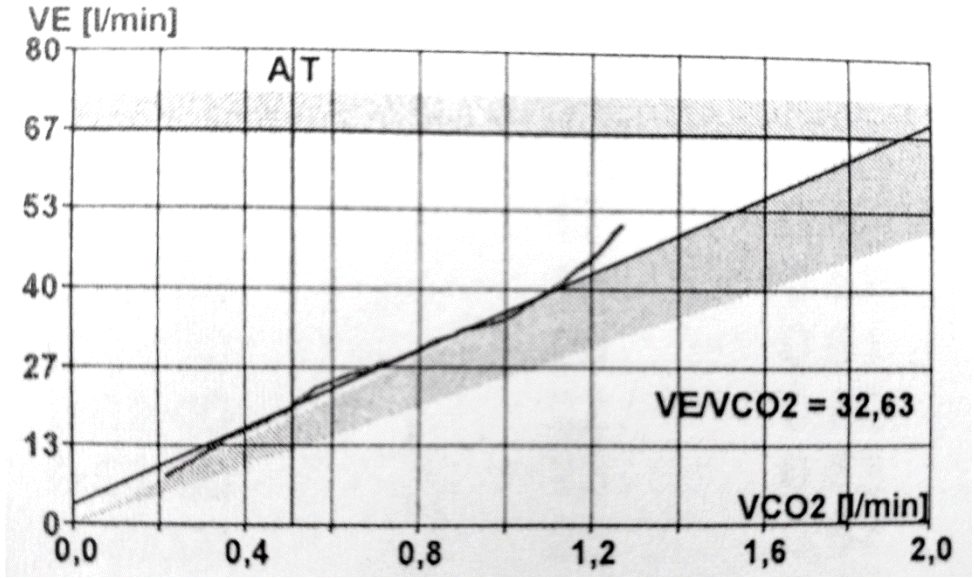


Steffens et al.; Ann Surg Oncol (2021) 28:7120–7146

Ghosh AK; The Malaysian Journal of Medical Sciences : MJMS, 01 Jan 2004, 11(1):24-36

3. Ventilační efektivita

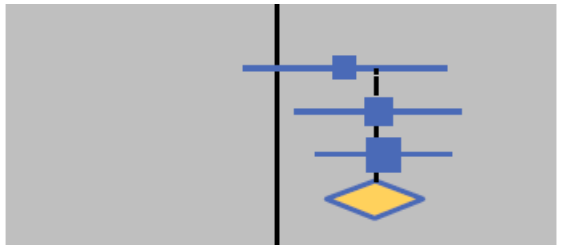
$$V_E/VCO_2 = \frac{863}{PaCO_2 - (1 - V_D/V_T)}$$



- Submaximální parametr
- Nekoreluje s VO_2
- Excelentní u pacientů s chronických srdečním selháním – lepší prognostická hodnota než VO_2 (Arena et al, 2004)

V_E/VCO_2 slope perioperačně

Junejo 2014	Pancreas (64)	V_E/V_{CO2}		No mortality (in–hospital)	Mortality (in–hospital)	0.79 (0.66–0.95)
Wilson 2010	Mixed (847)	V_E/V_{CO2} <34	V_E/V_{CO2} ≥34	No mortality (in–hospital)	Mortality (in–hospital)	0.20 (0.06–0.74)
Junejo 2014	Pancreas (64)	V_E/V_{CO2}		No mortality (30 days)	Mortality (30 days)	0.74 (0.56–0.97)
Mann 2020	Colorectal (1193)	V_E/V_{CO2} ≤34	V_E/V_{CO2} >34	No mortality (30 days)	Mortality (30 days)	0.30 (0.12–0.68)
Miyazaki 2018	Lung (172)	V_E/V_{CO2} <40	V_E/V_{CO2} >40	No mortality (90 days)	Mortality (90 days)	0.30 (0.09–0.86)



No pulmonary complication vs Pulmonary complication			
Bobbio, 2009	Lung	2.50 (-1.20 to 6.20)	21.47
Brat, 2016	Lung	3.70 (0.67 to 6.73)	31.98
Brunelli, 2012	Lung	3.90 (1.39 to 6.41)	46.51
Pooled effect (I^2=0%)		3.54 (1.82 to 5.25)	

Steffens et al.; Ann Surg Oncol (2021) 28:7120–7146

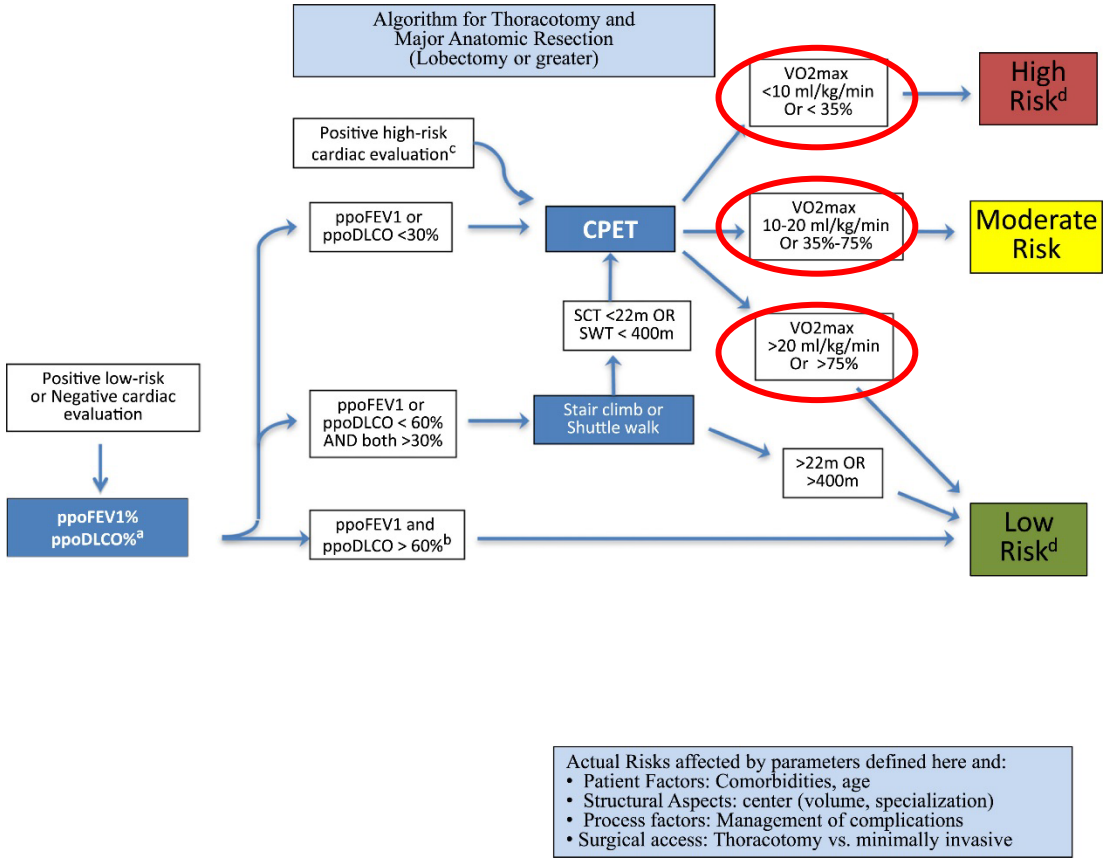
Jak je tomu v klinické praxi?

- Který parametr se používá nejčastěji?
- V jaké indikaci?

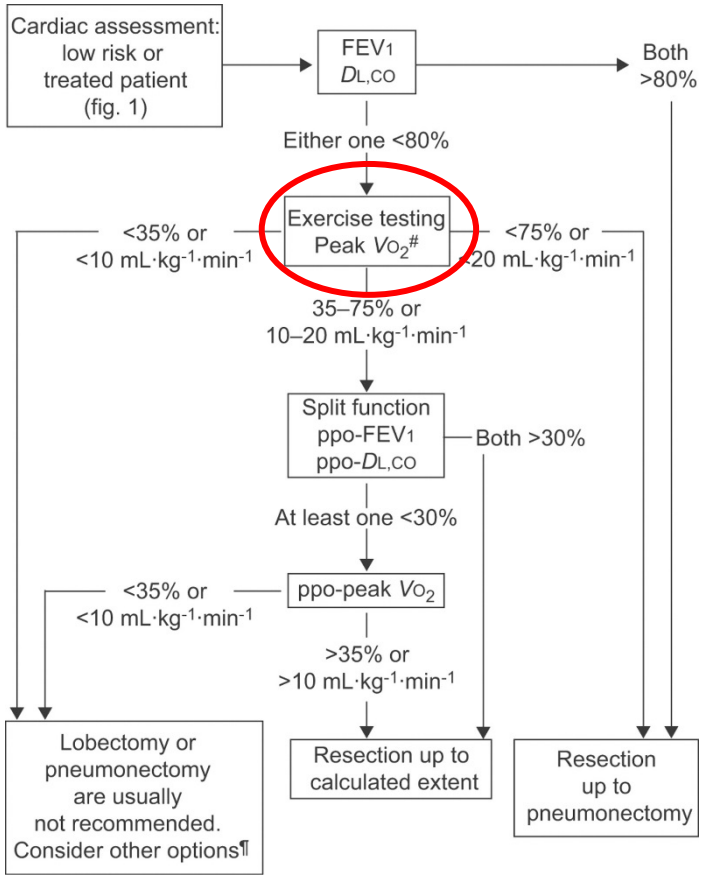
- Nejčastější indikace z pohledu anesteziologa je stanovení rizika u pacientů v hrudní chirurgii před plicní resekcí …

Hrudní chirurgie

ACCP 2013



ERS/ESTS 2009



2010 … se objevuje V_E/VCO_2 slope

Eur J Cardiothorac Surg. 2010 Jul;38(1):14-9. doi: 10.1016/j.ejcts.2010.01.032. Epub 2010 Mar 30.

Exercise ventilatory inefficiency and mortality in patients with chronic obstructive pulmonary disease undergoing surgery for non-small-cell lung cancer

Roberto Torchio [1], Marco Guglielmo, Roberto Giardino, Francesco Ardissone, Claudio Ciacco, Carlo Gulotta, Aleksandar Veljkovic, Massimiliano Bugiani

Considering all functional parameters before surgery and the postoperative predicted values, a logistic regression analysis individuated the V'(E)/V'(CO2) slope as the only independent mortality predictor (odds ratio (OR): 1.24 z=2.77; p<0.007). The V'(O2 peak) was instead the best predictor for the occurrence of severe cardiopulmonary postoperative complications (OR: 0.05, z=-2.39, p<0.02).

Jako houby po dešti

› Ann Thorac Surg. 2012 Jun;93(6):1802-6. doi: 10.1016/j.athoracsur.2012.03.022. Epub 2012 May 4.

Minute ventilation-to-carbon dioxide output (VE/VCO2) slope is the strongest predictor of respiratory complications and death after pulmonary resection

Alessandro Brunelli [1], Romualdo Belardinelli, Cecilia Pompili, Francesco Xiumé, Majed Refai, Michele Salati, Armando Sabbatini

Observational Study › Eur J Cardiothorac Surg. 2016 Oct;50(4):772-779. doi: 10.1093/ejcts/ezw104. Epub 2016 Apr 7.

Conclusions: VE/VCO2 slope is a better predictor of respiratory complications than peak VO2. This inexpensive and operator-independent variable should be considered in the clinical practice to refine operability selection criteria.

Risk of postoperative complications in chronic obstructive lung diseases patients considered fit for lung cancer surgery: beyond oxygen consumption

Hanaa Shafiek [1 2], Jose Luis Valera [1 3], Bernat Togores [1 3], Juan Antonio Torrecilla [4], Jaume Sauleda [1 3], Borja G Cosío [5 3]

› Eur J Cardiothorac Surg. 2016 Apr;49(4):1054-8; discussion 1058. doi: 10.1093/ejcts/ezv378. Epub 2015 Nov 24.

Conclusions: VO_2 is not the unique parameter to consider when CPET is performed to evaluate the postoperative risk of lung cancer surgery in COPD patients. The signs of ventilatory inefficiency such as VE/VCO_2 slope predict complications better than VO_2 does.

Outcome after video-assisted thoracoscopic surgery and open pulmonary lobectomy in patients with low VO2 max: a case-matched analysis from the ESTS database†

Shah Sheikh Sofina Begum [1], Kostas Papagiannopoulos [1], Pierre Emmanuel Falcoz [2], Herbert Decaluwe [3], Michele Salati [4], Alessandro Brunelli [5]

Conclusions: Low VO2 max was not associated with an increased surgical risk after VAT lobectomy, which challenges the traditional operability criteria when this technique is used.

Pacienti s vysokým rizikem

Multicenter Study > Ann Thorac Surg. 2016 Nov;102(5):1725-1730.
doi: 10.1016/j.athoracsur.2016.05.070. Epub 2016 Aug 3.

Resting End-Tidal Carbon Dioxide Predicts Respiratory Complications in Patients Undergoing Thoracic Surgical Procedures

Kristian Brat [1], Zuzana Tothova [2], Zdenek Merta [1], Alice Taskova [3], Pavel Homolka [4], Martina Vasakova [2], Jana Skrickova [1], Vladimir Sramek [5], Lyle J Olson [6], Ivan Cundrle Jr [7]

Table 3. Respiratory Complications: Ventilation at Rest and During Exercise

Variable	Yes (n = 56) Mean ± SD	No (n = 20) Mean ± SD	*p* Value
Resting ventilation and gas exchange			
$\dot{V}O_2$ (mL/kg/min)	5.1 ± 1.6	5.7 ± 1.1	0.14
O_2 pulse (mL/beat)	4.3 ± 1.5	5.1 ± 1.5	0.03
$\dot{V}_E$ (L/min)	14.5 ± 4.7	15.2 ± 4.1	0.56
V_T (L)	0.8 ± 0.3	0.9 ± 0.3	0.03
$P_{ET}CO_2$ (mm Hg)	28.1 ± 4.3	31.5 ± 4.2	<0.01
$\dot{V}_E/\dot{V}CO_2$ ratio	45.1 ± 7.1	41.0 ± 6.4	0.02
Peak exercise ventilation and gas exchange			
$\dot{V}O_2$ (mL/kg/min)	16.2 ± 5.1	17.4 ± 3.6	0.15
RER	1.1 ± 0.1	1.1 ± 0.1	0.64
O_2 pulse (mL/beat)	9.6 ± 2.9	10.7 ± 3.0	0.12
$\dot{V}_E$ (L/min)	50 ± 14	50.6 ± 12.4	0.86
V_T (L)	1.9 ± 2.6	2.6 ± 4.2	0.18
$P_{ET}CO_2$ (mm Hg)	31.6 ± 4.8	34.1 ± 4.2	0.04
$\dot{V}_E/\dot{V}CO_2$ ratio	38.8 ± 6.4	35.4 ± 6.1	0.04
$\dot{V}_E/\dot{V}CO_2$ slope	34.9 ± 6.4	31.2 ± 4.3	0.01

Dosud největší kohorta

› Ann Thorac Surg. 2022 Jan 21;S0003-4975(22)00060-1. doi: 10.1016/j.athoracsur.2021.11.073. Online ahead of print.

Prediction of Postoperative Complications: Ventilatory Efficiency and Rest End-tidal Carbon Dioxide

Kristian Brat [1], Pavel Homolka [2], Zdenek Merta [3], Milos Chobola [4], Michaela Heroutova [5], Monika Bratova [3], Ladislav Mitas [6], Zdenek Chovanec [7], Teodor Horvath [6], Michal Benej [8], Jaroslav Ivicic [6], Michal Svoboda [9], Vladimir Sramek [4], Lyle J Olson [10], Ivan Cundrle Jr [11]

TABLE 3 Cardiopulmonary Exercise Testing

Parameter	Without PPC (n = 294)	With PPC (n = 59)	P Value
Rest Ventilation and Gas Exchange			
VO_2, mL/kg/min	4.2 (3.4-4.9)	3.9 (3.2-4.6)	.08
VCO_2, mL/min	249 ± 94	230 ± 98	.16
V_T, mL	570 (410-730)	510 (320-680)	.11
f_b, bpm	18 (15-21)	20 (17-22)	.01
V_E, L/min	10 ± 4	10 ± 4	.97
V_D/V_T	0.29 (0.24-0.34)	0.31 (0.23-0.34)	.56
$P_{ET}CO_2$, mm Hg	29 (26-32)	27 (24-30)	<.01
V_E/VCO_2 ratio	40 (36-44)	43 (40-48)	<.01
Peak Exercise Ventilation and Gas Exchange			
VO_2, mL/kg/min	19.8 (16.5-24.5)	16.9 (14.8-22.1)	.01
VCO_2, mL/min	1655 (1270-2050)	1510 (1140-1800)	.04
RER	1.03 (0.91-1.13)	0.98 (0.86-1.08)	.02
V_T, mL	1750 (1350-2120)	1580 (1180-2020)	.16
f_b, bpm	32 (28-37)	34 (31-39)	.01
V_E, L/min	54 (43-68)	56 (44-70)	.85
V_D/V_T	0.21 ± 0.07	0.23 ± 0.06	.04
$P_{ET}CO_2$, mm Hg	35 ± 6	32 ± 5	<.01
V_E/VCO_2 ratio	33 (30-37)	38 (33-43)	<.01
V_E/VCO_2 slope	29 (25-33)	35 (30-40)	<.01

Ale …

TABLE 4 Logistic Regressions - Pulmonary Complications

	Univariate		Multivariate Stepwise			
			1st Model		2nd Model	
	OR (95% CI)	P	OR (95% CI)	P	OR (95% CI)	P
Male	1.88 (1.03-3.43)	.04			2.05 (1.05-4.02)	.04
Age	1.03 (1.01-1.06)	.02	1.04 (1.00-1.07)	.05		
S-MPM score	1.57 (1.21-2.06)	<.01				
Thoracotomy	3.71 (1.89-7.28)	<.01	3.31 (1.61-6.82)	<.01	3.09 (1.51-6.30)	<.01
Lobectomy	3.46 (1.84-6.48)	<.01	3.30 (1.64-6.63)	<.01	3.42 (1.70-6.87)	<.01
FEV_1	0.97 (0.96-0.99)	<.01	0.98 (0.96-0.99)	.01		
DL_{CO}	0.98 (0.97-1.00)	.01				
Rest $P_{ET}CO_2$	0.86 (0.80-0.92)	<.01	0.90 (0.83-0.97)	.01	not included	
Peak VO_2	0.94 (0.89-0.98)	.01				
V_E/VCO_2 slope	1.11 (1.07-1.16)	<.01	not included		1.10 (1.05-1.16)	<.01

CI, confidence interval; DL_{CO}, diffusing lung capacity for carbon monoxide; FEV_1, forced expiratory volume in one second; OR, odds ratio; $P_{ET}CO_2$, partial pressure of end-tidal carbon dioxide; S-MPM, Surgical Mortality Probability Model; V_E/VCO_2, ventilatory efficiency; VO_2, oxygen consumption.

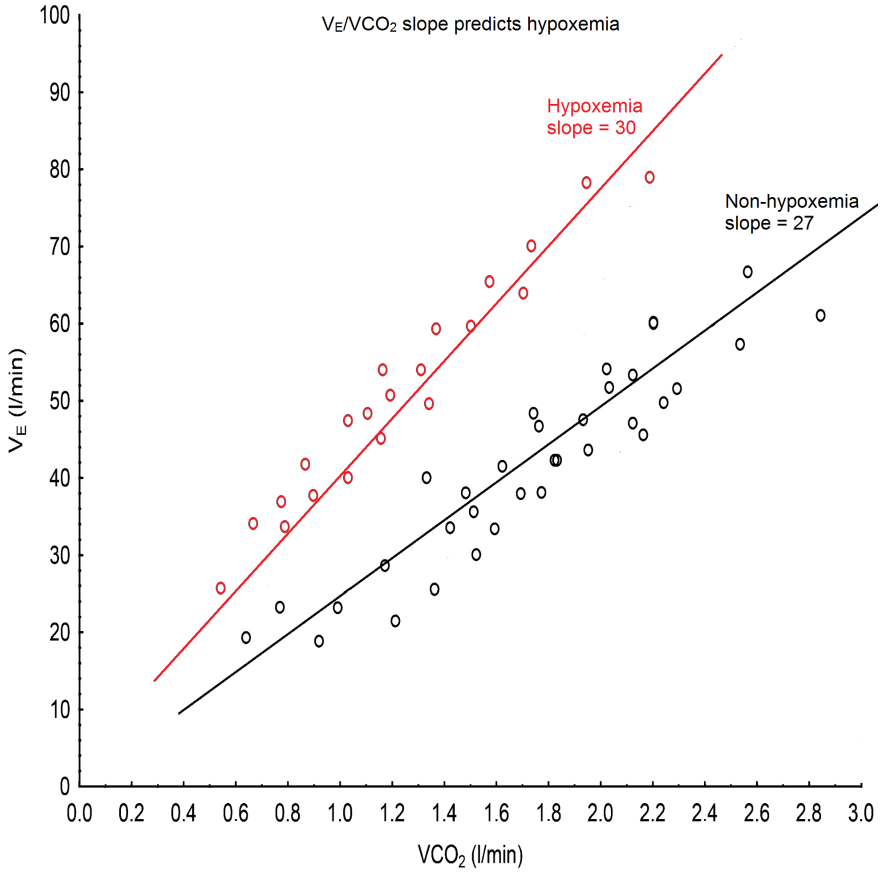
Perioperační hypoxémie

Observational Study > J Cardiothorac Vasc Anesth. 2019 Jul;33(7):1956-1962.
doi: 10.1053/j.jvca.2019.01.057. Epub 2019 Feb 8.

Ventilatory Efficiency Identifies Patients Prone to Hypoxemia During One-Lung Ventilation

Milos Chobola [1], Pavel Homolka [2], Michal Benej [3], Zdenek Chovanec [3], Kristian Brat [4], Vladimir Sramek [1], Lyle J Olson [5], Ivan Cundrle Jr [6]

	Hypoxemia (n = 24) Mean ± SD	Nonhypoxemia (n = 26) Mean ± SD	p
Peak exercise			
VO_2 (mL/kg/min)	18.4 ± 4.2	21.5 ± 6.7	0.07
VCO_2 (mL/min)	1,770 ± 521	1,981 ± 599	0.26
V_T (mL)	1,942 ± 584	1,991 ± 596	0.86
f_b (bpm)	31 ± 4	32 ± 5	0.49
V_E (L/min)	59 ± 17	62 ± 17	0.58
V_D/V_T	0.22 ± 0.06	0.23 ± 0.05	0.64
$P_{ET}CO_2$ (mmHg)	35 ± 5	38 ± 5	0.07
RER	1.1 ± 0.1	1.1 ± 0.1	0.97
V_E/VCO_2 slope	30 ± 5	27 ± 4	0.04



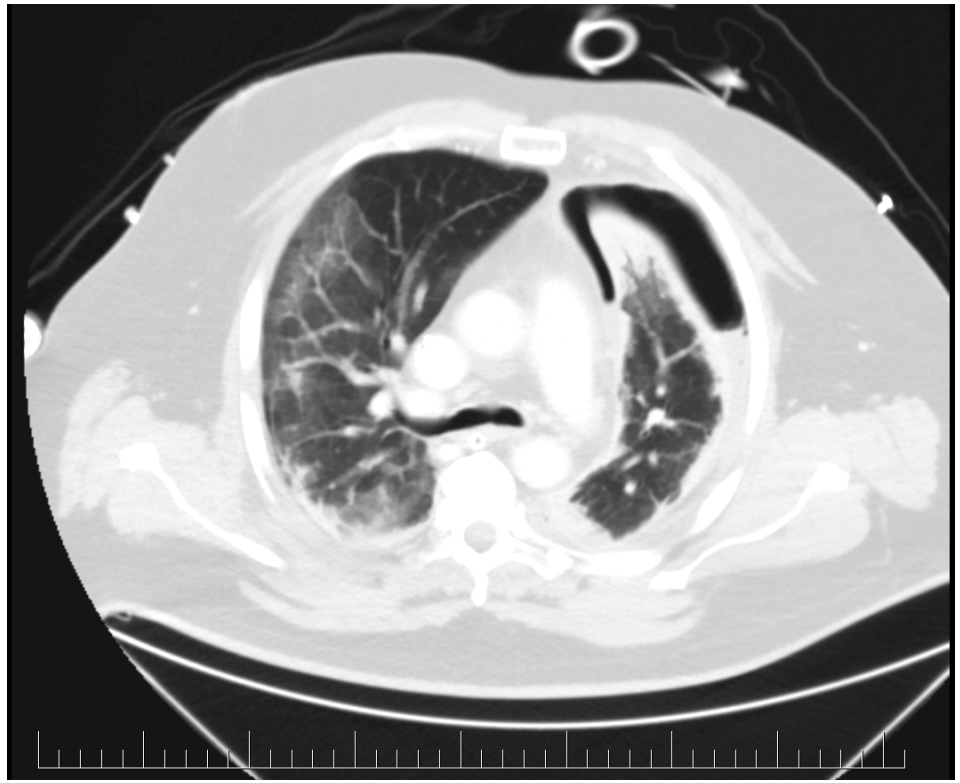
Dlouhodobý air-leak

› Interact Cardiovasc Thorac Surg. 2020 Feb 1;30(2):269-272. doi: 10.1093/icvts/ivz255.

Poor ventilatory efficiency during exercise may predict prolonged air leak after pulmonary lobectomy

Kristian Brat [1 2], Milos Chobola [2 3], Pavel Homolka [2 4], Michaela Heroutova [1], Michal Benej [2 5], Ladislav Mitas [2 6], Lyle J Olson [7], Ivan Cundrle [2 3]

	PAL ($n = 28$)	Without PAL ($n = 68$)	P-value
Peak exercise			
VO_2 (ml/kg/min), median (IQR)	19 (15.4–23.1)	19.4 (16.1–23.2)	0.76
VCO_2 (l/min), median (IQR)	1.54 (1.09–1.81)	1.53 (1.30–1.94)	0.48
RER, mean ± SD	0.99 ± 0.12	1.00 ± 0.14	0.78
V_E (l/min), mean ± SD	55 ± 15	53 ± 17	0.62
V_T (l), mean ± SD	1.73 ± 0.60	1.70 ± 0.57	0.99
f_b (bpm), mean ± SD	33 ± 6	32 ± 6	0.55
$P_{ET}CO_2$ (mmHg), mean ± SD	31 ± 6	34 ± 5	0.030
V_E/VCO_2 ratio, median (IQR)	39 (32–43)	33 (30–38)	0.005
V_E/VCO_2 slope, mean ± SD	35 ± 7	30 ± 5	0.001



Plicní vs. kardiovaskulární

- Spojení V_E/VCO_2 s plicními komplikacemi je jasné a vysvětlitelné determinanty V_E/VCO_2.

- Hlavní determinantou VO_2 je srdeční výdej, hlavní faktor spojený s pooperačními kardiovaskulárními komplikacemi *(Sellers. D et al, Anaesthesia. 2018;73(S1):34–42.)*

Kardiovaskulární komplikace

PLoS One. 2022 Aug 12;17(8):e0272984. doi: 10.1371/journal.pone.0272984. eCollection 2022.

Ventilatory efficiency is superior to peak oxygen uptake for prediction of lung resection cardiovascular complications

Andrej Mazur [1 2 3], Kristian Brat [2 3 4], Pavel Homolka [2 3 5], Zdenek Merta [2 4], Michal Svoboda [2 6], Monika Bratova [2 4], Vladimir Sramek [1 2 3], Lyle J Olson [7], Ivan Cundrle [1 2 3]

Parameter	Without complications (n=245)	Cardiovascular complications (n=78)	p
VO_2 (ml/kg/min)	19.9 (16.5-25)	18.3 (15.2-22.6)	0.01
VCO_2 (ml/min)	1.67 (1.30-2.10)	1.42 (1.10-1.82)	0.01
RER	1.05 (0.92-1.14)	0.97 (0.87-1.12)	0.13
V_E (l/min)	54 (44-68)	53 (42-65)	0.02
V_T (ml)	1.75 (1.37-2.11)	1.58 (1.13-2.02)	0.01
f_b (bpm)	32 (28-36)	34 (30-38)	0.13
V_D/V_T	0.21 ± 0.07	0.22 ± 0.06	
$P_{ET}CO_2$ (mmHg)	36 ± 5	32 ± 6	<0.01
V_E/VCO_2 slope	29 (25-33)	34 (30-38)	<0.01

Ale …

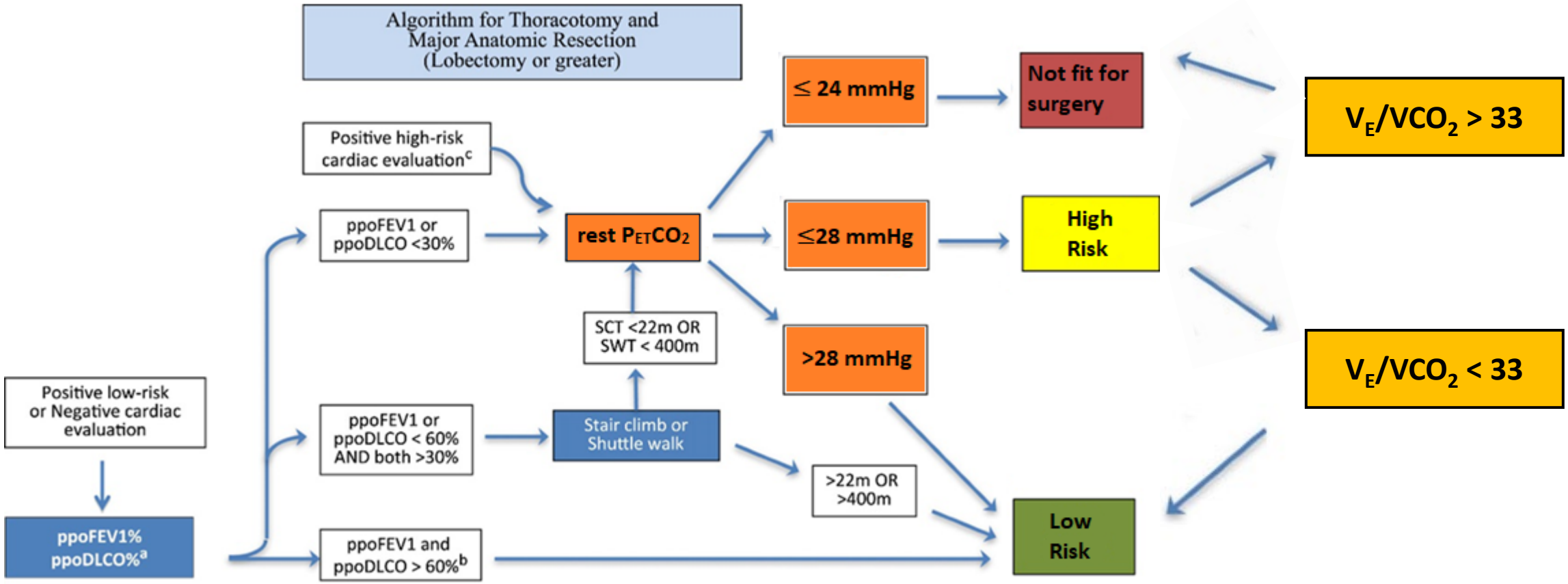
Table 5. Logistic regression analysis.

	univariate			multivariate stepwise		
	OR	95 CI	p	OR	95 CI	*P*
Age	1.05	1.02–1.08	<0.01	1.04	1.01–1.07	0.02
S-MPM	1.63	1.29–2.07	<0.01	NS		
Thoracotomy No (%)	1.77	1.05–3.00	0.03	NS		
Lobectomy No (%)	2.78	1.62–4.76	<0.01	NS		
Wedge resection No (%)	0.24	0.13–0.43	<0.01	0.28	0.15–0.53	<0.01
FEV_1/FVC	0.97	0.94–0.99	<0.01	NS		
DL_{CO}	0.98	0.97–1.00	0.01	NS		
peak VO_2	0.93	0.89–0.98	<0.01	NS		
V_E/VCO_2 slope	1.10	1.06–1.15	<0.01	1.06	1.01–1.11	0.01

- Lepší predikční hodnota V_E/VCO_2 – V/Q nepoměr, zvýšená aktivace sympatiku, chemoreflexu, ergoreflexu jsou všechno parametry spojené i s kardiální dysfunkcí.

Závěr

- Přibývá parametrů, které se zdají být lepšími než klasický VO_2 peak
- Především ventilační efektivita (sklon V_E/VCO_2) je jedním z nich
- Úprava doporučení je nutná, vzhledem k selekčnímu bias zatím formou začlenění V_E/VCO_2 slope pro stratifikaci pacientů s VO_2 v šedé zóně (10-20 ml/kg/min)



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Prediction of Postoperative Complications: Ventilatory Efficiency and Rest End-tidal Carbon Dioxide

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Děkuji za pozornost!