

How to assess exercise capacity - Ergometry

6-minute-walking-test (6MWT)

Cardiopulmonary exercise testing (CPET, CPX)

如何评估运动能力-
踏车测试、6分钟步行测试(6MWT)以及
心肺运动测试 (CPET, CPX)

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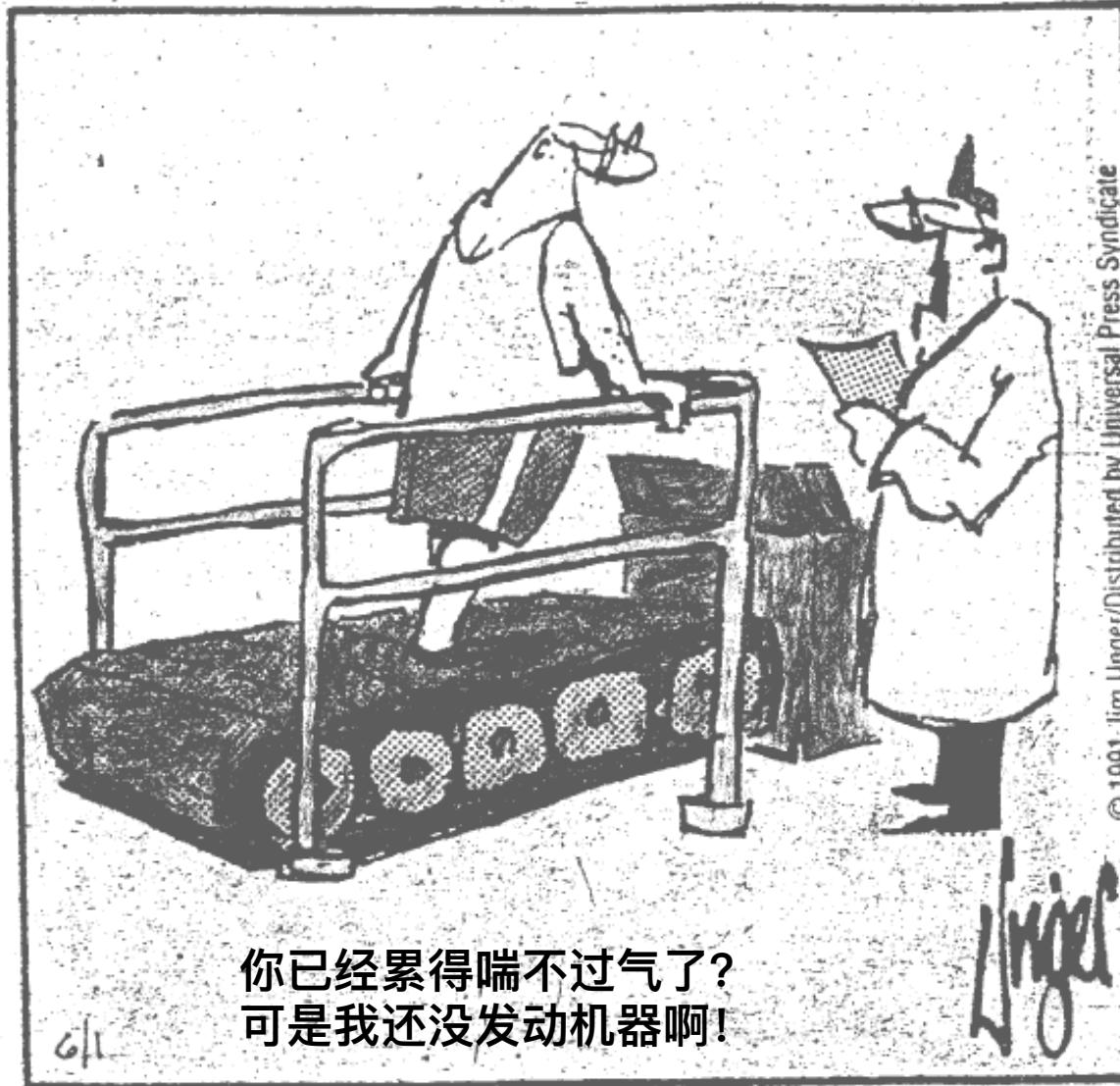
Physiology

生理学

Cardiovascular Physiology

心血管 生理学

HERMAN by Jim Unger



你已经累得喘不过气了?
可是我还没发动机器啊!

"What do you mean you're out of breath? I haven't switched it on yet!"

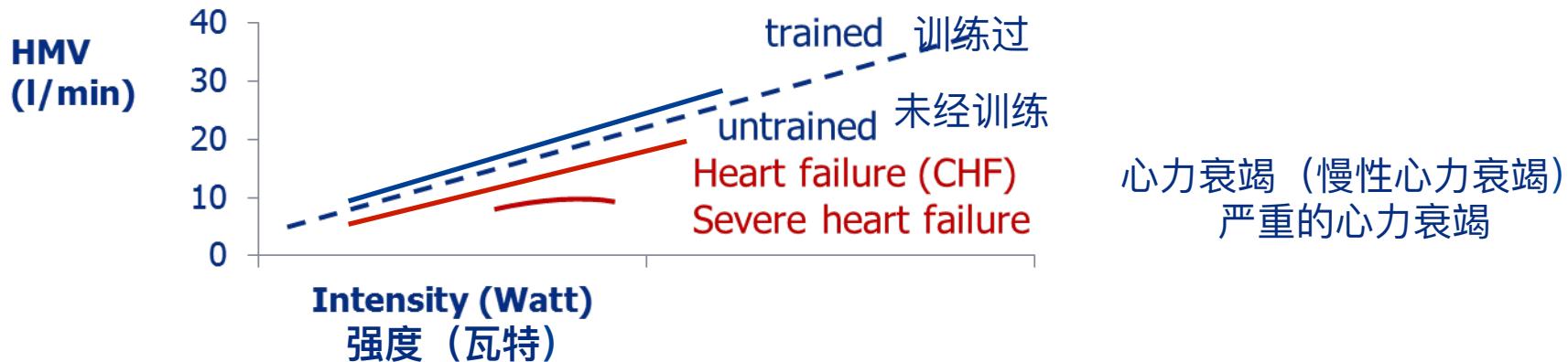
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Cardiovascular Physiology - I

心血管生理学-I

- heart minute volume and O₂-uptake
- 心脏分钟心排量 (HMV) 和摄氧量

- HMV = heart rate HR x stroke volume SV
HMV=心率HR × 每搏量SV
- equivalent to oxygen-uptake (assuming a constant peripheral Ausschöpfung avDO₂)
与摄氧量相等 (假设恒定的外周消耗、动静脉氧差)



- linear increase in Watt in healthy and trained subjects
受过训练和健康的受试者瓦特值呈线性增长

Cardiovascular Physiology - II

心血管生理学-II

- **heart minute volume and O₂-uptake** 心脏分钟心排量和摄氧量
- HMV - 5 - 6 l/min at rest
 - 15 -20 l/min in young healthy adults
 - > 40 l/min in highly-trained athletes
- HMV - 5-6 l/min 休息时
 - 15 -20 l/min 年轻健康的成人身上
 - > 40 l/min 高强度训练的运动员
- linear increase (Watt) in healthy and trained subjects受过训练和健康的受试者（瓦特）呈线性增长
- stroke volume SV = enddiastolic - endsystolic volume EDV – ESV
每搏量SV= 舒张末期-收缩末期容积
- EDV – depending on LV-filling-pressure and LV-compliance
舒张末期容积 - 取决于左室充盈压和左室顺应性
- ESV – depending on contractility of myocardium and afterload
收缩末期容积 - 取决于心肌收缩性和心室后负荷

Cardiovascular Physiology - III

心血管生理学 - III

- **heart minute volume and O₂-uptake**
心脏分钟心排量和摄氧量
- **exercise:** increase of O₂-uptake 8- to 10-fold 运动： 摄氧量增长8-10倍
- by
- HR: 2-4-fold
心率： 2-4 倍
- SV: 50% → 每搏量： 50%
- HMV 4-6-fold 分钟心排量4-6倍
- + blood distribution from the splanchnicus into heart and peripheral muscles
血液从内脏流入心脏和外周肌肉。

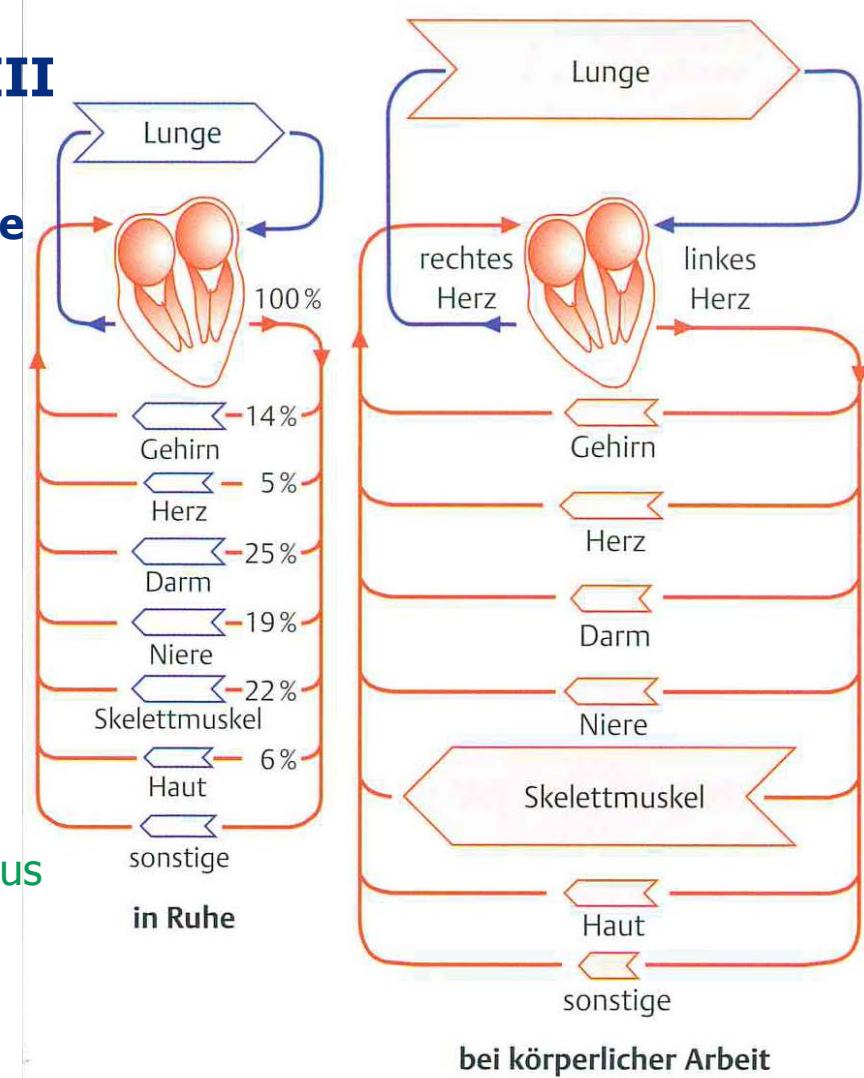


Fig. Kroidl et al, Thieme 2010

Cardiovascular Physiology - IV

心血管生理学 - IV

- **Heartrate and -rate-Reserve (HRR)**
心率和心率储备 (HRR)

- HR_{max} : 220 - age, with a variety of approx. 15% - „sufficient“
最大心率: 220 - 年龄, 从约15% - “正常”不等
- HR_{max} : $208 - (0,7 \times \text{age (y)})$
最大心率: $208 - (0.7 \times \text{年龄 (y)})$
- **(half-)supine-ergometry**: slower HR-increase due to higher SV, increased venous reflux and elevated left ventricular filling
(半-) 仰卧位-功率车测试: 由于每搏量升高, 心率升高减缓, 静脉回流增加, 左心室充填升高
- trained persons: slower increase of HR at same exercise level
受过训练的: 相同运动水平下, 心率增长更慢
- further relevant influences: acute disease / environment:
temperature / air pressure / humidity / ...
进一步相关影响: 急性疾病/环境: 温度/气压/湿度/....

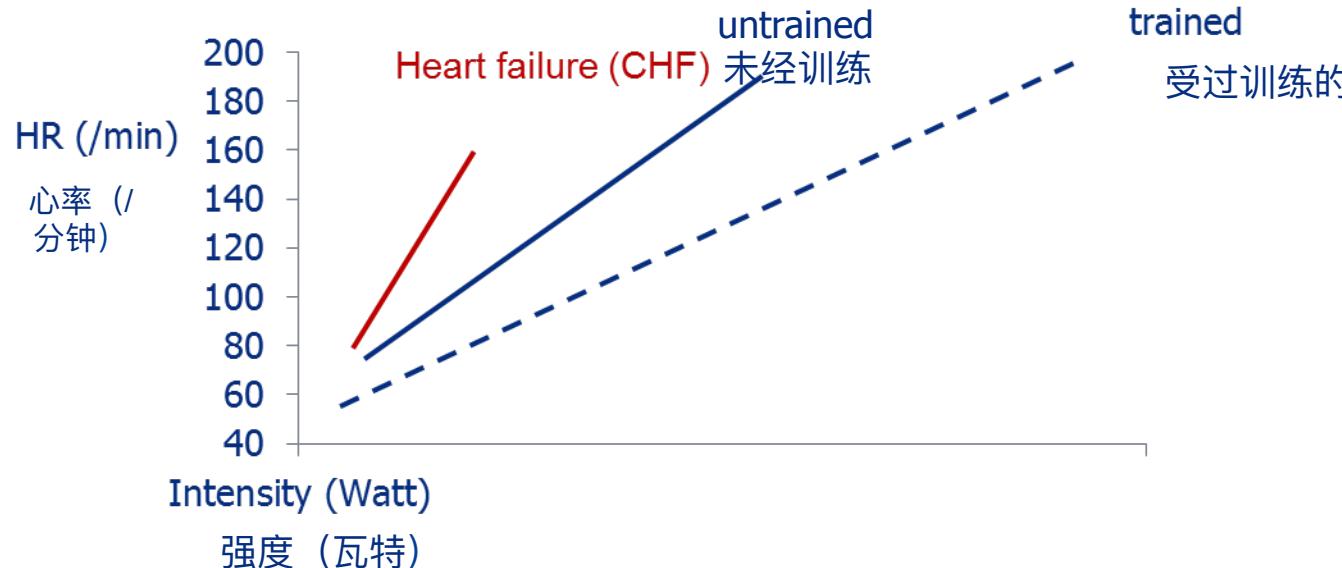
Cardiovascular Physiology - V

心血管生理学 - V

- **Heartrate und -rate-Reserve (HRR)**
- 心率和心率储备 (HRR)

心率衰竭 (慢性心力衰竭)

- trainable
- 可以被训练



- trained persons: slower increase of HR at same exercise level
受过训练的：相同运动水平下，心率增长更慢

Cardiovascular Physiology - VI

心血管生理学 - VI

- **Heartrate und -rate-reserve (HRR)**
- 心率和心率储备 (HRR)

- $HRR = HR_{max} \text{ pred} - HR_{max} \text{ act}$
- 心率储备= 最大心率预计值 - 最大心率实际值

- $\leq 10 \text{ bpm}$: ~ exertion level
- $\leq 10 \text{ bpm}$: ~ 力竭水平

Evaluation of physical fitness and exercise capacity

身体健康和运动能力的评估

- In CR evaluation of physical fitness and the individual dynamic exercise capacity should be performed by a safe, standardized, inexpensive and non-invasive procedure with diagnostic (and prognostic!) information :
- 在心脏康复中，应该通过一个安全、标准化、物美价廉和非侵入性的方式来评估身体水平和个体动态运动能力，并且应有诊断(和预后!)信息：
- 1. **bicycle ergometry** (standard in European countries)
- 运动功率车测试 (欧洲国家标准方法)
- 2. **treadmill ergometry** (standard in the Americas,...)
- 运动平板测试 (美国等地的标准方法)

Aims of exercise testing

运动测试的目标

- Assess physical fitness and (aerobic) endurance capacity
评估身体健康和(有氧)耐力能力
- Obtain references for „exercise prescription“
获得“运动处方”的参考资料
- Provide clinical diagnostic and prognostic information
提供临床诊断和预后信息
- Evaluate the necessity of (further) invasive diagnostics and/or therapeutic measures
评估(进一步)侵入性诊断和/或治疗措施的必要性
- **Functional capacity:** the ability to undertake physically demanding activities of daily living
功能性能力：从事日常生活中体力活动的能力
- most activities of daily living represent exertion at submaximal capacity
日常生活中的大多数活动都表示亚极限能力的努力

Guyatt 1985, Trappe and Löllgen 2000, Solvay 2001, Fletcher et al 2001, Bjarnason-Wehrens 2010

When to perform exercise testing in CR?

在心脏康复中何时进行运动测试？

- 1. at the beginning of / before starting each CR: individual > „exercise prescription“
每一次运动康复刚开始的时候/每次运动康复开始前：个人化>“运动处方”
- 2. in between CR to control effects of ET and to adjust ET intensity during CR
在心脏康复中控制运动训练的效果，并调整其强度。
- 3. at the end of CR to evaluate the efficiency of ET and to give individual further information for appropriate ET in CR phase III
在心脏康复末期，评估运动训练的效率，并给出个人化的进一步信息，来找到适于心脏康复III期的运动训练方法。

Bjarnason-Wehrens 2010

- **Established exercise protocols**

明确的运动方案

- **bicycle ergometry:** sitting /supine (or leg) ergometry

运动功率车测试：坐位/仰卧位（或者腿部）功率车测试

- **treadmill ergometry:** USA, protocol: Bruce, Naughton, Balke

运动平板测试：美国，惯例：**Bruce, Naughton, Balke**

- **arm ergometry:** PAD, massive overweight, insult

上肢功率车测试：外周动脉疾病、严重超重、损伤

- **6-minute-walking-test (6MWT)**

6分钟步行测试

- *Rowing ergometry: specific for athletes*

赛艇测试：运动员专用

- *Running / high altitude medicine etc : field tests: mobile*

跑步/高海拔 医学等： 现场试验：移动的

- *Swimming: Gegenstromanlage: used by National Olympic Centres*

游泳：室内游泳池：国家奥林匹克中心使用

- **Contraindications of cardiopulmonary exercise testing !!!**
- 心肺运动功能测试的禁忌症

Absolute 绝对禁忌症

- Acute MI (within 2 days) 急性心肌梗塞 (2天内)
- High-risk unstable angina 高危不稳定型心绞痛
- Uncontrolled cardiac arrhythmias causing symptoms of hemodynamic compromise 不可控的心律失常带来的血流动力学改变症状
- Active endocarditis 活动性心内膜炎
- Symptomatic severe aortic stenosis 症状严重的主动脉瓣狭窄
- Decompensated symptomatic heart failure 失代偿症状性心力衰竭
- Acute pulmonary embolus or pulmonary infarction 急性肺栓子或肺阻塞
- Acute noncardiac disorder that may affect exercise performance or be aggravated by exercise (eg, infection, renal failure, thyrotoxicosis)
- Acute myocarditis or pericarditis 感染、肾衰竭、甲状腺功能亢进
急性心肌炎和心包炎
- Physical disability that would preclude safe and adequate test performance 排除安全、充分的测试表现的身体残疾
- Inability to obtain consent 无法获得同意

Relative* 相对禁忌症

- Left main coronary stenosis or its equivalent 左主动脉狭窄或与之相当的疾病
- Moderate stenotic valvular heart disease 中等狭窄心脏瓣膜病
- Electrolyte abnormalities 电解质异常
- Tachyarrhythmias or bradyarrhythmias 快速性心律失常或心动过缓
- Atrial fibrillation with uncontrolled ventricular rate 心房颤动，心速率不受控
- Hypertrophic cardiomyopathy 肥厚性心肌病
- Mental impairment leading to inability to cooperate 智力损伤，导致无法配合
- High-degree AV block 高度房室传导阻滞

*Relative contraindications can be superseded if benefits outweigh risks exercise.

利大于弊的相对禁忌症可以忽略

Fletcher et al 2001

- **Rates of Perceived Exertion (BORG-scales RPE and CR-10)**
- 自体疲劳感觉程度 (BORG量表RPE和心脏康复-10)

RATING OF PERCEIVED EXERTION (RPE)

Borg's Scale BORG量表	(Gunner borg 1982):	Modified Borg Scale: 休息时	BORG量表 修订版
6-		0- at rest	
7- very, very light	非常轻	1- very easy	很容易
8-		2- somewhat easy	有些容易
9- very light	很轻	3- moderate	中等
10-		4- somewhat hard	有些困难
11- fairly light	相当轻	5- hard	困难
12-		6-	
13- somewhat hard	有些困难	7- very hard	很困难
14-		8-	
15- hard	困难	9-	
16-		10- very, very hard	极困难
17- very hard	很困难		
18-			
19- very, very hard	极困难		
20-			

Borg 1962 and 1982

Exercise Testing - Protocols

运动测试 - 方案

- **Rates of Dyspnea and Angina (CCS, NYHA)**
- 呼吸困难和心绞痛程度 (加拿大心血管协会, 纽约心脏协会)

表1: 纽约心脏协会心力衰竭分级

Table 1

New York Heart Association Classification of Heart Failure

Class I	Symptoms of HF only at activity levels that would limit normal individuals
Class II	Symptoms of HF with ordinary exertion
Class III	Symptoms of HF with less than ordinary exertion
Class IV	Symptoms of HF at rest

Source: Reference 9.

表2: 加拿大心血管协会分类系统的心绞痛分类

Table 2. Grading of Angina Pectoris by the Canadian Cardiovascular Society Classification System

Class I	Ordinary physical activity, such as walking or climbing stairs, does not cause angina. Angina occurs with strenuous, rapid, or prolonged exertion at work or recreation.
Class II	Slight limitation of ordinary activity. Angina occurs when walking or climbing stairs rapidly, walking uphill, walking or stair climbing after meals, in cold weather, in the wind, or under emotional stress, or only during the few hours after awakening. Angina occurs after walking more than 2 level blocks and climbing more than 1 flight of ordinary stairs at a normal pace and under normal conditions.
Class III	Marked limitations of ordinary physical activity. Angina occurs when walking 1-2 level blocks and climbing 1 flight of stairs at a normal pace under normal conditions.
Class IV	Inability to perform any physical activity without discomfort. Symptoms of angina may be present at rest.

Source: Reference 7.

ACC/AHA guidelines 2005
美国心脏病学会/美国心脏病协会指南2005

Parker 2004

- **Which form of testing should be chosen – Bicycle ergometry**
- 应选择哪种测试形式-运动功率车测试
- **Performed either sitting or (half-)supine:**
- 坐位或（半）仰卧位进行
 - Sitting predominantly in ambulatory centres
非卧床型康复中心主要是坐姿体位
 - Half-supine predominantly in inpatient CR centres
住院型心脏康复中心主要是半卧位
 - **advantage:** safe, non-weight-bearing, better ECG-lead quality, better reproducibility, additional procedures in supine position (stress-ECG, PA cath), less movement artefacts in spiroergometry
优势：安全、不承重、更好的心电图导联质量、更好的重现性、仰卧位的额外措施（压力-心电图、PA导管、呼吸量测定中移动伪像更少）
 - **disadvantage:** possible lack of coordination / experience in certain persons, orthopedic problems, PAD patients
劣势：特定人群可能缺少协调性/经验、骨科问题、外周动脉疾病患者
 - **focus:** elder or insecure subjects, obesity, post-stroke, post-CABG or other (thoracic) surgery, children, but also trained cyclists
焦点：年老或没有安全感的受试者、肥胖、中风后、冠状动脉旁路移植术或其他胸腔手术后、儿童，包括受过训练的自行车运动员。

- **Which form of testing should be chosen - treadmill ergometry**
- 应选择哪种测试形式-运动平板测试
- **performed in less CR centres:** greater muscle mass, VO₂ 10-15% higher
- 采取这种方法的心脏康复中心更少：肌肉质量更大、摄氧量高出10-15%
 - predominantly in ambulatory or sports-scientists co-led centres
 - 主要在非卧床型或运动科学家共同参与的康复中心进行
 - **advantage:** more natural way of moving, higher workloads
„birds fly, fish swim, man runs“ – Emil Zatopek (Czech marathon runner, 1950s)
优势：活动方式更自然、更高的工作负荷“鸟飞、鱼游、人跑”- Emil Zatopek （1950年代捷克马拉松运动员）
 - **disadvantage:** bigger, more expensive, noisier, unsafer by higher workloads, worse ECG quality, lack of BP control, less accurate and ? worse reproduction by subject's learning
劣势：更大、更贵、更嘈杂、在更高的工作负荷下更不安全、心电图质量更差、缺少血压控制、更不准确、因受试者的习得，所以重现性更差
 - **focus:** younger or more experienced and secure subjects, PAD patients, post-PCI / no (thoracic) surgery, adolescents, but also trained runners in phase III
焦点：更年轻或更有经验和安全感的受试者、外周动脉疾病患者、经皮冠状动脉介入治疗后/无（胸腔）手术、青少年，以及第三阶段的受训跑步运动员

Exercise Testing - Protocols

运动测试 - 方案

• Exercise protocols – bicycle ergometry 运动方案-运动功率车测试

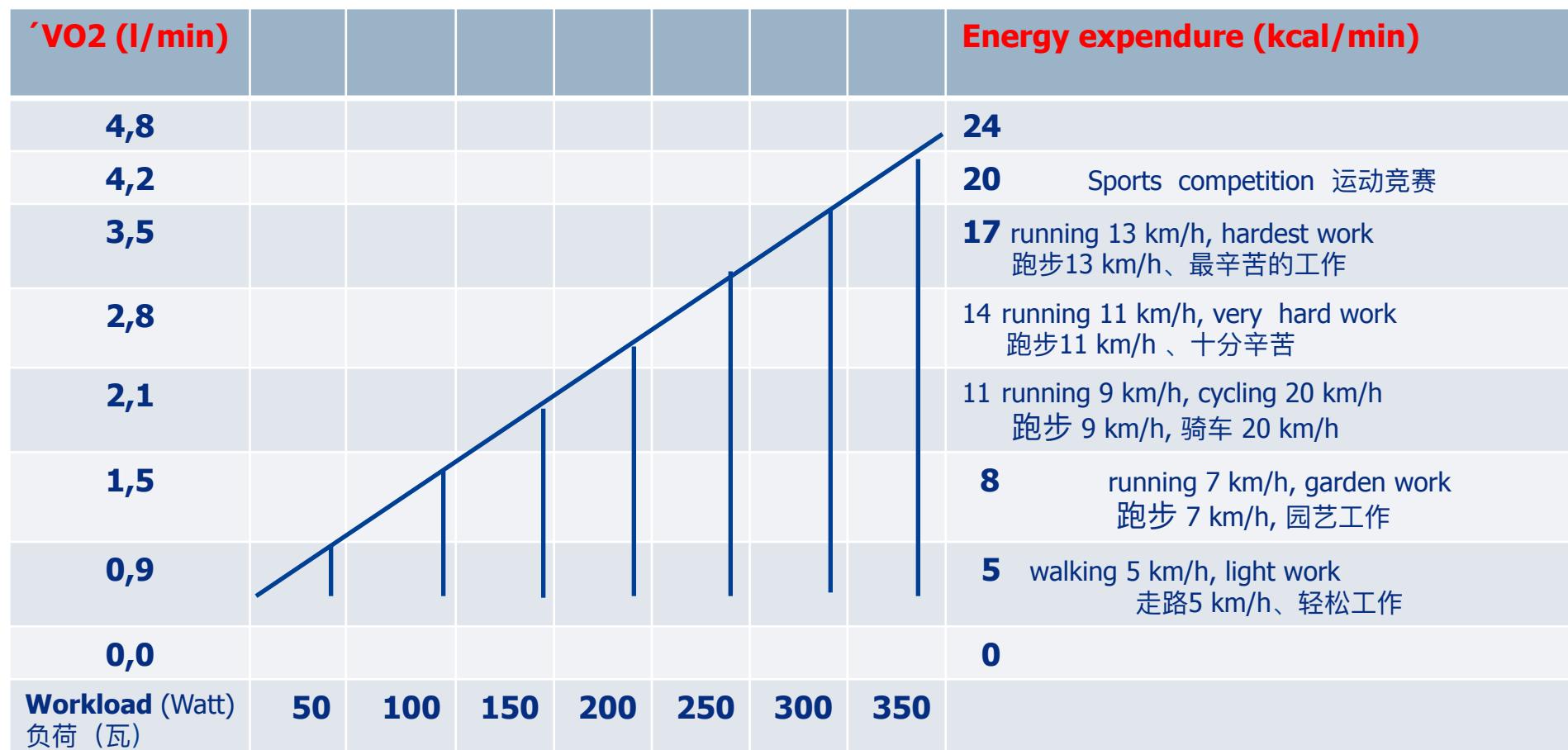
Focus 焦点	Starting level 开始水平	Increase 增加
CR centre, hospital ("routine"), Occupational Medicine e心脏康复中心、医院 ("常规") 职业病科	50 Watt (75-100 Watt with normal performance) 50 瓦特 (75-100 瓦特, 表现 正常)	25 Watt / 2 min 25 瓦特 / 2 分钟
reports, nuclear medicine 报告、核医学	50 Watt (25 Watt with reduced performance) 50 瓦特 (25 瓦特, 表现水平降 低)	25 Watt / 2 min 25 瓦特 / 2 分钟
Pneumology (incl. BGA, pulmonary artery catheter)肺 病学 (包含BGA、肺动脉导管)	25 (50 Watt) 25 (50 瓦特)	25 Watt / 2 min 25 瓦特 / 2 分钟
Children 儿童	1 Watt /kg 1 瓦特 /千克	0,5 Watt /kg / 3 min
Sports Medicine 运动医学	50 Watt ♀ 50 瓦特 ♀ 100 Watt ♂ 100 瓦特 ♂	50 Watt /2 min 50 Watt /3 min 25 Watt - near maximal levels 25 瓦特 - 接近最高水平

mod. after Löllgen 2005, Cardiopulmonary Exercise Testing Löllgen 2005修改后, 心肺运动功能测试

Exercise protocols and ADLs 运动方案和日常生活活动

- **linear correlation of `VO₂ and workload (Watt)**

摄氧量和工作负荷（瓦特）的线性联系



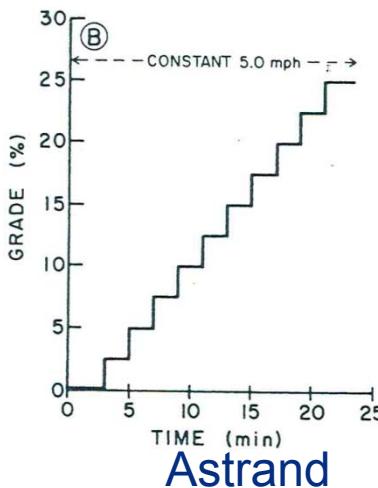
Exercise Testing - Protocols

运动测试 - 方案

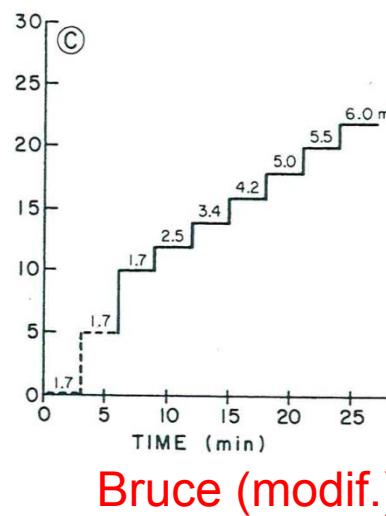
Exercise protocols and oxygen-uptake- XI

运动方案和摄氧量-XI

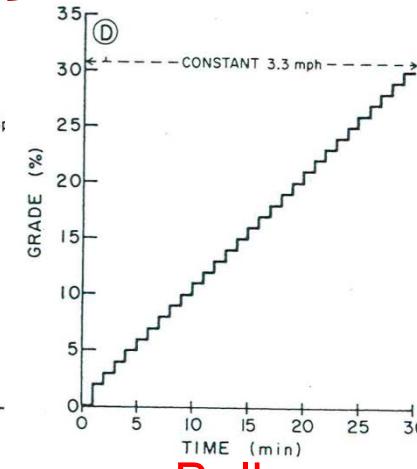
- Exercise protocols - IV
- 运动方案-IV
- treadmill:
- 跑步机: walking, not running !!!
走路, 不是跑步!!!!



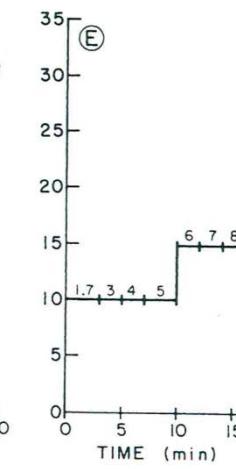
Astrand



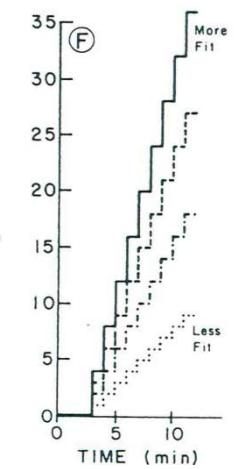
Bruce (modif.)



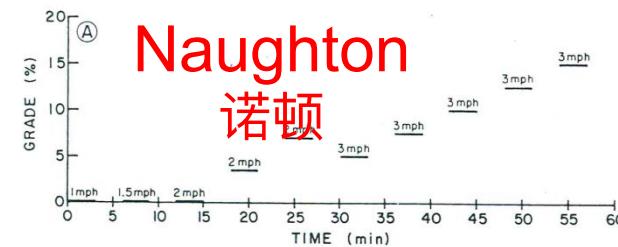
Balke



Ellestad



Harbour



Naughton
诺顿

Fig: Wasserman, Principles of Clinical Exercise Testing, 2005
图: Wasserman, 临床运动试验的原则, 2005

Exercise protocols and oxygen-uptake- XII

运动方案和摄氧量-XII

Bruce - Protocol
布鲁斯方案

斜率

walking pace !!!
走路节奏

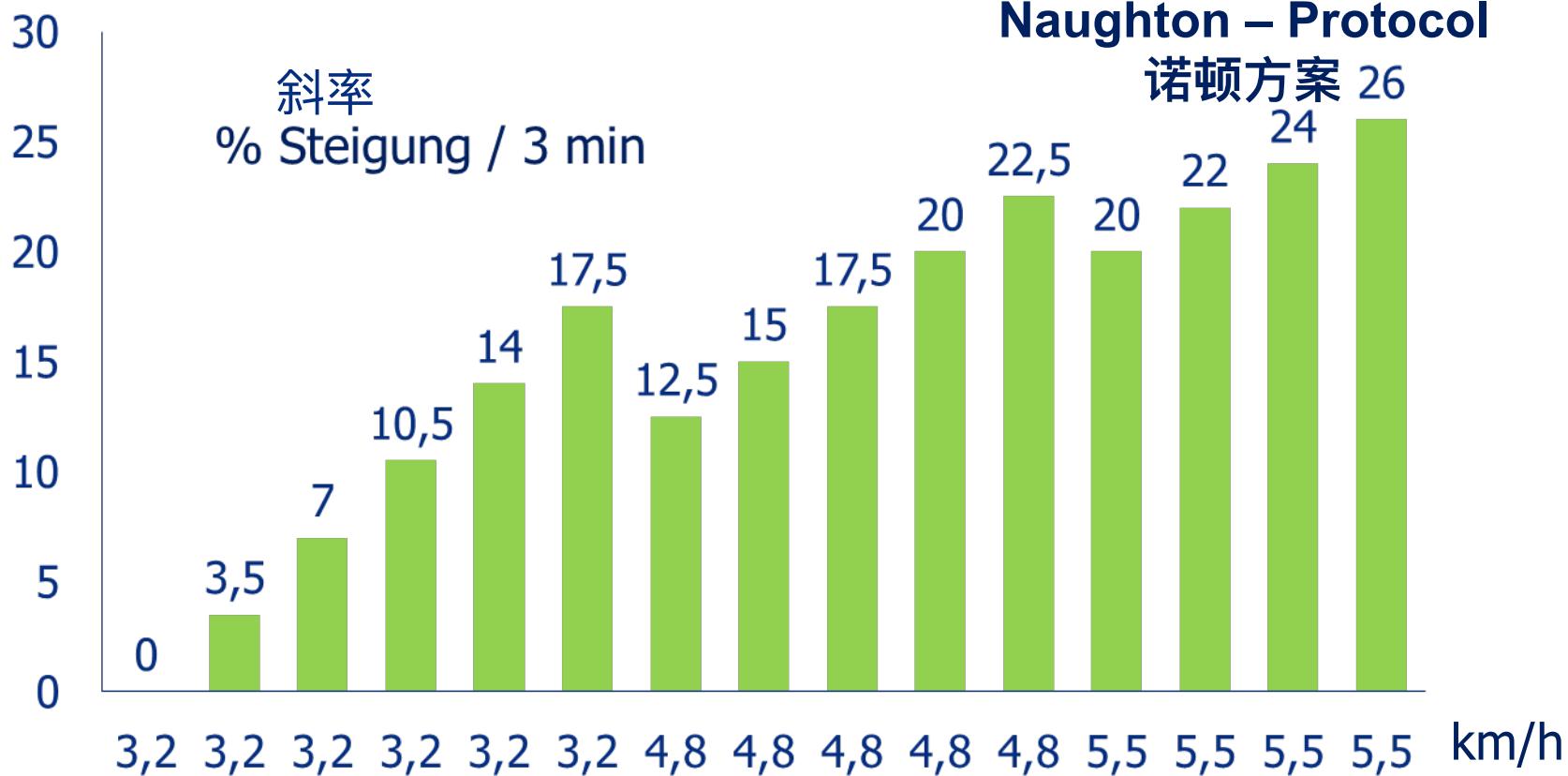
Exercise protocols and oxygen-uptake- XIII 运动方案和摄氧量-XIII



Bruce – Protocol modified (German Cardiac Association, DGK)

Trappe and Löllgen
布鲁斯方案修订版
(德国心脏病协会)

Exercise protocols and oxygen-uptake- XIV 运动方案和摄氧量-XIV



Exercise protocols and oxygen-uptake- XV 运动方案和摄氧量-XV



Exercise Testing - Protocols

运动测试 - 方案

more important advantage (++) or disadvantage (-);
less important advantage (+) or disadvantage (-)

更重要的有利条件 (++) 或不利条件 (-) ;
次重要有利条件 (+) 或不利条件 (-)

Feature 特点	Treadmill 跑步机	Cycle 自行车
Higher maximum VO_2 and Higher maximum O_2 pulse	+	
Similar maximum heart rate and maximum V_E	+	+
Familiarity of exercise	++	+
Quantitation of external work	--	++
Freedom from artefacts in ECG, airflow, and pressure tracing	--	++
Ease of obtaining arterial/venous blood specimens	--	++
Safety (fewer musculoskeletal injuries)		+
Usefulness in supine position		+
Greater experience in the United states	+	
Greater experience in Europe		+

Wasserman 2011

- **Exercise protocols - IX**
- **运动方案-IX**

1. step test (3 - 6 min / level > steady state)

台阶测试 (3-6分钟/层级>稳定状态)

2. incremental test (1 min / level)

增量式测试 (1分钟/层级)

3. ramp test (continuous, max. 16 sec / level)

斜坡测试 (持续性, 最多 16分钟/层级)

4. endurance-protocol (only one defined workload)

耐力方案 (只有一个设定的工作负荷)

spiroergometry: introduction of **breath-by-breath-analysis** and introduction of

9-panel-plot by Wasserman –

呼吸量测定：介绍**每口呼吸法分析**和Wasserman 9图分析

no need for steptests no more

不需要再做台阶测试

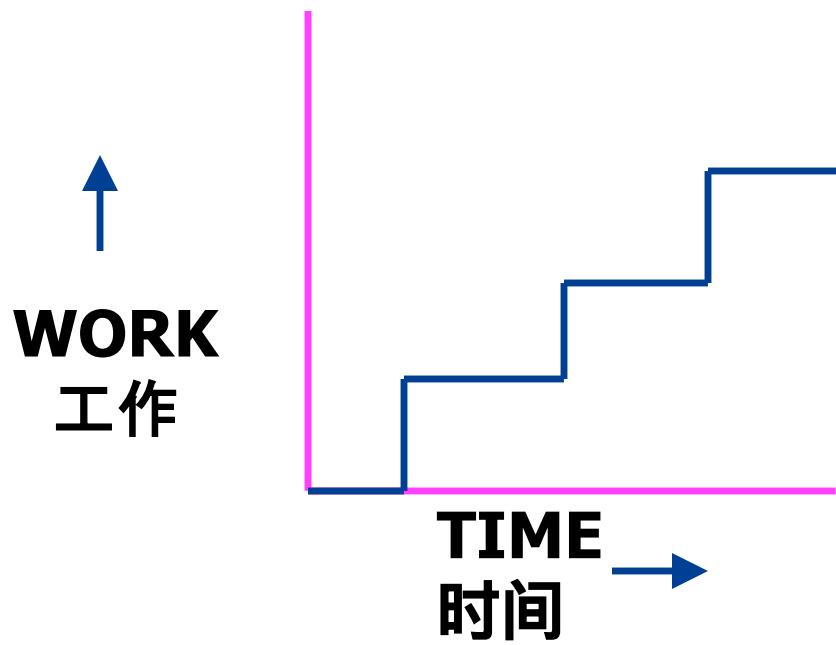
Incremental vs. Ramp Exercise Test Protocol

SIEG REHA SIEG PHYSIO-SPORT

增量式 vs. 斜坡运动测试方案

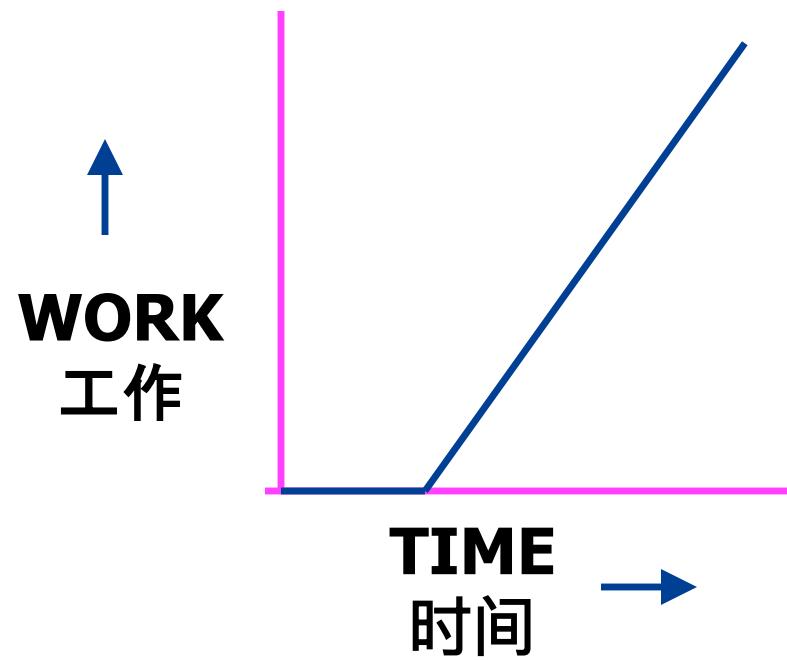
INCREMENTAL -

增量式



RAMP +

斜坡

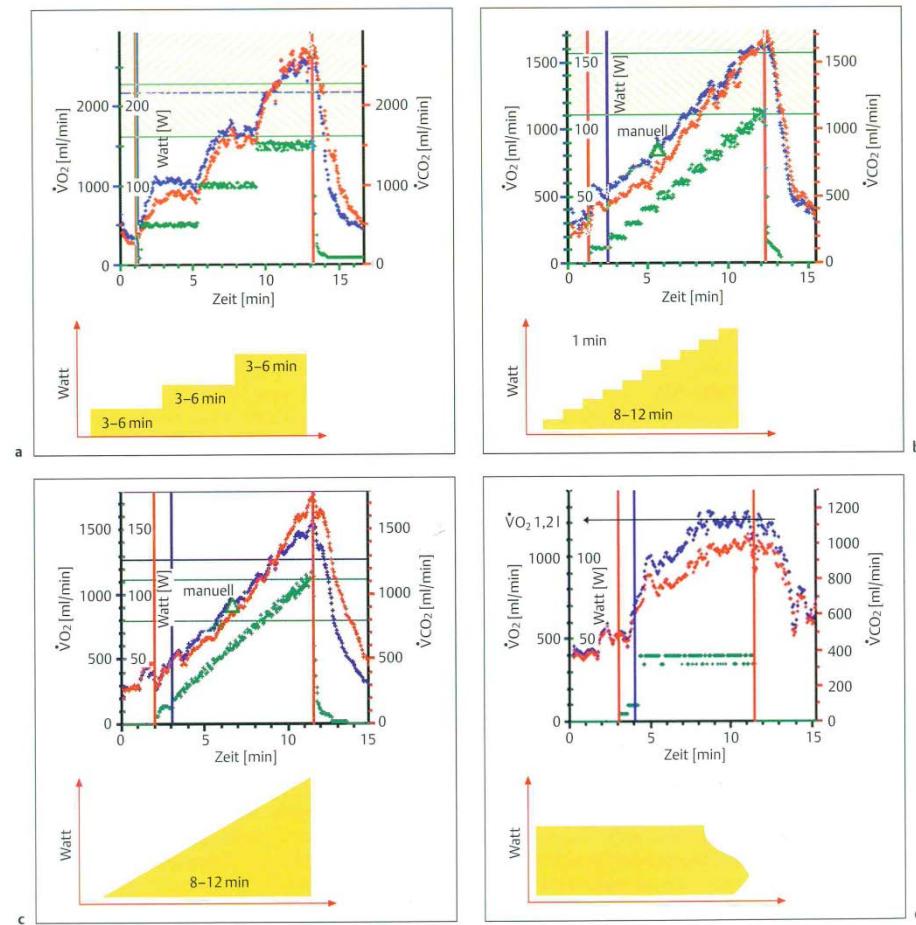


Exercise protocols and oxygen-uptake- XVII

运动方案和摄氧量-XVII

- **Exercise protocols - X**
- 运动方案-X

- a. step test
台阶测试
- b. incremental test
增量式测试
- c. ramp protocol
斜坡测试
- d. endurance test
耐力测试



Exercise protocols XI

运动方案 XI

1. Resting phase (1 - 3 min)

休息阶段 (1-3分钟)

2. Reference phase (2 - 3 min - unloaded pedaling)

基准阶段 (2-3分钟-无负荷踏车)

3. Exercise phase (continuous - 8 - 12 (15) min)

运动阶段 (持续-8-12 (15) 分钟)

4. Regeneration phase (3 - 5 min - unloaded pedaling)

更新阶段 (3-5分钟 -无负荷踏车)

Total duration 8-12, max. 15 min ! (not with well-trained athletes)

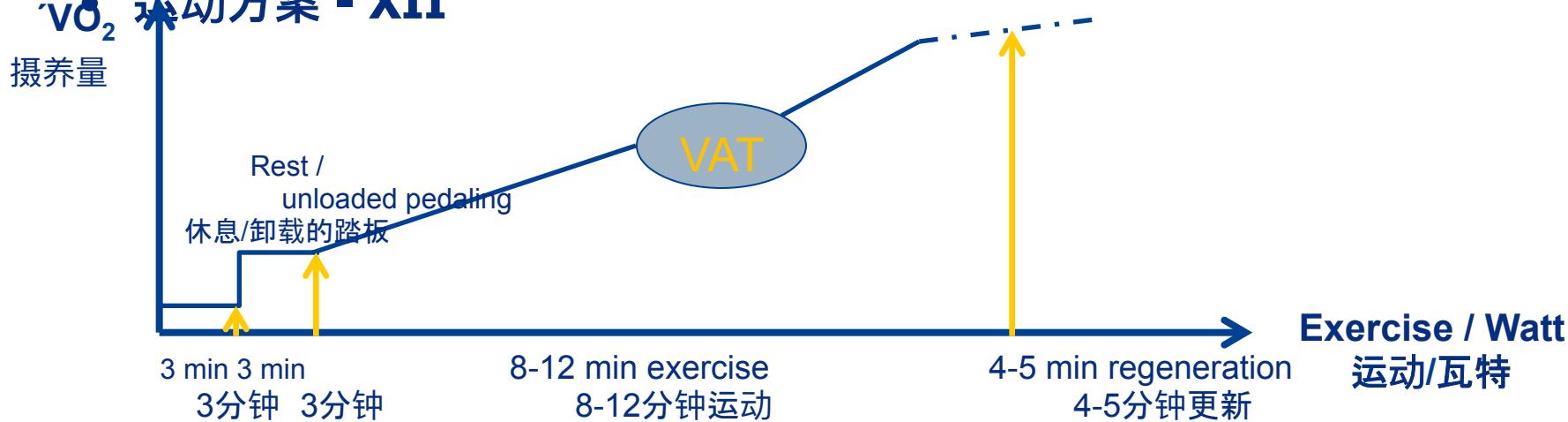
总体时长8-12分钟，最多15分钟！ (训练有素的运动员不在此列)

Exercise protocols and oxygen-uptake- XIX

运动方案和摄氧量-XIX

- Exercise protocols - XII

运动方案 - XII



- Time-schedule in CPET
- 心肺运动功能测试时间表

Maximum exercise capacity 最大运动能力

• estimated relative maximum exercise capacity:

相对最大运动功能预估值:

- in untrained healthy subjects between 20 – 30 years

未经训练的、健康的20-30岁的受试者

- 3,0 watt per kg body weight in men 男性每千克体重3.0瓦特

- 2,0 watt per kg body weight in women 女性每千克体重2.0瓦特

- decrease with increase in age 随年龄增长而减少

- (10% per decade in men, 8% in women) (男性每10年10%，女性8%)

- American Collage of Sports Medicine (**ACSM**), in Europa modified by **Reiterer** (1977)
(max. age 64 years, invalid in obesity)

美国运动医学会 (**ACSM**), 在欧洲由**Reiterer**修订 (1977) (最大年龄 64 岁, 肥胖者无效)

- **Jones**: 1. variables: sex, age, height

 2. variables: sex, age, height, weight

- 琼斯: 1. 变量: 性别, 年龄, 身高

 2. 变量: 性别, 年龄, 身高, 体重

- **Nordenfeldt** (1985) 诺登佛特(1985)

- World Heath Organisation (**WHO**), with predominantly only ~ 75% in comparison to other workgroups > to low

世界卫生组织 (**WHO**) 约为与其他工作组的75% > 低

Exercise Testing - Protocols

运动测试 - 方案

Maximum exercise capacity (Watt) - ♀ 最大运动能力(瓦特)

Nordenfeldt 1985

诺登佛特 1985

weight 体重

age (years) 年龄 (岁)

Exercise capacity
运动能力

	20–29	30–39	40–49	50–59	60–69	70–79
< 65	> 162	> 159	> 157	> 142	> 123	> 103
	108–162	106–159	105–157	95–142	82–123	68–103
	94–108	93–106	92–105	83–95	72–82	60–68
	67–94	66–93	65–92	59–83	51–72	43–60
	40–67	40–66	39–65	36–59	31–52	26–43
	< 40	< 40	< 39	< 36	< 31	< 26
65–85	> 169	> 167	> 164	> 149	> 129	> 107
	113–169	111–167	110–164	99–149	86–129	72–107
	99–113	97–111	96–110	87–99	75–86	63–72
	70–99	69–97	69–96	62–87	54–75	45–63
	42–70	42–60	41–69	37–62	32–54	27–45
	< 42	< 42	< 41	< 37	< 32	< 27
> 85	> 177	> 174	> 172	> 156	> 135	> 112
	118–177	116–174	115–172	104–156	90–135	75–112
	103–118	102–116	100–115	91–104	78–90	66–75
	74–103	73–102	72–100	65–91	56–78	47–66
	44–74	44–73	43–72	39–65	34–56	28–47
	< 44	< 44	< 43	< 39	< 34	< 28

Good 优良

Normal 正常

Slightly decreased 轻度下降

Decreased 下降

Much decreased 大幅下降

Very much decreased 严重下降

Good 优良

Normal 正常

Slightly decreased 轻度下降

Decreased 下降

Much decreased 大幅下降

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Much decreased 大幅下降

Very much decreased 严重下降

Exercise Testing - Protocols

运动测试 - 方案

Maximum exercise capacity (Watt) - ♀ 最大运动能力(瓦特)

Nordenfeldt 1985
诺登佛特 1985

weight 体重		age (years) 年龄 (岁)				79	Exercise capacity 运动能力
< 55	> 267	> 253	> 239	> 208	> 170	> 132	Good 优良
	178–267	169–253	160–239	139–208	113–170	88–132	Normal 正常
	156–178	148–169	140–160	121–139	99–113	77–88	Slightly decreased 轻度下降
	111–156	106–148	100–140	87–121	71–99	55–77	Decreased 下降
	67–111	63–106	60–100	52–87	42–71	33–35	Much decreased 大幅下降
	< 67	< 63	< 60	< 52	< 42	< 33	Very much decreased 严重下降
55–70	> 275	> 261	> 246	> 214	> 175	> 136	Good 优良
	183–275	174–261	164–246	143–214	117–175	90–136	Normal 正常
	160–183	152–174	144–164	125–143	102–117	79–90	Slightly decreased 轻度下降
	115–160	109–152	103–144	89–125	73–102	57–79	Decreased 下降
	69–115	65–109	62–103	54–89	44–73	34–57	Much decreased 大幅下降
	< 69	< 65	< 62	< 54	< 44	< 34	Very much decreased 严重下降
> 70	> 283	> 268	> 253	>	> 180	> 140	Good 优良
	188–283	179–268	169–253	147–220	120–180	93–140	Normal 正常
	165–188	156–179	148–169	128–147	105–120	81–93	Slightly decreased 轻度下降
	118–165	112–156	105–148	92–128	75–105	58–81	Decreased 下降
	71–118	67–112	63–105	55–92	45–75	35–58	Much decreased 大幅下降
	< 71	< 67	< 63	< 55	< 45	< 35	Very much decreased 严重下降

Maximum exercise capacity (Watt)

最大运动功能 (瓦特)

1. predicted exercise capacity – formulas

运动功能预测 - 公式

- **Jones** (without weight):

- 琼斯 (无体重)

- $W_{\text{soll}} \text{ (M)} = (2526 \times \text{KH} \text{ (m)} - 9,08 \times \text{age} - 2759) \times 0,163 (\pm 18\%)$

- $W_{\text{soll}} \text{ (F)} = (950 \times \text{KH} \text{ (m)} - 9,21 \times \text{age} - 756) \times 0,163 (\pm 22\%)$

- **Jones** (with weight):

- 琼斯 (有体重)

- $W_{\text{soll}} \text{ (M)} = (2169 \times \text{KH} \text{ (m)} - 9,63 \times \text{age} + 4,0 \times \text{KG} - 2413) \times 0,163 (\pm 18\%)$

- $W_{\text{soll}} \text{ (F)} = (950 \times \text{KH} \text{ (m)} - 9,21 \times \text{age} + 6,1 \times \text{KG} - 756) \times 0,163 (\pm 22\%)$

- **Wasserman** (with weight) 瓦塞尔曼 (有体重) : non validated 未验证

- $W_{\text{soll}} \text{ (M)} = [\text{KG} \times (50,72 - 0,372 \times \text{age}) - 5,8 \times \text{KG} - 151] / 10,1$

- $W_{\text{soll}} \text{ (F)} = [(\text{KG} + 43) \times (22,78 - 0,17 \times \text{age}) - 5,8 \times \text{KG} - 151] / 10,1$

Exercise Testing - Protocols

运动测试 - 方案

Maximum exercise capacity (Watt) and maximum treadmill pace

最大运动功能（瓦特）和最大跑步机步速

	Physically inactive persons 缺乏体育运动者	Physically active persons (level) 体育运动活跃者（水平）			
		fair 尚可	good 好	very good 非常好	maximum 最大程度
NP ♂	-3				
NP ♀	-2,5	2,6–2,9	3,0–3,3	3,4–3,8	3,9–
(Watt/kg max.)					
Endurance 耐力 trained persons 受训者		4,1–4,5 3,3–3,7	4,6–5,0 3,8–4,2	5,1–5,5 4,3–4,7	5,6– 4,7
(Watt/kg max.)					
Cyclists 骑自行车者		4,5–5,0	5,1–5,6	5,7–6,1	6,2–
Cyclists 骑自行车者		3,7–4,2	4,3–4,8	4,9–5,3	5,4–
(Watt/kg max.)					
NP ♂	ascendence 升高	9,5–10,5	10,6–12	12,1–14	14,1–16
NP ♀		7,3–8,4	8,5–9,7	9,8–11,6	11,7–13,4
(km/h max. bei 5 %)	升高				
Athletes 运动员 (track and field) (田径)	♂		14–16	16,1–18,0	18,1–20
	♀		11,5–12,5	12,6–14,1	14,2–16,0
(km/h max. bei 5 %)	升高				20,1–22 16,1–18
Bachl 1981, 1987					

American Thoracic Society 美国胸腔协会

6分钟步行测试指南

ATS Statement: Guidelines for the Six-Minute Walk Test

THIS OFFICIAL STATEMENT OF THE AMERICAN THORACIC SOCIETY WAS APPROVED BY THE ATS BOARD OF DIRECTORS
MARCH 2002

CONTENTS

- Purpose and Scope
- Background
- Indications and Limitations
- Contraindications
- Safety Issues
- Technical Aspects of the 6-Minute Walk Test
- Required Equipment
- Patient Preparation
- Measurements
- Quality Assurance
- Interpretation
- References

PURPOSE AND SCOPE

This statement provides practical guidelines for the 6-minute walk test (6MWT). Specifically, it reviews indications, details

pulmonary exercise test (1, 2). Other professional organizations have published standards for cardiac stress testing (3, 4).

Assessment of functional capacity has traditionally been done by merely asking patients the following: "How many flights of stairs can you climb or how many blocks can you walk?" However, patients vary in their recollection and may report overestimations or underestimations of their true functional capacity. Objective measurements are usually better than self-reports. In the early 1960s, Balke developed a simple test to evaluate the functional capacity by measuring the distance walked during a defined period of time (5). A 12-minute field performance test was then developed to evaluate the level of physical fitness of healthy individuals (6). The walking test was also adapted to assess disability in patients with chronic bronchitis (7). In an attempt to accommodate patients with respiratory disease for whom walking 12 minutes was too exhausting, a 6-minute walk was found to perform as well as the 12-minute walk (8). A recent review of functional walking

...1960年代早期，巴尔克开发出一个简单的测试，通过测量一个人在特定时间段内的步行距离，来评估其功能性能力。....

- **The 6 minute walk test (6MWT)**

- 6分钟步行测试

- depending on CR centre's availability, experience and tradition
- 根据心脏康复中心的可用性、经验和传统
- **Advantages**
- **有利条件**
- submaximal test (relevant for functional capacity in ADL)
- 次最大负荷量测试(与日常生活活动中的功能性能能力相关)
- can be performed by non-doctors
- 可以被非医生者操作
- requires only little equipment
- 只需要很少的设备
- can be performed with 3 - 5 patients at the same time
- 可以3-5个患者同时进行
- meet the needs of weaker / weaker patients
- 可以满足身体较虚弱的患者的需求

American Thoracic Society 美国胸腔协会

ATS Statement: Guidelines for the Six-Minute Walk Test 6分钟步行测试指南

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Safety Issues

Technical Aspects of the 6-Minute Walk Test

Required Equipment

Patient Preparation

Measurements

Quality Assurance

Interpretation

References

PURPOSE AND SCOPE

This statement provides practical guidelines for the 6-minute walk test (6MWT). Specifically, it reviews indications, details

...1960年代早期，巴尔克开出一个简单的测试，通过测量一个人在特定时间段内的步行距离，来评估其功能性能力。....

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A. 技术层面

6分钟步行测试应在室内进行，沿着一条长长的、地面平坦坚硬、环境封闭且笔直的走廊。走道必须有30米长。走廊每隔3米须有标记。转弯处应有标记。起始点（标志着60米走道的起点和终点）应有亮丽的彩色标记。

A. Technical aspects

The 6MWT should be performed indoors, along a long, flat, straight, enclosed corridor with a hard surface. The walking course must be 30 m in length. The length of the corridor should be marked every 3 m. The turnaround points are marked with a sign (e.g. traffic cone). A starting line, which marks the beginning and end of each 60-m lap, should be marked on the floor using brightly colored tape (figure 1).

www.klinikum-muenchen.de/Child-EU/en/care/checklist/SOP-6-min-walk-test.pdf

Exercise Testing - Protocols

运动测试 - 方案

REQUIRED EQUIPMENT

1. Countdown timer (or stopwatch)
2. Mechanical lap counter
3. Two small cones to mark the turnaround points
4. A chair that can be easily moved along the walking course
5. Worksheets on a clipboard
6. A source of oxygen
7. Sphygmomanometer
8. Telephone
9. Automated electronic defibrillator

所需设备：

1. 计时器 (或秒表)
2. 机械计量器
3. 两个锥形体来对转弯点进行标记
4. 一张椅子，且能很容易地在跑道上移动
5. 剪贴板上的工作表
6. 氧气源
7. 血压计
8. 电话
9. AED

American Thoracic Society

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美国胸科协会
6分钟步行测试指南

After the first minute, tell the patient the following (in even tones): "You are doing well. You have 5 minutes to go."

When the timer shows 4 minutes remaining, tell the patient the following: "Keep up the good work. You have 4 minutes to go."

When the timer shows 3 minutes remaining, tell the patient the following: "You are doing well. You are halfway done."

When the timer shows 2 minutes remaining, tell the patient the following: "Keep up the good work. You have only 2 minutes left."

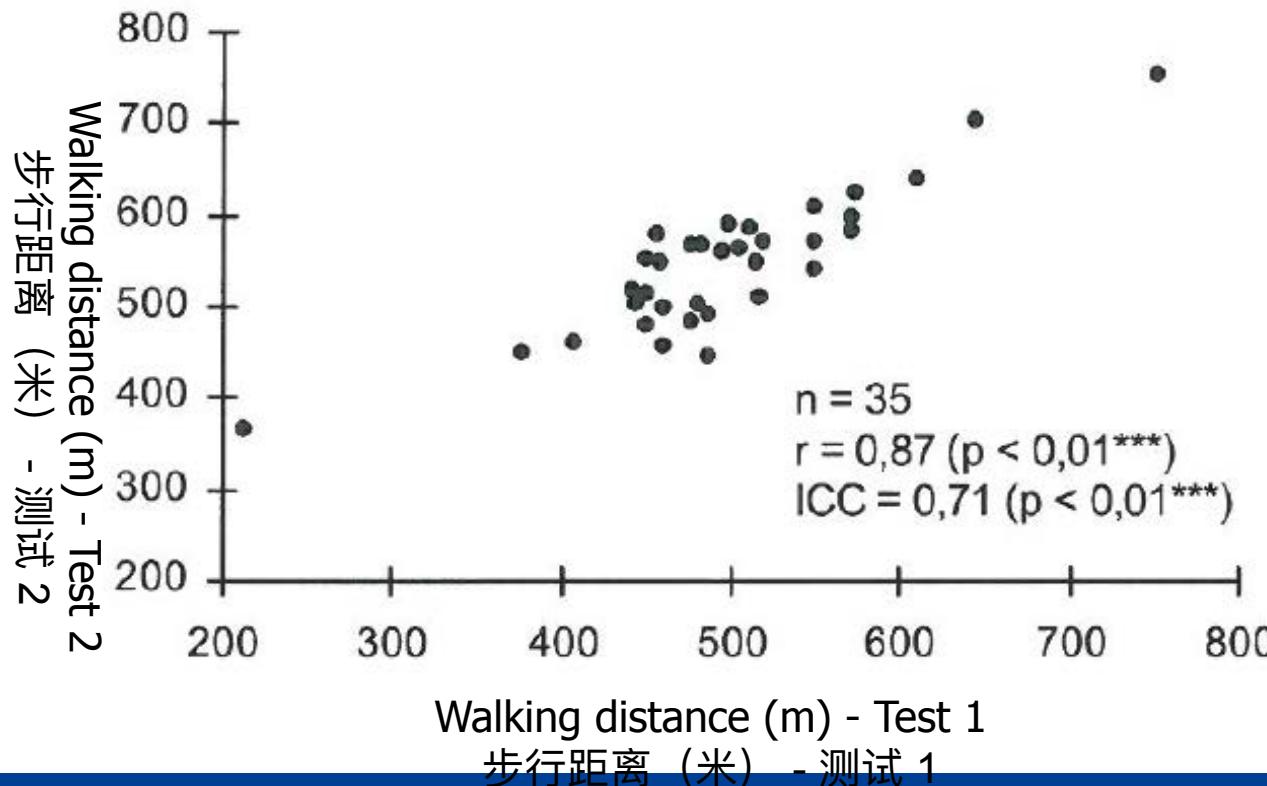
When the timer shows only 1 minute remaining, tell the patient: "You are doing well. You have only 1 minute to go."

Do not use other words of encouragement (or body language to speed up).

Exercise Testing - Protocols

运动测试 - 方案

- The 6 minute walk test (6MWT)
- 6分钟步行测试
- good correlation between first and second test:
- 第一次和第二次测试良好的相关性

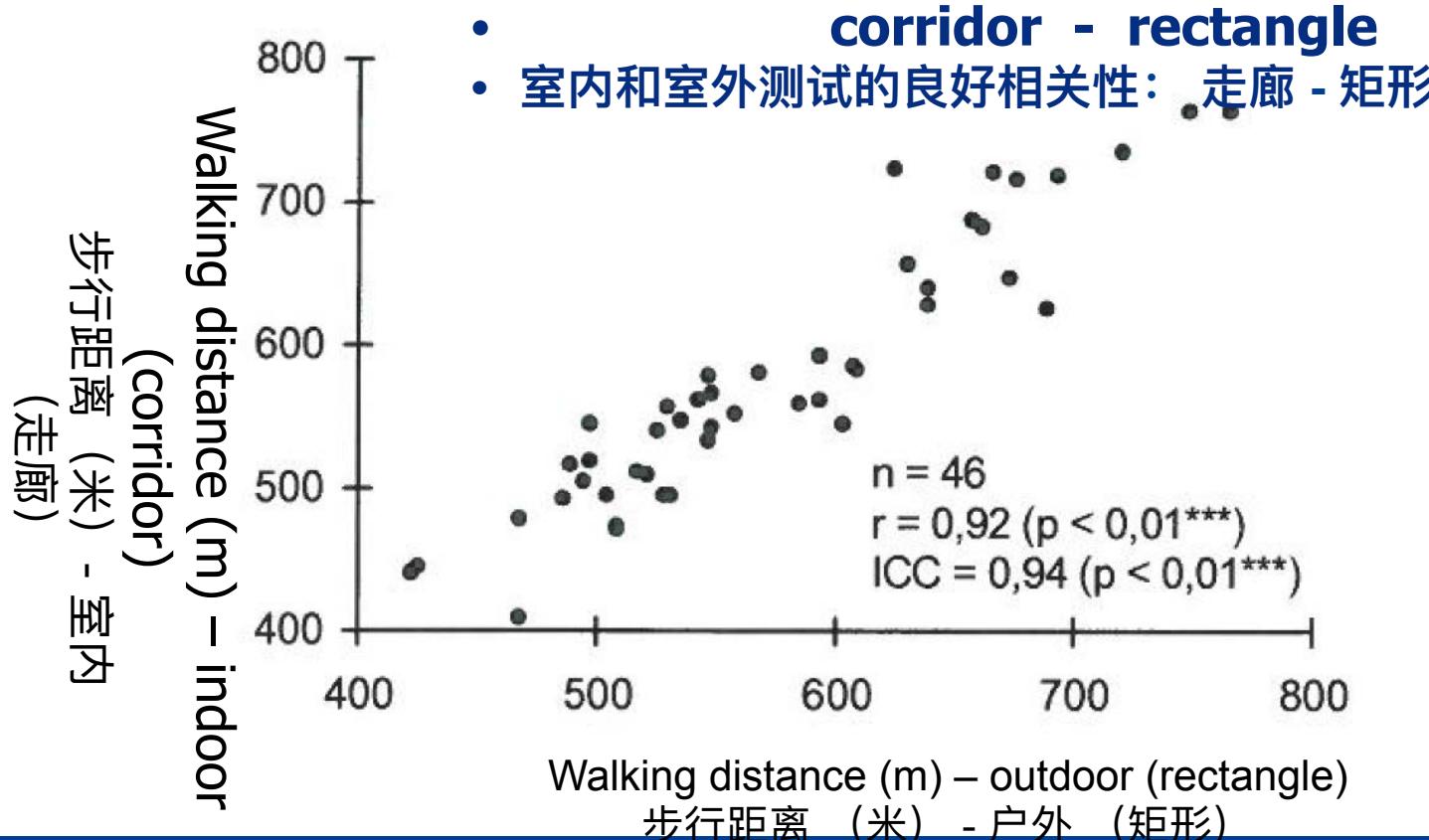


Schell 2013

Exercise Testing - Protocols

运动测试 - 方案

- The 6 minute walk test (6MWT)
- 6分钟步行测试
- good correlation between indoor and outdoor test:

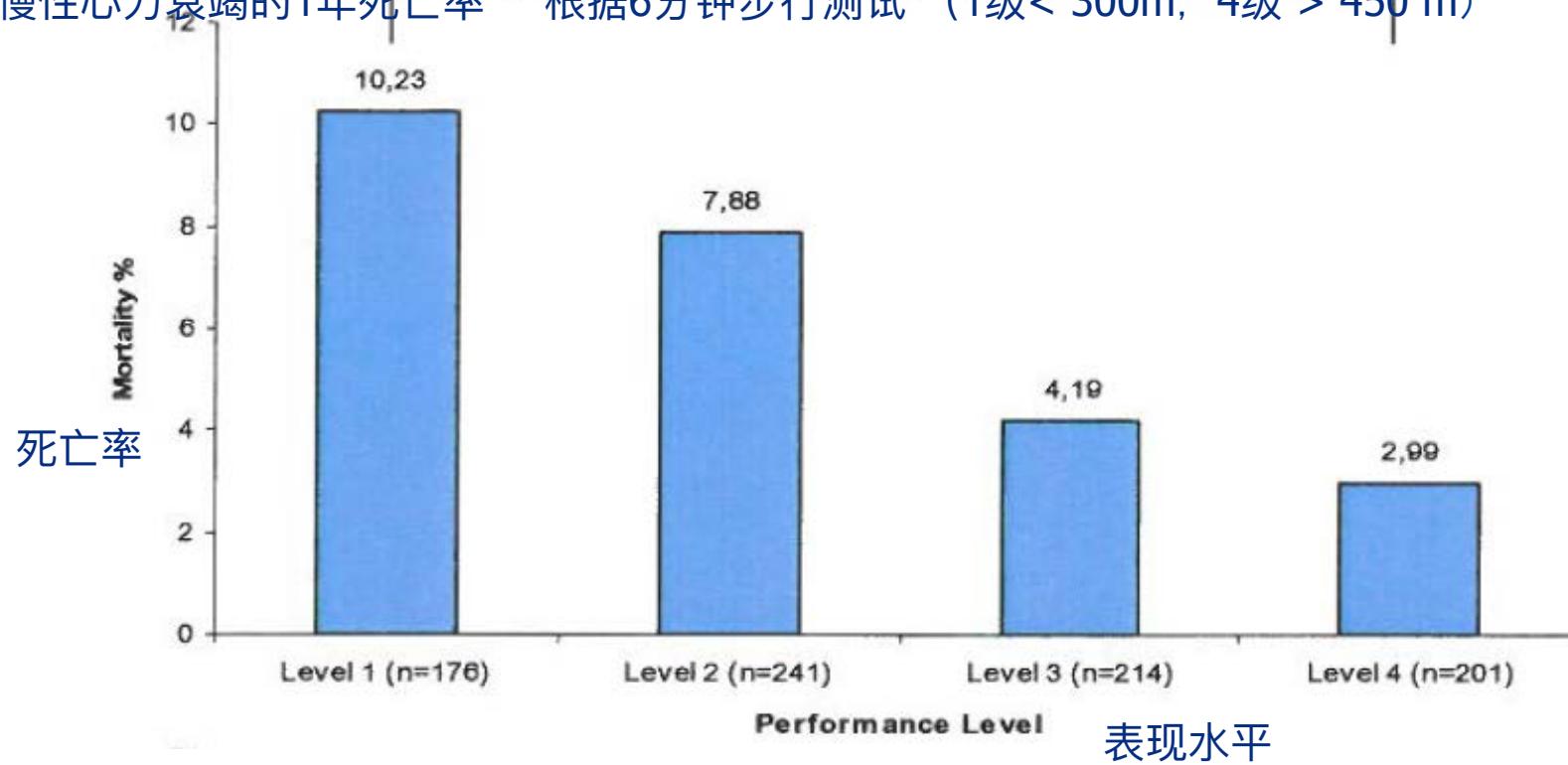


Schell 2013

Exercise Testing - Protocols

运动测试 - 方案

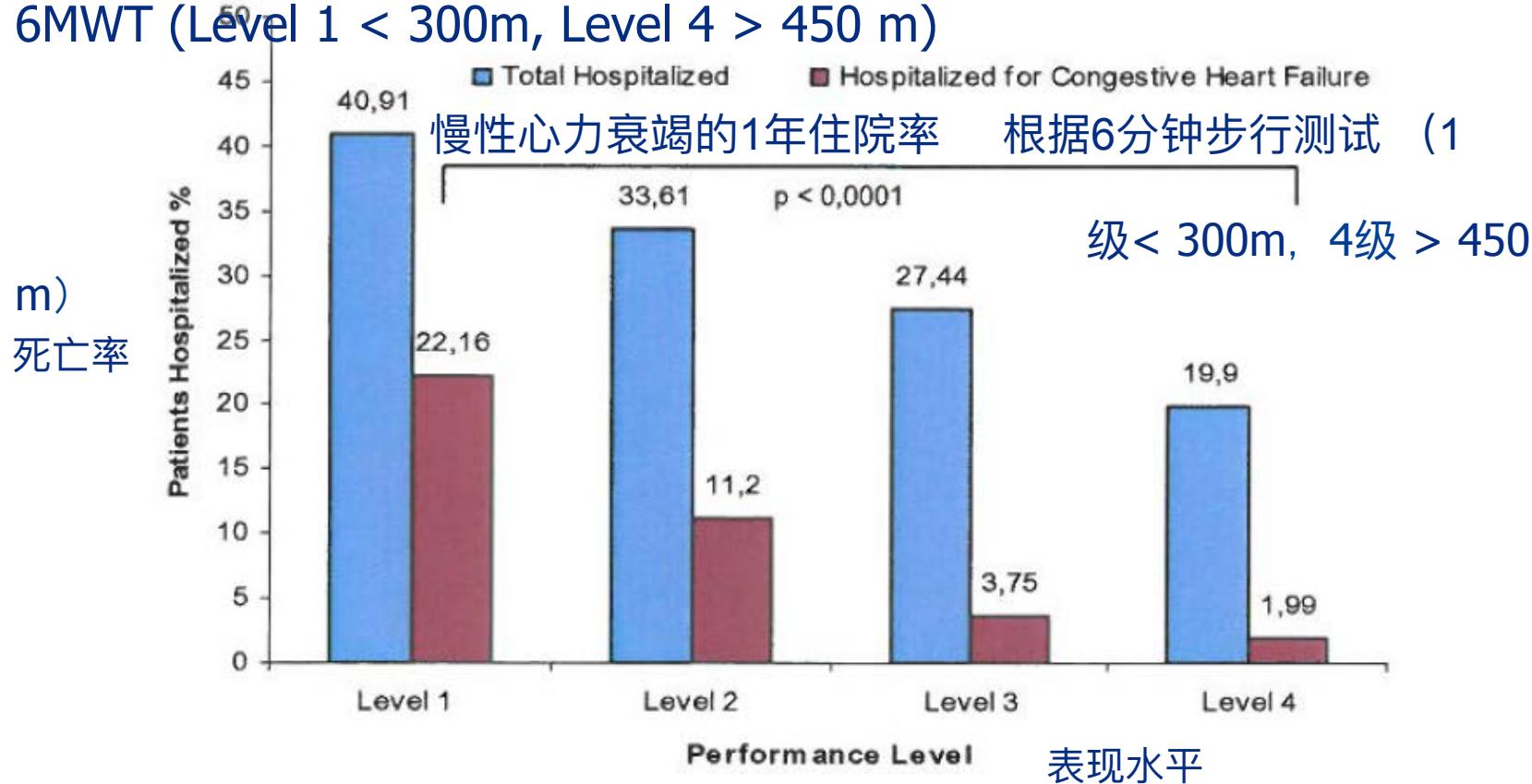
- **6 minute walk test (6MWT) - Prognostic value**
- 6分钟步行测试 - 预后价值
- **1-year-mortality in CHF-patients (n=)** depending on 6MWT
(Level 1 < 300m, Level 4 > 450 m)
 $p = 0,01$
- 慢性心力衰竭的1年死亡率 根据6分钟步行测试 (1级< 300m, 4级 > 450 m)



Exercise Testing - Protocols

运动测试 - 方案

- **6 minute walk test (6MWT) - Prognostic value**
- 6分钟步行测试 - 预后价值
- **1-year-Hospitalisation in CHF-patients (n=)** depending on 6MWT (Level 1 < 300m, Level 4 > 450 m)



- Optimal **reference equations from healthy population-based samples** using standarized 6MWT methods are not yet available:

目前还没有使用标准的6分钟步行测试方法，从健康人群样本中得到的最优参考方程

- median 580 metres for men (n=117)
- 男人平均580米 (n=117)
- median 500 metres for women (n=173)
- 女人平均500米 (n=173)

(Miyato S et al 2000)

- median 630 metres (n=51 older subjects)
- 平均630米 (n=51个年长受试者) American Thoracic Society

ATS Statement: Guidelines for the Six-Minute Walk Test

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Association of Long-Distance Corridor Walk Performance With Mortality, Cardiovascular Disease, Mobility Limitation, and Disability

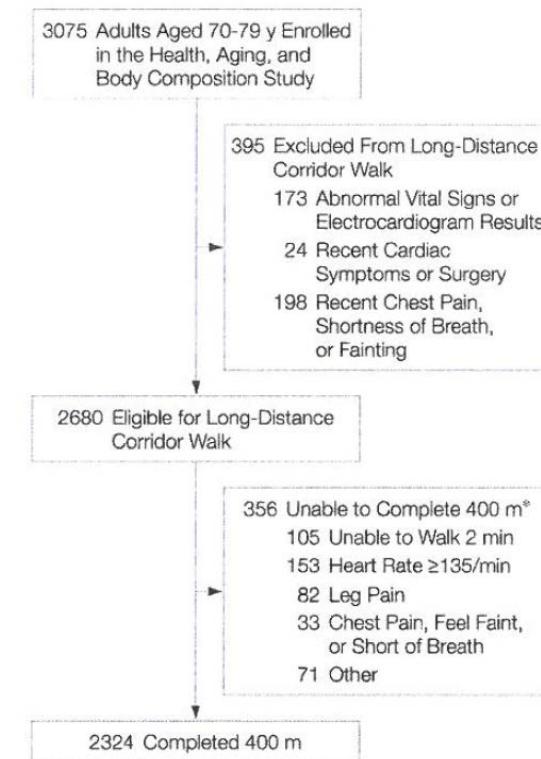
Newman A B et al. JAMA 2006;295(17):2018-2026

长距离走廊步行表现和死亡率、心血管疾病、活动限制和残疾的关系

- significant prognostic value ($p<0.01$) ($n=2324$) for
- 对于以下方面有显著的预后价值($p<0.01$) ($n=2324$)

- total cardiovascular events
- 总体心血管事件
- mortality
- 死亡率
- immobility
- 不活动
- reduced mobility
- 活动能力下降

Newman A et al 2006

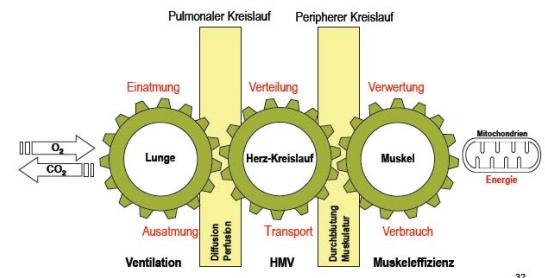


Cardiopulmonary Exercise Testing (CPET, CPX)

Spiroergometry – Ergospirometry

心肺功能运动测试 (CPET, CPX)

呼吸量测定-心肺功能测试



Karlman Wasserman – UCLA, California, USA

Karlman Wasserman - 加州大学洛杉矶分校、加利福尼亚、美国

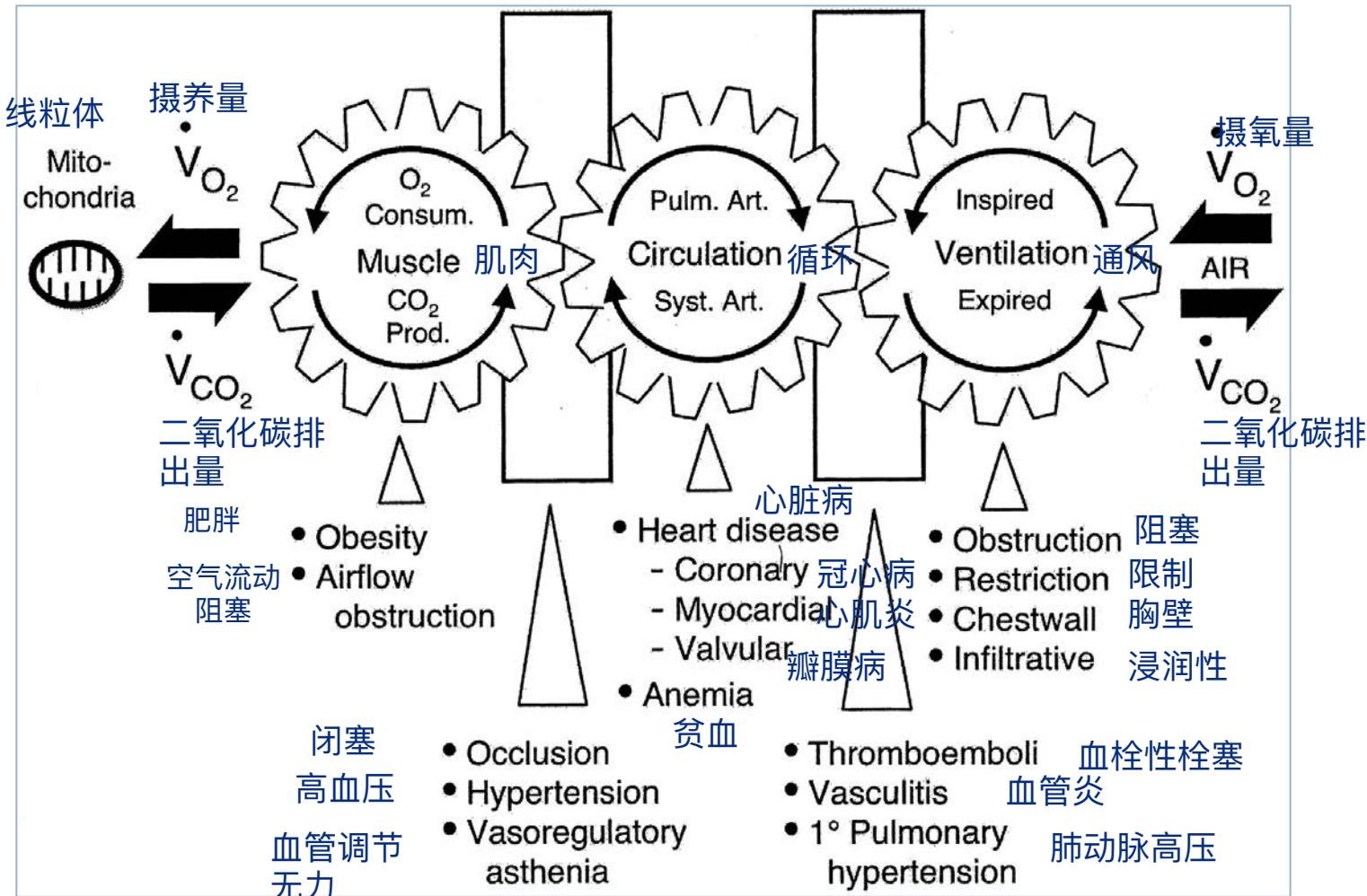
Wildor Hollmann – DSHS Cologne, Germany

Wildor Hollmann – 科隆德国体育学院，德国



Coupling of External Ventilation and Cellular Metabolism – Wasserman's Gears

外部通气和细胞代谢的藕联—Wasserman 齿轮



Determinants of Peak VO₂: the Fick Equation

峰值摄氧量的决定因素： Fick方程

$$VO_2 = HR \times SV \times (CaO_2 - CvO_2)$$

Sinus node dysfunction
窦房结失调
Drugs
药物

Cardiomyopathies
心肌病
Valvular Heart Diseases
心瓣膜病
Conditioning
调节
Genetic factors
遗传因素

PaO₂
动脉氧分压
Hemoglobin
血红蛋白
SaO₂
血氧饱和度

Skeletal muscle dysfunction
骨骼肌功能异常
Capillary density
毛细血管密度



- **Pulmonary 肺**

- Ventilatory 通气
- Respiratory muscle dysfunction 呼吸肌肉功能障碍
- Impaired gas exchange
- 气体交换受损

- **Cardiovascular 心血管**

- Reduced stroke volume
每搏量减少
- Abnormal HR response
心率异常反应
- Circulatory abnormality
循环系统异常
- Blood abnormality 血液异常

- **Peripheral 外周**

- Inactivity 不活动
- Atrophy 萎缩
- Neuromuscular dysfunction
神经肌肉功能障碍
- Reduced oxidative capacity of skeletal muscle
骨骼肌氧化能力减少
- Malnutrition 营养不良

- **Perceptual 直觉**

- **Motivational 动机**

- **Environmental 环境**

- symptom-limited exercise test
- 症状限制性运动测试
- measures airflow/ ventilation, O₂-consumption, CO₂-production, SpO₂ or PO₂
- 测量气流/通风、氧气消耗、二氧化碳产生、血氧饱和度或者氧分压
- allows calculation of peak oxygen consumption, (an-)aerobic thresholds VT1 and VT2
- 允许计算峰值摄氧量, (a)有氧阈值通气阙1和通气阙2



Overview: CPET Measurements

综述：心肺运动功能测试测量

- work 工作
- VO_2 摄氧量
- VCO_2 二氧化碳排出量
- VT1, VT2, (VT3) 通气阙1、
通气阙2（通气阙3）
- HR 心率
- ECG 心电图
- BP 血压
- R 通用气体常数
- SpO_2 血氧饱和度
- Art. blood gas 血液气体
- lactate 乳酸
- CP 心肺
- dyspnea 呼吸困难
- leg fatigue 腿部疲劳

Indications for CPET

心肺功能测试适应症

- **Evaluation of dyspnea** 呼吸困难的评估
 - Distinguish cardiac vs pulmonary vs peripheral limitation vs other 区分心脏vs肺vs外周限制vs其他
 - Detection of exercise-induced bronchoconstriction 检测运动诱发的支气管收缩
 - Detection of exertional desaturation 检测劳力性低氧血症
- **Cardiac and Pulmonary rehabilitation** 心肺康复
 - Exercise intensity and prescription 运动强度和处方
 - Response to participation 对社会参与的反应
- **Pre-op evaluation and risk stratification** 预评价和风险分级
- **Prognostication** of life expectancy (VO_2 -slope at AT, ...)
预测平均寿命(二氧化碳通气当量斜率在无氧代谢阈值,...)
- **Disability determination** (occupational medicine) 残疾测定(职业医学)
- Fitness evaluation 健康评估
- (Diagnosis) (诊断)
- **Assess response to therapy** 评估对治疗的反应

Mortality in CHF Patients (pre-beta-blocker era)

慢性心力衰竭患者的死亡率 (前β受体阻滞剂时代)

SIEG REHA

SIEG PHYSIO-SPORT

- **Nixon et al, NEJM 1992**

- 尼克松等, 《新英格兰医学杂志》 1992年
- 109 patients with CHF for 8 yrs from CPET
- 根据心肺功能运动测试, 109个患慢性心力衰竭的患者

▪ Peak VO ₂	>81% predicted	83% survival
▪ 峰值摄氧量 >81% 预测值		83% 生存率
▪ Peak VO ₂	59-81% predicted	51% survival
▪ 峰值摄氧量 59-81% 预测值		51% 生存率
▪ Peak VO ₂	<59% predicted	28% survival
▪ 峰值摄氧量 <59% 预测值		28% 生存率

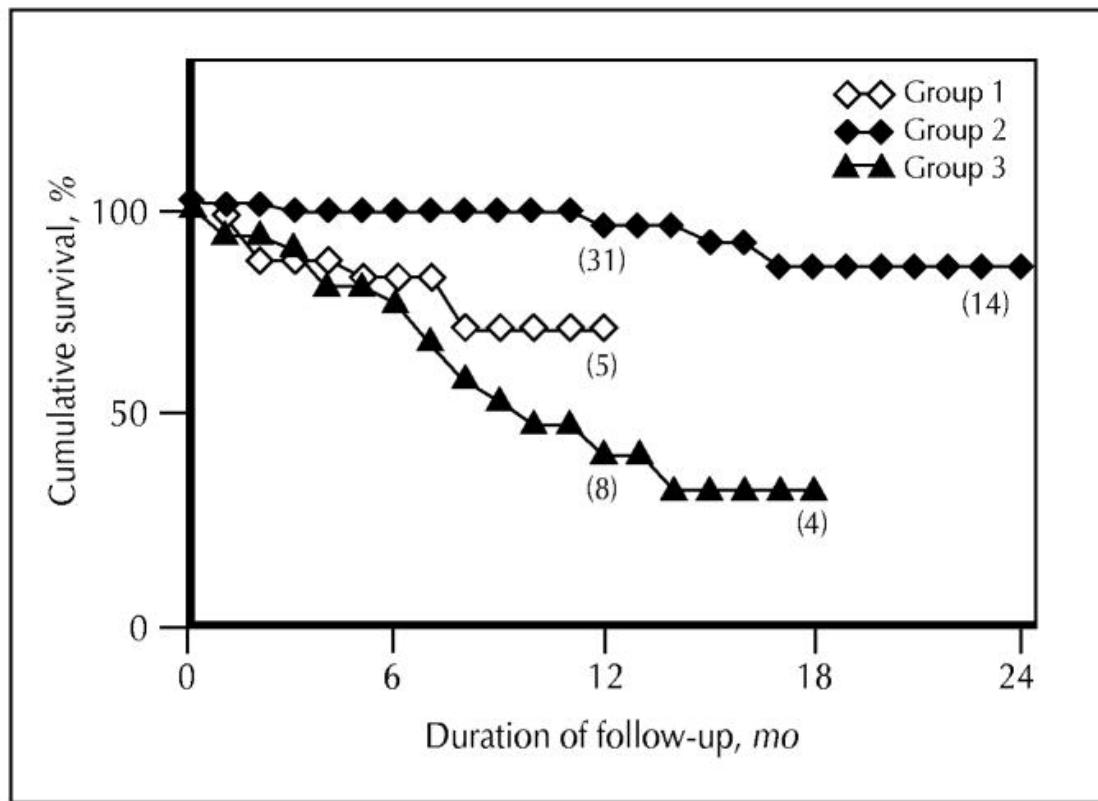
- **Mancini et al, Circulation 1991**

- **曼奇尼等, Circulation杂志, 1991**

▪ Peak VO ₂ >14 ml/kg/min:		
▪ 峰值摄氧量 > 14 ml/kg/min		
▪ 1-yr survival 94%	2-yr survival 84%	
▪ 1年生存率 94%	2年生存率 84%	
▪ Peak VO ₂ ≤14 ml/kg/min:		
▪ 峰值摄氧量 ≤14 ml/kg/min:		
▪ 1-yr survival 47%	2-yr survival 32%	1年生存率 47%
		2年生存率 32%

Prognosis - Cardiac Transplant Evaluation

预后 - 心脏移植评估



Survival curves for groups accepted (group 1) and rejected (group 3) for transplant are similar but are significantly reduced compared with group 2 ($P < 0.001$). The numbers in parentheses are the number of patients remaining at each point in the survival analysis.

Group 1: Peak VO₂ < 14 ml/kg/min, transplanted

组1：峰值摄氧量<14 ml/kg/min, 已移植

Group 2: Peak VO₂ > 14 ml/kg/min, transplant deferred

组2：峰值摄氧量>14 ml/kg/min, 移植推迟

Group 3: Peak VO₂ < 14 ml/kg/min, not transplant candidates

组3：峰值摄氧量<14 ml/kg/min, 不可作为移植候选人

Mancini et al 1991

慢性心力衰竭患者的功能性分类

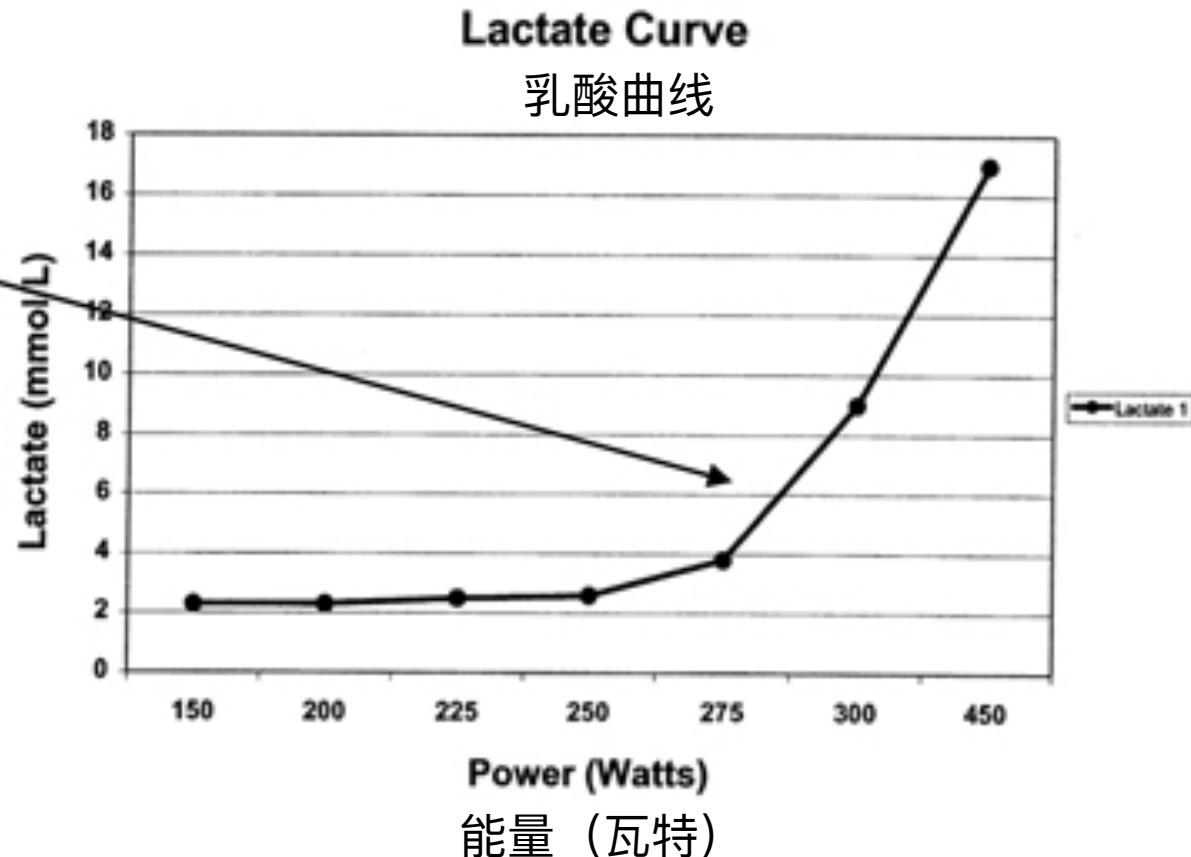
类别	严重程度	摄氧量最大值	无氧阈值	最大心脏指数
	从无到轻度			
	从轻度到中度			
	从中度到重度			
	严重			
	非常严重			

Lactate Threshold

乳酸阙值

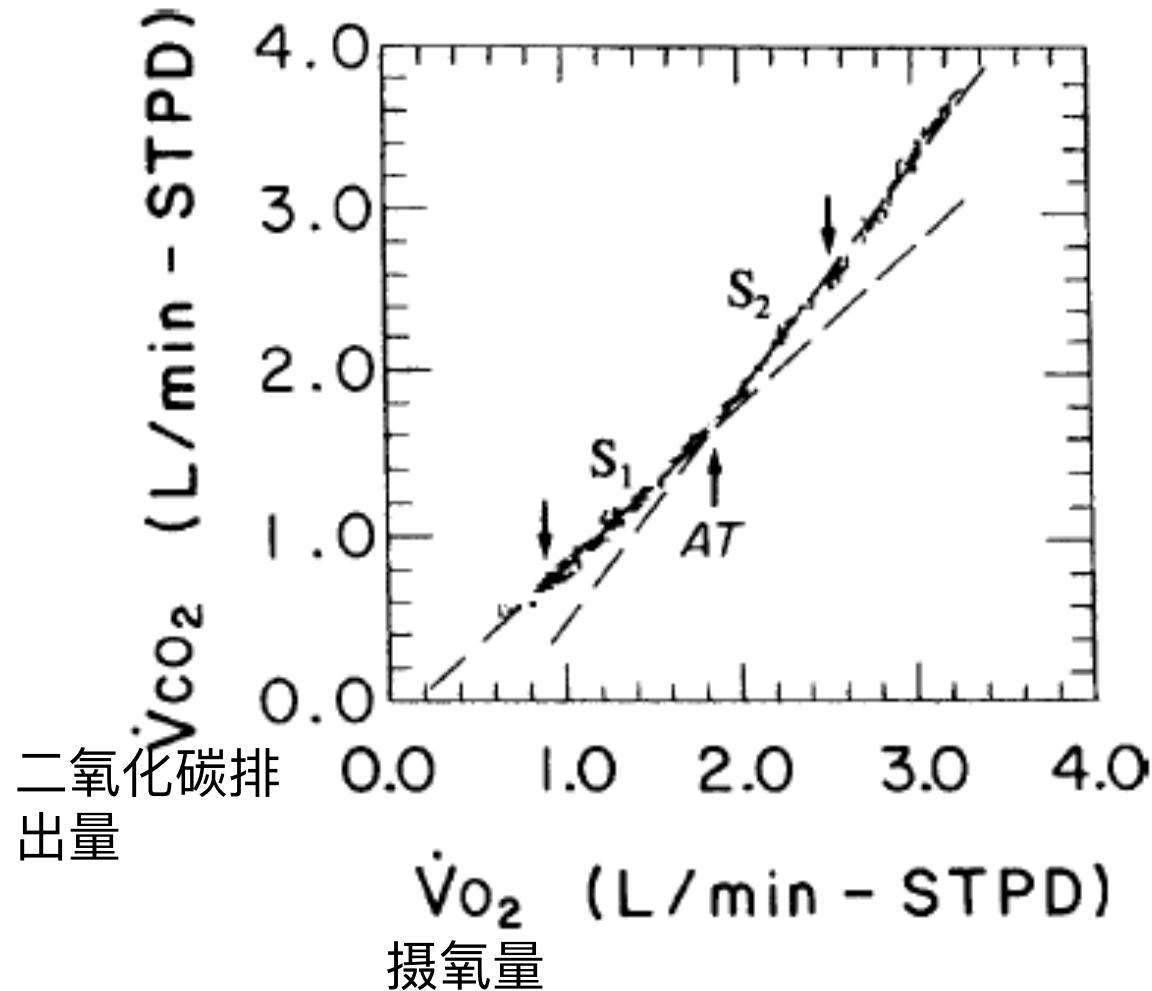
The lactate measurement shows the sudden increase in lactate

乳酸测量显示乳酸水平突然增高



Determination of VAT1 from panel 5(V-Slope method)

从图5测定无氧通气阙1 (V-Slope 法)



- Ventilatory equivalent for carbon dioxide = Minute ventilation / VCO₂

二氧化碳的通气当量=分钟通气量/ 二氧化碳排出量

- **Efficiency of ventilation**

通气效率

- Liters of ventilation to eliminate 1 liter of CO₂

通气几公升排出1公升二氧化碳

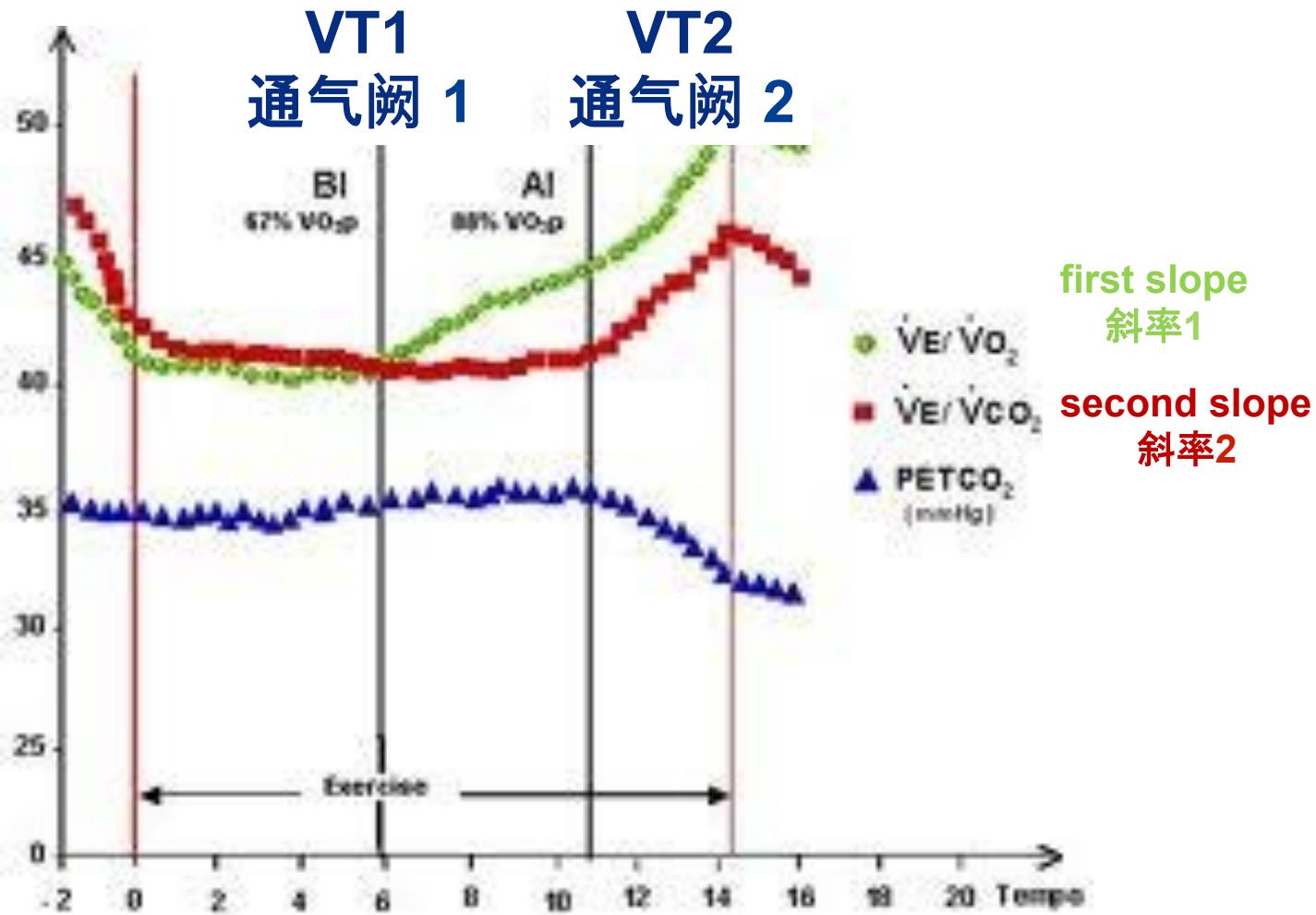
- Ventilatory equivalent for oxygen = Minute ventilation / VO₂

氧气通气当量=每分通气量/ 摄氧量

- Liters of ventilation per liter of oxygen uptake

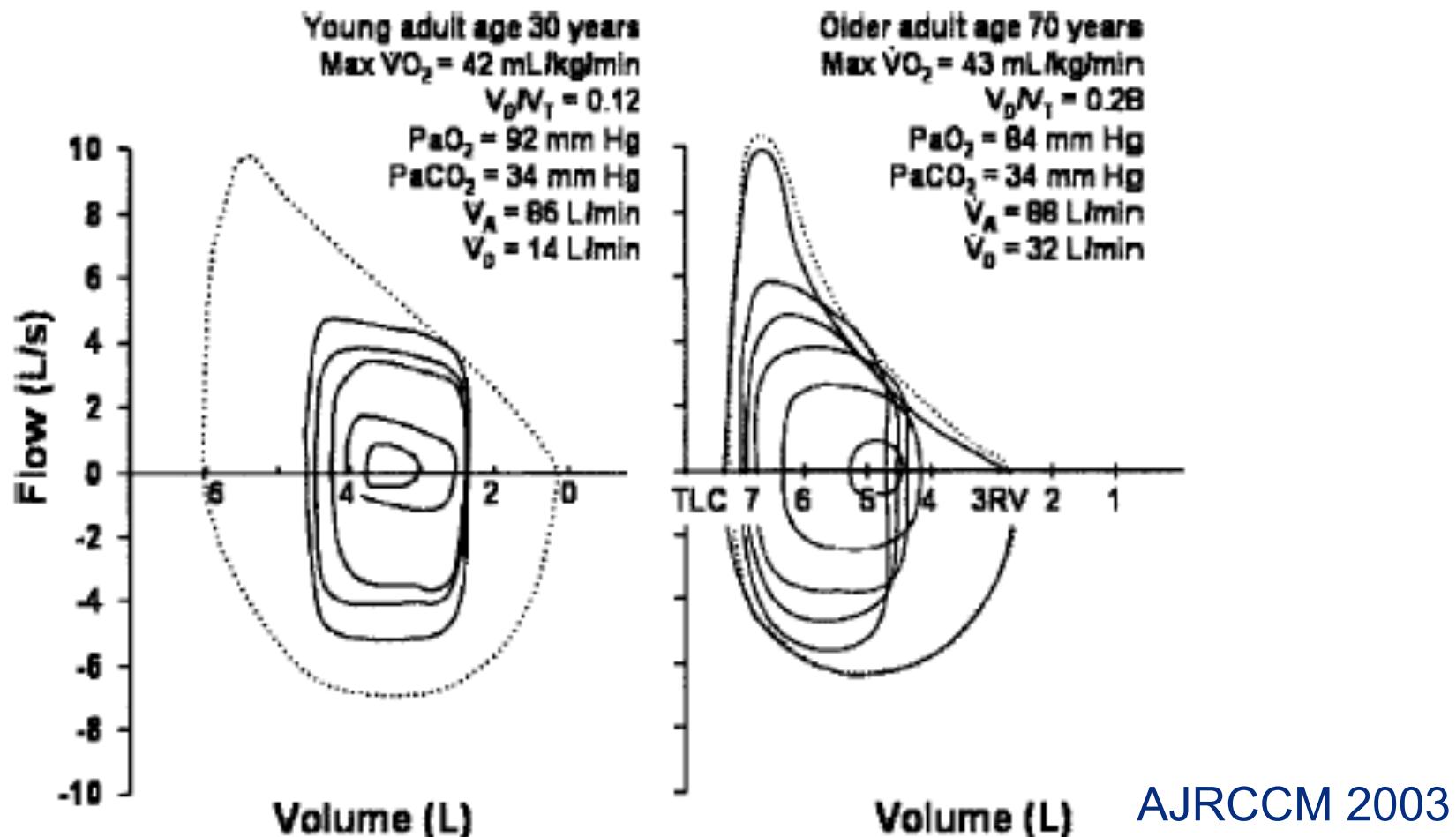
每摄取1公升氧气需要几公升的通气量

Determination of VT1/VT2 from panel 6 (also: ventilatory equivalents) 从图6测定VT1/VT2 (以及: 通气当量)



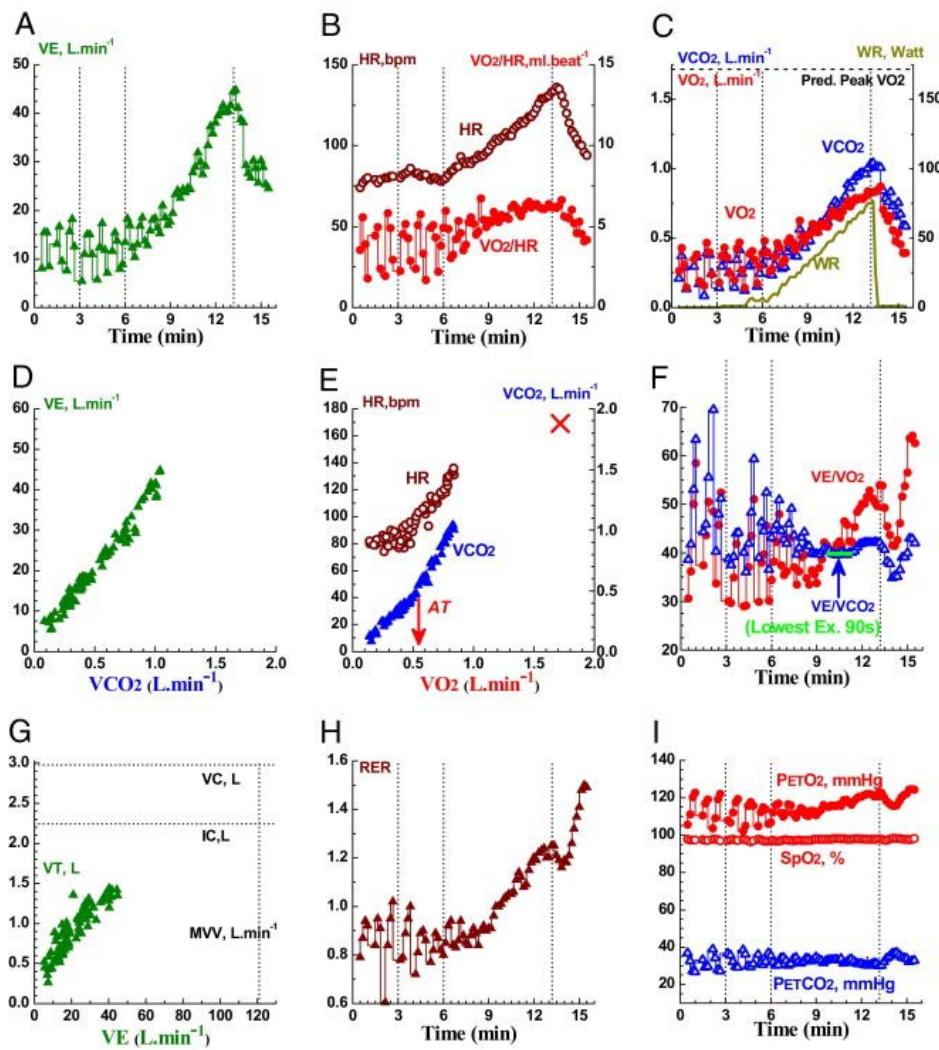
Normal Exercise Tidal Flow-Volume Loops

正常运动潮气流速-容量曲线



Wasserman's 9-Panel Plot

Wasserman 9图分析



CPET Interpretation

心肺运动功能测试解读

	Peak VO₂	HRR	BR	AT/VO₂max	A-a Diff
	峰值摄氧量	心率储备	卧床休息	AT/峰值摄氧量	A-a 差分
Normal 正常	>80%	<15%	>30%	>40%	normal 正常
Heart disease 心脏病	<80%	<15%	>30%	<40%	normal 正常
Pulm vasc disease 肺心血管疾病	<80%	<15%	>30%	<40%	increased 增高
Pulm mech disease 肺机械疾病	<80%	>15%	<30%	>40%	increased 增高
Deconditioning 去适应作用	<80%	>15%	>30%	>40%	normal 正常

Summary of CPET

心肺运动功能测试总结

- Cardiopulmonary measurements obtained at rest may not estimate functional capacity reliably
- 在休息时获得的心肺测量可能无法可靠地估计功能性能力
- CPET includes the measurement of expired oxygen and carbon dioxide
- 心肺运动功能测试包含对呼出的氧气和二氧化碳的测量
- the Borg scale is a validated instrument for measurement of perceptual responses
- Borg量表是一个经过验证的测量知觉反应的工具
- CPET is essential in pre-op evaluation and risk stratification, prognostication of life expectancy, therapy control (medication, devices like CRT) and disability determination
- 心肺运动功能测试在术前评估和风险分级、预测寿命、治疗控制(药物, 像起搏器这样的装置)和残疾测定方面是很重要的

“Normal” Values

“正常”值

TABLE 17. SUGGESTED NORMAL GUIDELINES FOR INTERPRETATION OF CARDIOPULMONARY EXERCISE TESTING RESULTS* 解读心肺运动功能测试结果的建议常规指南

Variables	变量	Criteria of Normality	常态标准
$\dot{V}O_{2\text{max}}$ or $\dot{V}O_{2\text{peak}}$	摄氧量最大值和峰值摄氧量	> 84% predicted	
Anaerobic threshold	无氧阙值	> 40% $\dot{V}O_{2\text{max}}$ predicted; wide range of normal (40–80%)	
Heart rate (HR)	心率	$HR_{\text{max}} > 90\% \text{ age predicted}$	
Heart rate reserve (HRR)	心率储备	$HRR < 15 \text{ beats/min}$	
Blood pressure	血压	< 220/90	
$O_2 \text{ pulse } (\dot{V}O_2/\text{HR})$	血氧脉搏 (摄氧量/心率)	> 80%	
Ventilatory reserve (VR)	通气储备	$MVV - \dot{V}E_{\text{max}}: > 11 \text{ L or } \dot{V}E_{\text{max}}/MVV \times 100: < 85\%$. Wide normal range: $72 \pm 15\%$	
Respiratory frequency (fr)	呼吸频率	< 60 breaths/min	
$\dot{V}E/VCO_2$ (at AT)	二氧化碳通气当量 (在无氧阙)	< 34	
V_D/V_T	生理无效腔	< 0.28; < 0.30 for age > 40 years	
Pao_2	动脉氧分压	> 80 mm Hg	
$P(A-a)O_2$	肺泡动脉氧分压差	< 35 mm Hg	

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“Typical” Response Patterns on CPET

心肺运动功能测试中的典型反应模式



测量	心力衰竭	慢性阻塞性肺病	间质性肺病	肥胖	去适应作用
峰值摄氧量				肺血管疾病	
心率储备				病	
血氧脉搏					
通气储备					
每分通气量/气体交换					
生理无效腔					
肺泡动脉氧分压差					

Approach to Interpretation of CPET

心肺运动功能测试的解读方法

American Thoracic Society/
American College of Chest Physicians

ATS/ACCP Statement on Cardiopulmonary Exercise Testing

THIS JOINT STATEMENT OF THE AMERICAN THORACIC SOCIETY (ATS) AND THE AMERICAN COLLEGE OF CHEST PHYSICIANS (ACCP)
WAS ADOPTED BY THE ATS BOARD OF DIRECTORS, MARCH 1, 2002 AND BY THE ACCP HEALTH SCIENCE POLICY COMMITTEE,
NOVEMBER 1, 2001

- Is the exercise capacity normal?
运功能力正常么?
 - peak VO₂, max work rate
峰值摄氧量, 最大工作效率
- Is the cardiovascular response normal?
心血管反应正常么?
 - HR vs VO₂, O₂ pulse, anaerobic threshold, VO₂ vs work rate
心率 vs 摄氧量, 血氧脉搏, 无氧阈值, 摄氧量 vs 工作效率
- Is the ventilatory response normal?
通气反应正常么?
 - V_E/MVV, max RR, PaCO₂
每分通气量/最大通气量, 最大呼吸储备, 动脉血二氧化碳分压
 - Is gas exchange normal? 气体交换正常么?
 - V_D/V_T, V_E/VCO₂, PaO₂, P(A-a) O₂, SpO₂
生理死腔/潮气量, 每分通气量/二氧化碳排出量, 动脉氧分压, 肺泡动脉氧分压差
血氧饱和度