DZHK
DEUTSCHES ZENTRUM FÜR
HERZ-KREISLAUF-FORSCHUNG E.V.

DZHK-SOP-C-07

Cardiopulmonary exercise test (spiroergometry)

Version: V1.2 Effective date: 21.06.2023

Replaces version: 1.1 Dated: 01.07.2015

Change note: Definition of the load limit
Supplementary information on treadmill protocols
Adaptation of the eCRF

This SOP is a translation from the original German SOP and valid without signatures. Printouts are not updated!

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1 INTRODUCTION

1.1 LIST OF ABBREVIATIONS

The following values are measured during the test and explained in the table below.

Abbreviation	Unit	Explanation	Standard parameter
[AT]		[Anaerobic threshold, equivalent to VT1]	
BE		Base excess	
BF	l/min	Breathing frequency	*
BGA		Blood gas analysis	
ECG/EKG		Electrocardiogram	
EQ CO_2		Ventilatory equivalent for CO_2, corresponds to VE/VCO_2	
EQO_2		Ventilatory equivalent for O_2, corresponds to VE/VO_2	
HCO3		Bicarbonate	
HR (exercise)	Beats per minute (bpm)	Heart rate at maximum exercise [highest value during exercise]	*
HR (resting)	Beats per minute (bpm)	Heart rate at rest [last value of the resting phase]	*
HRR	bpm or %	Heart rate reserve, as the difference between the calculated maximum heart rate (200 – age in years) and the maximum heart rate achieved – absolute or as a percentage	
MVV	l	Maximum voluntary ventilation as a calculated value (FEV1 x 41)	
O_2/HR	ml/heartbeat	Oxygen pulse, expressed as a ratio between oxygen uptake and heart rate	
PET CO_2 (exercise)	mmHg	Maximum value of the end-tidal CO_2 partial pressure	*
PET CO_2 (resting)	mmHg	End-tidal CO_2 partial pressure (at the end of exhaling) at rest [averaged across 3 minutes of resting]	*
PET CO_2-AT	mmHg	End-tidal CO_2 partial pressure at the aerobic/anaerobic threshold	
PET O_2-AT	mmHg	O_2 partial pressure at the aerobic/anaerobic threshold	
PET O_2-max	mmHg	Maximum value of O_2 partial pressure	

Abbreviation	Unit	Explanation	Standard parameter
PET O_2 (resting)	mmHg	End-tidal O_2 partial pressure at rest	
[RCP]		[Respiratory compensation point, corresponds to VT 2 (see 1.5)]	
RER		Respiratory exchange ratio, corresponds to RQ	
RQ (exercise)		Respiratory quotient at the end of exercise, corresponds to RER during exercise	*
RQ (resting)		Respiratory quotient at rest, corresponds to RER at rest	*
RQ maxpost		Maximum respiratory quotient post-exercise, corresponds to the max. RER post-exercise	
RR		Manual blood pressure measurement	
RRdia (exercise)	mmHg	Diastolic blood pressure at the end of exercise	
RRdia (resting)	mmHg	Diastolic blood pressure at rest	*
RRsys (exercise)	mmHg	Systolic blood pressure at the end of exercise	*
RRsys (resting)	mmHg	Systolic blood pressure at rest	*
SO_2 (exercise)	%	Peripheral oxygen saturation at the end of exercise	*
SO_2 (resting)	%	Peripheral oxygen saturation at rest	*
VE max	l/min	Maximum respiratory minute volume, measured during exhalation	*
VE max./MVV	%	Maximum achieved ventilation in relation to MVV	
VE/VCO_2 (resting)		Respiratory equivalent for CO_2 (volume of inhaled air to emit one litre of CO_2) at rest, corresponds to Eq CO_2 [averaged across 3 minutes of resting]	*
VE/VCO_2-AT		Respiratory equivalent for CO_2 at the aerobic/anaerobic threshold	
VE/VCO_2 slope		Increase (slope) of the ventilation-CO_2 ratio [determination via the slope (1 min. after starting exercise until RCP]	*
VE/VO_2 (resting)		Respiratory equivalent for O_2 (volume of inhaled air to absorb one litre of O2), corresponds to Eq O_2 [averaged across 3 minutes of resting]	*
VE/VO_2-AT		Respiratory equivalent for O_2 at the aerobic/anaerobic threshold	
VO_2 (AT)	ml/min	O_2 uptake at the aerobic/anaerobic threshold	*
VO_2 (normal)	ml/min	See section 8.2 for reference values	*

Abbreviation	Unit	Explanation	Standard parameter
VO_2 (resting)	ml/min	O_2 uptake at rest [averaged across a resting phase]	*
VO_2 peak	ml/min	Peak O_2 uptake at the end of exercise* [highest quantifiable value during exercise]	*
VO_2 peak/kg	ml/min/kg	Peak O_2 uptake per kilogram of bodyweight[1]	
VO_2-AT/kg	ml/min/kg	O_2 uptake at the aerobic/anaerobic threshold per kilogram of bodyweight	
VO_2/Watt	ml/Watt	Aerobic capacity	
VT	L	Tidal volume	
VT1		first ventilatory threshold, former AT	
VT2		equals respiratory compensation point (RCP)	

* Averaging of the respiratory gas analyses across 30 seconds

1.2 OBJECTIVE

Spiroergometry is used to assess general physical performance and endurance. For this purpose, a differentiated observation of the function of the cardiovascular, pulmonary and peripheral-muscular system is carried out at rest and at different timepoints during physical exercise. Important parameters in this observation are values of gas exchange (oxygen uptake at the anaerobic threshold and at maximum load, ratio of oxygen uptake and carbon dioxide release), of cardiovascular function (heart rate and blood pressure curves, ECG changes), of ventilation (determination of the respiratory minute volume, of the breathing pattern, of the coupling of gas exchange and ventilation, so-called breathing equivalents).

1.3 TARGET GROUP

The SOP shall be applied in all interventional studies and registries in the DZHK.

1.3.1 Inclusion criteria

All persons who are capable of cycling on an ergometer or of doing exercise on a treadmill and to whom no exclusion criteria apply may participate. Special inclusion criteria can be found in the study protocol of the respective study/registry.

1.3.2 Exclusion criteria

Absolute contraindications:

- acute relevant disease, e.g. recent myocardial infarction, systemic infections, thromboses or embolisms, acute exacerbation of a respiratory disease
- severe cardiac arrhythmias or block formation (AV block of II or III degree)
- insufficiently controlled arterial hypertension (RRsyst >170 mmHg, and/or RRdiast >110 mmHg)
- known symptomatic or severe aortic stenosis

Relative contraindications:

- resting tachycardia (>120 bpm)
- poorly controlled epilepsy with risk of seizure provocation by exercise
- symptomatic electrolyte disturbance or metabolic imbalance
- symptomatic cerebral circulatory disturbance

If necessary, specific criteria of the respective studies or registries have to be observed.

1.4 APPLICATION AND TASKS

Spiroergometry is a diagnostic procedure that qualitatively and quantitatively analyses the reactions and interactions of the heart, circulation, respiration and metabolism during gradually increasing

exercise. Three measurement signals are recorded by a breathing mask: the oxygen fraction of exhaled air, the carbon dioxide fraction of exhaled air and the volume of exhaled air. Together with the recorded heart rate and blood pressure, further meaningful parameters can be calculated from these variables. Modern devices are programmed to measure these variables with every breath (breath-by-breath analysis) using rapid analyzers and to numerically record and graphically process the results online using corresponding software.

1.5 TERMS AND DEFINITIONS

Anaerobic threshold determined by ventilation (AT or VT1): Defines the first increase in lactate and represents the beginning of the aerobic/anaerobic transition. This value can be determined via the first change in the slope in field 5 of the Wassermann graphs (see, for example, Meyer FJ and Preßler A. Stress testing - spiroergometry in DGIM Innere Medizin, Springer-Verlag 2018) (VCO_2/VE) or via the first increase in the oxygen equivalent in field 6 of the Wassermann graphs (EQO_2).

VE/VCO_2 slope: Defined as the slope of the straight line in field 5 (VE to VCO_2) value one minute after starting the exercise until VT2 (RCP).

Respiratory compensation point (RCP or VT2): Defined as the point at which there is a disproportionate increase from VE to VCO_2, read as an increase in $EQCO_2$ in field 6.

1.6 RELATIONSHIPS TO OTHER EXAMINATIONS

The relationships between the individual SOP to other procedures are outlined below.

Mandatory preliminary examination (SOP …):	Pulmonary function analysis
Recommended preliminary examination (SOP …):	Examination at rest
Preliminary examination to be excluded (SOP …):	Other exercise test
Impairment of other examination parts:	Other (exercise) tests

Mandatory follow-up (SOP …):	Does not apply
Recommended follow-up (SOP …):	Spiroergometry should be the last examination performed on the examination day
Follow-up to be excluded (SOP ...):	Echocardiography

1.7 QUALITY LEVEL

DZHK quality level	
Performance	
Level 1	The examination is performed in accordance with the guidelines of the scientific societies.
Level 2	The examination is performed in accordance with the specifications of the DZHK-SOP. Minimum requirements to ensure the quality of the implementation and the examiners are defined in the SOP.
Level 3	The examination is performed in accordance with the specifications of the DZHK-SOP and certification of the investigators: Definition of intra- and interobserver variability (standard of epidemiological studies).

This SOP describes level 2.

2 PREREQUISITES OF THE EXAMINATION

2.1 REQUIREMENTS REGARDING ROOMS/EQUIPMENT

Requirements regarding rooms

Recommended for all spiroergometry facilities:

- recommended temperature: 22°C (range 20-26°C) stable during the day, with as little ventilation as possible
- room temperature: is measured and adjusted automatically (+18 - +34°C)
- humidity: is measured and adjusted automatically
- brightness: no requirements
- air pressure: is measured and adjusted automatically
- no passage room, if possible washing facilities/shower for participating persons

Room equipment

- laptop for data entry
- color printer for printing the findings sheet
- desk with an office chair
- desk lamp
- telephone
- chair for participant
- body plethysmograph or spirometry (optional, sufficient if available in close proximity)
- blood gas analyzer
- ergometer
- spiroergometry workstation (complete)
- examination couch
- emergency case
- defibrillator
- blood pressure monitor for manual control
- BORG scale (6-20 or 0-10)
- gloves, consumables (including disinfectant wipes, gauze compresses, plasters)

2.2 DEVICES/HARDWARE

2.2.1 Device name and description

Center specific.

2.2.2 Calibration

It is important, among others, to perform calibrations using calibration gases (once per workday) according to the manufacturer's instructions.

In addition, volume calibration has to be performed on the device (after every examination).

Instrument calibration/verification is done daily before the start of the examination and includes the following components (performed according to the instrument-specific instructions):

- instrument calibration
- volume calibration

Volume calibration is carried out in the morning after the calibration and after each examination. As a result of the calibration, the computer calculates the correction factors.

The results of calibration and volume calibration are stored in the instrument.

- Gas analyzer calibration

Biological calibration

Every 12 months, the same person should perform an examination on the same spiroergometer to verify the plausibility of the entire system (especially if O2 electrodes with a time limitation are used).

If the room temperature changes by more than 5°C during the day, a new calibration has to be performed.

2.2.3 Sources of error

- Automatic blood pressure measurement:

With increasing load, there are more upper body movements of the participating persons, which can lead to incorrect measurements of the sensors due to movement. If implausible values occur, a second measurement should be done manually.

- ECG:

Movement and transpiration can cause detachment of electrodes. In this case, the electrode should be reattached or replaced (exchanged).

- Breathing mask:

Lack of contact of the breathing mask with the skin (e.g. small face, beard, talking, grimacing) can cause leaks that lead to incorrect breathing gas determination. Therefore, the correct fit of the mask should be checked prior to the examination and a different mask tried out if necessary. The participant should be instructed to speak only in case of emergency after the breathing mas has been fitted and to indicate a desired termination of the examination by means of a hand signal towards the examiner. The sample tubes located on the turbine should always point at least 45° upwards.

- Adjusting the seat height on the bike:

This has to be adjusted specifically for the participant prior to each examination to ensure an optimal transmission of force. Sufficient fastening of sturdy footwear to the pedals is mandatory.

2.2.4 Wear- spare parts

Masks:

- There should be 2-3 masks in varying sizes (children's mask, small, medium, large). The masks can be used as long as they are working correctly. The Velcro straps for fitting the masks have to be replaced as soon as sufficient closure for correct positioning of the mask is no longer given.

Sensors:

- A defective sensor may be the cause of a calibration error.

Condensate tube:

- The condensate tube should be replaced whenever the computer system displays a corresponding alert.

ECG suction electrodes:

- Replace only in case of a defect (decision by the medical technical staff).

2.2.5 Storage

No special requirements.

2.2.6 Maintenance/ device care

Clean and disinfect the device (ear clip, blood pressure cuff, ECG suction electrodes and cycle) with Cleanisept wipes after each use.

Maintenance is performed in accordance with EN 62353.

2.3 SPECIAL CLINICAL CONSUMABLES

Prepare the following items for the examination:

- 1 skin disinfectant spray,
- 1 pair of gloves,
- 3 lancets (optional),
- glass capillaries, if possible with lid systems (optional for ABG and/or lactate measurement),
- magnets (mixing wires) (optional for HSM, ICD deactivation),
- compresses,
- 1 small plaster,
- contact spray for ECG electrodes,
- Elacur ointment (optional)

2.4 ESSENTIAL DOCUMENTS

Information, informed consent, other clinical documents (see below).

2.5 ESSENTIAL INFORMATION

The correct choice of the testing program, complete information about the participating person, patient ID.

2.6 STAFF

The staff must have had special training and certification at the examination center (see section 6).

1 performing examiner (certified nursing staff or MTA).

1 assisting examiner (certified nursing staff or MTA) (if BGA collection is planned).

1 medical examiner on call to monitor and evaluate the examination.

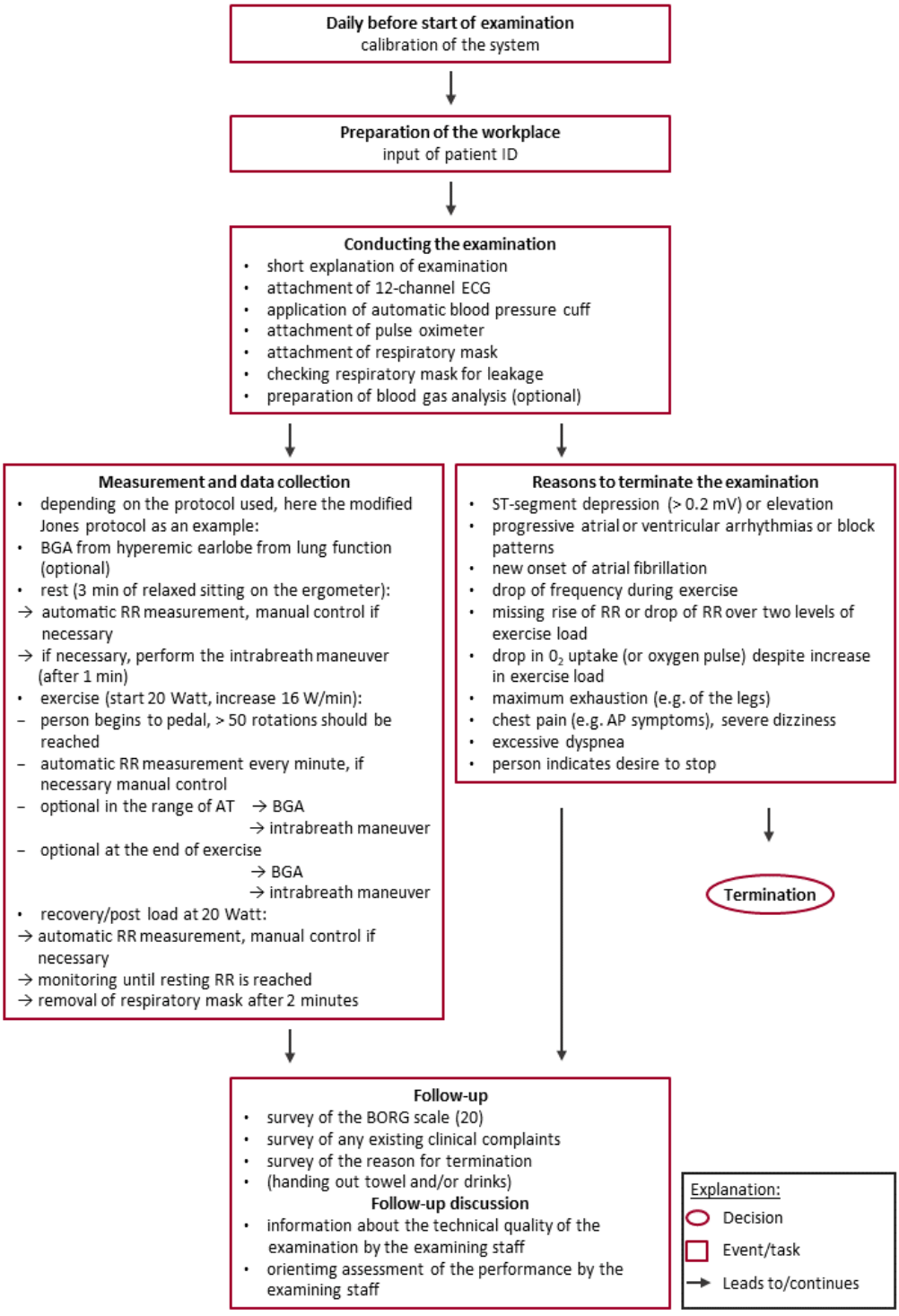
Staff must be trained on general emergencies and resuscitation.

Training of examining staff

Newly trained staff should accompany an experienced during 5 spiroergometries performed according to this DZHK-SOP-C-07, and then independently carry out at least 20 spiroergometries under supervision, and also complete the regular certification sessions of level 2/3.

3 IMPLEMENTATION/WORKFLOW/WORK STEPS

3.1 FLOWCHART OF THE PROCEDURE



3.2 PREPARING FOR THE EXAMINATION

3.2.1 Verification the informed consent form

In the context of studies, the in- and exclusion criteria are already described in the study information; so that all participants who give their consent can perform the examination. In the context of a clinical application, it is necessary to clarify whether there are contraindications to the performance of spiroergometry by means of a medical history or available doctor's letters and questioning of the participating person.

3.2.2 Identification of the participant

The identity of a participating person is clarified by querying name and date of birth. In the context of studies, a patient ID is entered into the software.

3.2.3 Checking inclusion criteria

3.2.4 Check whether consent for study participation has been obtained. **Preparing the workplace**

Disinfect the mentioned materials and equipment parts listed. Reach a comfortable room temperature, ventilate if necessary.

3.2.5 Preparing the devices

Preparation according to the device-specific instructions. Averaging of the respiratory gas analysis should take place over 10 seconds during the examination to ensure the monitoring of the patient and to enable the BGA sampling (optional) can be taken as close as possible within the range of the anaerobic threshold.

3.2.6 Preparing the participant for the examination

Explanations, instructions for participant

Spiroergometry:

- the ECG, blood pressure cuff, saturation clip and the breathing mask are now applied
- the breathing mask will be connected to a sensor that measures the respiratory gases. Do not speak after the sensor has been connected
- you must now sit quietly for 3 minutes[†] to record resting respiratory, blood pressure and ECG
- at the beginning you will start the examination with a load of 20 watts*, which will be increased by 16 watts* every minute. Please try to maintain 55-65 rotations when pedaling. [Note: example modified Jones protocol]
- at rest, during the exercise and just before the end of the exercise, I will ask you to take one deep breath and then to continue breathing normally; this is to record the intrabreath maneuver (optional, defined in the respective study protocol).
- the examination will be terminated by you, unless irregularities occur beforehand that result in the examination to be terminated. Please give us a signal with your hand when you want to

[†,*] The value depends in each case on the load protocol used (chapter 8.2)

end the examination. Please continue pedaling after your hand signal; I will decrease the load again to allow you to recover slowly at 20 watts.

- Immediately after ending the examination please use your fingers to rate your level of exertion using the BORG scale (6-20 or 0-10 depending on the requirements of the respective study protocol) which I am showing to you here. You must not speak yet.
- Do you have any questions?

Blood gas analysis (optional):

- During the examination, a colleague will assist me and will collect two samples of blood from your earlobe.

3.3 CARRYING OUT THE EXAMINATION

3.3.1 Exercise protocol

In principle, spiroergometry can be performed according to different exercise protocols that should be selected depending on the target population [2].

The respective study/registry protocol must define which protocol is to be used. A selection of cycling and treadmill protocols is provided in the appendix (see 8.2)

3.3.2 Preparing the participant, measuring position

- correct application of the 12-lead ECG
- correct application of the breathing mask and checking for leaks
- correct application of the blood pressure cuff
- correct application of the saturation sensor
- for cycle ergometers additionally:
- adjustment of seat height and handlebar on the ergometer
- attaching the Velcro fasteners of the pedals to the foot of the participating person
- for treadmills additionally:
- attaching the safety belt/auto-stop

3.3.3 Performing the stress test

Values measured at rest:

- first perform spirometry at rest to rule out significant lung disease (Tiffeneau's test); alternatively: pulmonary function testing prior to spiroergometry testing (spirometry, body plethysmography)
- then record the gas exchange for 3 minutes at rest
- start the exercise test if RER is < 1. If the RER is > 1 after 3 minutes at rest and still after another 3 minutes (total 6 min), the test should still be started
- measure the RR before starting the exercise phase. Prior to starting the exercise, the RR should not exceed 170/110 mmHg

3.3.4 Exercise phase:

- The speed will be constant at 55-65 rpm (bicycle ergometry) for the duration of the test. While the speed (cadence) remains constant, the resistance is gradually increased according to the exercise protocol. At the end of each stage, HR and RR are measured and noted
- the participants should be strongly encouraged to continue the exercise as long as possible (observing the termination criteria, see below)
- optional: if the RER is 0.9, preparation for the BGA should be started at the AT so that the blood sample can be collected before RER 1
- optional: the BGA at the end of the exercise is done if the participant indicates to end the test immediately, or if the examiner has the impression that the participant will stop the test soon (severe exhaustion, drop in cadence, etc.) or if reasons for termination are present
- the test should be continued until the participant meets subjective or objective termination criteria that justify terminating the test

  Objective termination criteria are:

  - ST-segment depression (> 0.2 mV) or elevation
  - progressive atrial or ventricular arrhythmia or block images
  - new onset atrial fibrillation
  - rate decrease during exercise
  - absence of rise or drop in RR across 2 levels of exercise
  - drop in O_2 uptake (or oxygen pulse) despite increase in load

  Subjective termination criteria are:

  - maximal exhaustion (e.g. of the legs)
  - chest pain (e.g. AP symptoms), severe dizziness
  - excessive dyspnea
  - participant indicates desire to discontinue

3.3.5 Recovery phase:

- the participant keeps the mask on
- immediately after the end of the exercise, the BORG scale is queried by means of hand signal
- the participant should continue pedaling without resistance for 2 minutes. After 2 more minutes, the participant should stop pedaling
- the mask should be removed at the earliest 2 minutes after starting the recovery phase
- continue the ECG, HR and RR measurements for at least 6 minutes in 2-minute intervals. Continue the RR measurements until the blood pressure returns to baseline
- during the recovery phase, it is a known that individuals may have a sharp drop in RR. Therefore, the participant should be asked regularly about dizziness and malaise. If dizziness/extreme pallor occur, or if the participant responds inadequately, the examination must be discontinued

3.3.6 Documentation:

- all relevant data will be documented in the eCRF after completing the examination

3.4 FOLLOW-UP AND DATA COLLECTION

Post processing of the examination

The spiroergometry equipment is cleaned with Cleanisept Wipes®. The mask and sensor are disinfected as described in section 1.3.2.

3.4.1 Biomaterial

As an optional analysis, one capillary of blood is collected from the earlobe hyperemized with ELACUR hot 2.0 % (Riemser®) at rest, in the anaerobic threshold region and at maximum load.

3.4.2 Preanalytics on site

The blood gas analysis is evaluated on site using a blood gas analyzer (e.g. ABL 90).

The analysis is either performed immediately or the capillary is sealed with a cap and analyzed after completion of the spiroergometry.

The following parameters are recorded at rest, in the anaerobic threshold range and during maximum load:

- pH value
- peripheral oxygen saturation (SO_2)
- partial pressure of oxygen (pO_2)
- partial pressure of carbon dioxide (pCO_2)
- base excess (BE)
  - bicarbonate (HCO_3-)
  - lactate

3.4.3 After the measurement

a) printout the exercise ECG

b) activate the blood gas mode and enter data (optional)

c) printout the findings

3.4.4 Follow-up discussion, feedback on findings

Whether and which information is shared with the participant has to be defined in the respective study protocol.

3.4.5 Evaluation / reporting of the examination

The evaluation of the spiroergometry data follows the recommendation of the EACPR and AHA [1]. It should be performed offline using appropriate software (e.g. JLAB, CareFusion Corporation, San Diego, USA) following the steps below, manual evaluation is also possible:

1. Checking the settings
   - ***Standard: Averaging of the respiratory gas analyses over 30 seconds***

2. Plausibility check
   - ***Review the following plausibility criteria using the 9-field chart:***
     - ✓ **RER** implausible if e.g. below 0.7 at rest
     - ✓ **VE** implausible if the respiratory minute volume is too low (rule of nine: increase of about 9 l/25 watts)
     - ✓ **Aerobic capacity** implausible if the VO_2 increase/watt is too low (rule of thumb in healthy individuals: power (watts) x 10 ml)

3. Determining the VO_2 peak:
   Highest VO_2 value achieved during exercise. A reliable statement about VO_2 peak is only possible if an RER >1.05 was achieved during exercise.

4. Determining the anaerobic threshold (AT or VT1):
   AT/VT1 is determined in the range one minute after starting the exercise until RER = 1, either by determining the change in the slope of the VE/VCO_2 curve (field 5) or the increase in oxygen equivalent (EQO_2) in field 6.

5. Determining the respiratory compensation point (RCP or VT2):
   The RCP is the point at which there is a disproportionate increase in VE to VCO_2, read as the increase in $EQCO_2$ in field 6.

3.5 DEALING WITH DEVIATIONS

Documentation/handling of/with irregularities

During the stress test, the participant may experience clinical complaints, ECG and blood pressure abnormalities or oxygen uptake disorders, which were mentioned in particular in the termination criteria. If any of these changes occur, the physician responsible for monitoring spiroergometry should be consulted in order to decide whether to continue or discontinue the examination. These abnormalities are documented in the software in the field for termination criteria.

Emergency equipment including a defibrillator and emergency kit must be available to provide first aid. If it is foreseeable that the incident requires extended medical care, inform the rescue coordination center by calling the emergency number 112 or a resuscitation team.

Termination criteria

Objective termination criteria include:

- ST-segment depressions (> 0.2 mV) or elevations
- progressive atrial or ventricular arrhythmia or block patterns
- new onset of atrial fibrillation
- rate decrease during exercise
- absence of RR rise or RR fall across 2 exercise levels
- decrease of O_2 uptake (or oxygen pulse) despite increase of load

Subjective termination criteria include:

- maximum exhaustion (e.g. of the legs)
- chest pain (e.g. AP symptoms), severe dizziness
- excessive dyspnea
- participant signals desire to terminate

4 DATA MANAGEMENT

Paper version/findings sheets

One complete report (including the ECG registration) is printed out in a paper version and archived chronologically.

Data flow

The data is stored locally in the PC. The data should be additionally secured by regular/daily backups.

Currently, all relevant information is entered manually into the eCRF. The following information should be obtained in all DZHK studies/registers:

1. process-related information:

- date of the examination (dd.mm.yyyy)
- cardiac pacemaker (yes/no/unknown/not assessed)
- cardiac rhythm (sinus rhythm/atrial fibrillation/pacemaker rhythm)
- use of beta-blockers (yes/no/unknown/not assessed)
- duration of exercise (mm:ss)
- type of exercise
    - treadmill with indication of specific protocol (drop-down list: Bruce protocol / modified Bruce protocol / modified Naughton protocol)
    - bicycle with indication of specific protocol (selection list: modified Jones protocol / WHO protocol)
- Specify reason for termination
    - - maximum exertion reached (Alternative criteria: RER > 1.1 [in exercise phase], heart rate > 80% of the age- / sex-specific /sex-specific set point (= 220/200-lifetime; caveat: beta-blockers), lactate > 4mM, VO_2 plateau [usually only in very well-trained people = Vmax])

      - ST-segment depression (> 0.2 mV) or elevation

      - progressive atrial or ventricular arrhythmia or block patterns

      - new onset of atrial fibrillation

      - rate decrease during exercise

      - absence of RR rise or RR fall across 2 exercise levels

      - decrease of O_2 uptake (or oxygen pulse) despite increase of load

      - maximum exhaustion (e.g. of the legs)

      - chest pain (e.g. AP symptoms), severe dizziness

      - excessive dyspnea

- participant signals desire to examiner to terminate

2. Findings

- Standard measurements (see "Standard parameters", Abbreviations and definitions, chapter 1)

5 LITERATURE AND REFERENCES

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6 MODIFICATIONS

Modifications as compared to the previous version.

Section	Description of the modifications as compared to the previous version
3.2.6	Editorial changes
3.3.4	Editorial changes
4	Definition of load limit
8.2	Supplementary information on treadmill logs

7 LIST OF CONTRIBUTORS

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8 APPENDIX

8.1 ECRF MODULE

Spiroergometry (20.06.2023 - 14:20:05 (CEST))

Examination details

I. **Was the cardiopulmonary exercise testing performed?*** ○ yes ○ no ○ unknown ○ not assessed

II. **Date of examination*** [ ] dd.mm.yyyy ○ unknown ○ not assessed

III. **Quality level*** [ ] 1)

Help:

Level 1
The examination is performed in accordance with the guidelines of the medical associations.

Level 2
The examination is performed in accordance with the specifications of the DZHK SOP. Minimum requirements to ensure the quality of the implementation and the examiners are defined in the SOP.

Level 3
The examination is performed in accordance with the specifications of the DZHK SOP and certification of the examiners: Definition of intra-observer and inter-observer variability (standard of epidemiological studies).

Examination

1. **Pacemaker*** ○ yes ○ no ○ unknown ○ not assessed
2. **Cardiac rhythm*** ○ sinus rhythm ○ atrial fibrillation ○ pacemaker rhythm ○ unknown ○ not assessed
3. **Use of beta blockers*** ○ yes ○ no ○ unknown ○ not assessed
4. **Duration of exercise*** [ ] mm:ss ○ unknown ○ not assessed
5. **Type of exercise***
   Treadmill* [ ] 2)
   Bicycle* [ ] 3)
6. **Reason for termination*** [ ] 4)

Help:

maximum exertion reached:
(Alternative criteria: RER > 1.1 [in exercise phase], heart rate > 80% of the age- / sex-specific /sex-specific set point (= 220/200-lifetime; caveat: beta-blockers), lactate > 4mM, VO2 plateau [usually only in very well-trained people = Vmax])

7. **HR (at rest)*** [ ] /min ○ unknown ○ not assessed
8. **Maximum HR (during exercise)*** [ ] /min ○ unknown ○ not assessed
9. **HR (1 minute after exercise)*** [ ] /min ○ unknown ○ not assessed
10. **RRsys (at rest)*** [ ] mmHg ○ unknown ○ not assessed
11. **RRdia (at rest)*** [ ] mmHg ○ unknown ○ not assessed

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12.	**RRsys (during exercise)***	☐ mmHg ○ unknown ○ not assessed
13.	**RRdia (during exercise)***	☐ mmHg ○ unknown ○ not assessed
14.	**Watt (max)***	☐ Watt ○ unknown ○ not assessed
15.	**VE/VCO2 (at rest)***	☐ ○ unknown ○ not assessed
16.	**VE/VCO2 (during exercise)***	☐ ○ unknown ○ not assessed
17.	**PET CO2 (at rest)***	☐ mmHg ○ unknown ○ not assessed
18.	**PET CO2 (during exercise)***	☐ mmHg ○ unknown ○ not assessed
19.	**VE/VCO2 slope***	☐ ○ unknown ○ not assessed
20.	**VO2 (at rest)***	☐ ml/min ○ unknown ○ not assessed
21.	**VO2 peak***	☐ ml/min ○ unknown ○ not assessed
22.	**VO2 Norm***	☐ ml/min ○ unknown ○ not assessed
23.	**VO2 AT***	☐ ml/min ○ unknown ○ not assessed
24.	**VE max***	☐ l/min ○ unknown ○ not assessed
25.	**BF (respiratory rate) (at rest)***	☐ l/min ○ unknown ○ not assessed
Help:	BF - breathing frequency	
26.	**BF (during exercise)***	☐ l/min ○ unknown ○ not assessed
Help:	BF - breathing frequency	
27.	**Maximum BF***	☐ l/min ○ unknown ○ not assessed
Help:	BF - breathing frequency	
28.	**VT (at rest)***	☐ ml ○ unknown ○ not assessed

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29.	**VT (during exercise)***	☐ ml ○ unknown ○ not assessed
30.	**VD/VT (at rest)***	☐ % ○ unknown ○ not assessed
31.	**VD/VT (during exercise)***	☐ % ○ unknown ○ not assessed
32.	**Saturation sO2 (at rest)***	☐ % ○ unknown ○ not assessed
33.	**Saturation sO2 (during exercise)***	☐ % ○ unknown ○ not assessed
34.	**Respiratory quotient (RQ) at rest***	☐ ○ unknown ○ not assessed
35.	**Respiratory quotient (RQ) during exercise***	☐ ○ unknown ○ not assessed
36.	**Respiratory quotient after end of exercise (RQ maxpost)***	☐ ○ unknown ○ not assessed
37.	**Used BORG scale***	○ Borg rating of perceived exertion scale (6/20) ○ Borg dyspnoea scale (0/10) ○ unknown ○ not assessed
	Borg rating of perceived exertion scale*	☐ 5)
	Borg – dyspnoea scale*	☐ 6)

Possible entries

Please select one of the following entries for the corresponding items marked above.

1)

1
2
3

2)

Bruce protocol
modified Bruce protocol
modified Naughton protocol)
unknown
not assessed

3)

modified Jones protocol
WHO protocol
unknown
not assessed

4)

maximum exertion reached
ST segment depression (> 0.2 mV) or elevation
progressive atrial or ventricular arrhythmias or block patterns
new onset of atrial fibrillation
rate decrease during exercise
absence of RR rise or RR fall across 2 exercise levels
decrease of O2 uptake (or oxygen pulse) despite increase of load
maximum exhaustion (e.g. of the legs)
chest pain (e.g. AP symptoms), severe dizziness
excessive dyspnea
participant signals desire to examiner to terminate
unknown
not assessed

5)

6 - no exertion at all
7 - extremely light
8
9 - very light
10
11 - light
12
13 - somewhat hard
14
15 - hard (heavy)
16
17 - very hard
18
19 - extremely hard
20 - maximal exertion
unknown
not assessed

6)

0 - nothing at all
0,5 - very, very slight (just noticeable)
1 - very slight
2 - slight
3 - moderate
4 - somewhat severe
5 - severe
6 - severe to very severe
7 - very severe
8 - very severe to very, very severe
9 - very, very severe (almost maximal)
10 - maximal dyspnoea
unknown
not assessed

8.2 CYCLE AND TREADMILL PROTOCOLS

The following exercise protocols are some of those used within the scope of DZHK studies and registers; this list can be continuously upgraded as needed:

1. Cycle ergometry

a) Modified Jones protocol [2]:

- 3-minute resting phase
- Start exercise with 20 Watts, then increase by 16 Watts every minute; symptom-limited termination of the exercise
- Advantage: availability of German reference values from a large sample of a population-based study [3-5].

b) WHO protocol [6, 7]:

- 3-minute resting phase
- Start exercise with 25 Watts, then increase by 25 Watts every 2 minutes; symptom-limited termination of the exercise.

2. Treadmill cardiopulmonary exercise test

a) Bruce protocol [8]:

- 3-minute resting phase
- Symptom-limited exercise in 6 stages (3 minutes per stage) with varying speeds and slopes:

Stage	Speed (km/h)	Slope (%)
1	2.7	10
2	2.7	12
3	2.7	14
4	4.0	16
5	5.4	18
6	6.7	20

b) modified Bruce protocol [9]

- 3-minute resting phase
- Symptom-limited exercise in 9 stages (3 minutes per stage) with varying speeds and slopes:

Stage	Speed (km/h)	Slope (%)
1	2.7	0
2	2.7	5
3	2.7	10
4	4.0	12
5	5.4	14
6	6.7	16
7	8.0	18
8	8.8	20

c) modified Naughton protocol [8]

- 3-minute resting phase
- Symptom-limited exercise in 13 stages (2 minutes per stage) with varying speeds and slopes

Stage	Speed (km/h)	Slope (%)
1	1.6	0
2	2.4	0
3	3.2	3.5
4	3.2	7
5	3.2	10.5
6	4.8	7.5
7	4.8	10
8	4.8	12.5
9	4.8	15
10	4.8	17.5
11	4.8	20
12	4.8	22.5
13	4.8	25

8.3 BORG SCALE

The original scale that was used to assess the level of perceived exercise (RPE, ratings of perceived exercise) went from 1-20. A non-linear correlation between the perceived exercise and performance was found, so that the scale was consequently changed to a scale from 6-20, which has been tried and tested over many decades [8, 9]. In addition to this, the scale enables an approximate estimation of the respective heart rate during dynamic exercise (in healthy persons) by multiplying it by a factor of 10 (scale rating x 10 = heart rate) [8, 9].

A different, new scale ranging from 1-10 was later published. The scale is suitable for other questions such as evaluating the level of pain and isometric stress.

It is recommended to preferably use the 6/20 scale for DZHK studies. The variant of the BORG scale to be used has to be stipulated in the study protocol of the respective studies.

BORG Ratings of Perceived Exercise

Subjectively perceived exertion with exercise according to Borg [10, 11]:

(Borg-RPE scale, RPE = ratings of perceived exercise)

6	No exertion at all
7	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard (heavy)
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

BORG Dyspnoea Scale

Subjectively perceived dyspnoea according to Borg [12]:

0	Nothing at all
0.5	Very, very slight (just noticeable)
1	Very slight
2	Slight
3	Moderate
4	Somewhat severe
5	Severe
6	Severe to very severe
7	Very severe
8	Very severe to very, very severe
9	Very, very severe (almost maximal)
10	Maximal dyspnoea