

The European Association of Preventive Cardiology Exercise Prescription in Everyday Practice and Rehabilitative Training (EXPERT) tool: A digital training and decision support system for optimized exercise prescription in cardiovascular disease. Concept, definitions and construction methodology.

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The EAPC **EX**ercise **P**rescription in **E**veryday practice & **R**ehabilitative Training  
(**EXPERT**) tool: a digital training and decision support system for optimized  
exercise prescription in cardiovascular disease.

Concept, definitions and construction methodology

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## **Abstract**

### *Background*

Exercise rehabilitation is highly recommended by current guidelines on prevention of cardiovascular disease (CVD), but its implementation is still poor. Many clinicians experience difficulties in prescribing exercise in the presence of different concomitant CVDs and risk factors within the same patient. It was aimed to develop a digital training and decision support system for exercise prescription in CVD patients in clinical practice: EAPC EXercise Prescription in Everyday practice & Rehabilitative Training (EXPERT) tool.

### *Methods*

EXPERT working group members were requested to define 1. diagnostic criteria for specific CVDs, CVD risk factors, and other chronic non-CV conditions, 2. primary goals of exercise intervention, 3. disease-specific prescription of exercise training (intensity, frequency, volume, type, session and programme duration), and 4. exercise training safety advices. The impact of exercise tolerance, common CV medications and adverse events during exercise testing were further taken into account for optimized exercise prescription.

### *Results*

Exercise training recommendations and safety advices were formulated for ten CVDs, five CVD risk factors (type 1 and 2 diabetes, obesity, hypertension, hypercholesterolemia), and three common chronic non-CV conditions (lung and renal failure and sarcopenia), but also accounted for baseline exercise tolerance, common CV medications and occurrence of adverse events during exercise testing. An algorithm, supported by an interactive tool, was constructed based on these data. This training and decision support system automatically provides an exercise prescription according to the variables provided.

### *Conclusion*

This digital training and decision support system may contribute in overcoming barriers in exercise implementation in common CVDs.

**Keywords:** cardiovascular disease, rehabilitation, exercise training, training and decision support system

## Introduction

Exercise training is a cornerstone in the prevention and treatment of cardiovascular disease (CVD), as it leads to reductions in CV event rates, hospitalisations, and improves CVD risk profile, exercise capacity, muscle strength and endurance, quality of life and life expectancy in patients with CVD (risk).<sup>1-4</sup> Participation to preventive programmes for therapy optimisation, adherence and risk factor management, that include exercise training, are now recommended for patients with CVD to reduce disease recurrence by the 2016 European guidelines for CVD prevention.<sup>5</sup>

To facilitate implementation of exercise training intervention in the treatment of patients with CVD (risk), clinical recommendations have been published.<sup>5</sup> In general, it is recommended that CVD patients should execute >150 minutes per week of endurance exercise training, ideally spread over three to five days per week. It is advised to initiate the exercise training intervention at a low(er) exercise intensity, and gradually increase this intensity. An energy expenditure of 1000–2000 kcal per week should be achieved, and endurance exercise training should be complemented by resistance exercise training two times per week at a moderate exercise intensity.<sup>5</sup> Also, neuromotor training involving balance, agility, and coordination exercise are recommended in specific indications.

However, evidence is accumulating that a different exercise prescription is required when different goals are aimed at (e.g. for reducing adipose tissue mass, improving blood lipid profile, exercise tolerance, or glycaemic control, etc) and according to the severity of CVD.<sup>6</sup> For example, it has been shown that in type 2 diabetes patients a higher exercise training frequency is key to greater clinical benefits (improvement in glycaemic control),<sup>7</sup> while in patients with symptomatic peripheral arterial disease walking, but not cycling, exercise training leads to improvements in walking capacity.<sup>8</sup> Tailoring the exercise training programme to each single patient according to his/her specificity is thus a crucial aspect in this endeavour. However, clinicians are confronted with the difficulties to properly prescribe exercise in presence of combinations of CVDs, CVD risk factors and/or other chronic non-CV diseases within the same patient and to keep patients adherent to the prescribed programme. Indeed, a large heterogeneity in exercise prescription (exercise type, frequency, volume, intensity, session and programme duration) has been shown in CV rehabilitation programmes.<sup>9-16</sup>

With this in mind, the European Association of Preventive Cardiology (EAPC) aimed to optimise exercise prescription in patients with different CVDs and risk factors by the publication of recommendations for prescription of specific exercise training modalities for patients with different CVD risk factors or CVDs.<sup>17,18</sup> However, these recommendations remained distinct between different CVDs and risk factors. Yet, the challenge for clinical practice is how to combine these different exercise training guidelines, taking into account CV medication intake, presence of common non-CV co-morbidities, and adverse events during exercise testing, when shaping an exercise prescription for a single individual. We hypothesised that CV rehabilitation specialists could potentially benefit from a

digital training and decision support system that assists them in exercise prescription.<sup>19</sup> Due to the complexity, such a tool must be able to define or advise automatically which exercise training programme should be prescribed.

The aim of the present paper is to describe the concept, definitions and construction methodology of a digital training and decision support system for exercise prescription for patients with CVD: EAPC **EX**ercise **P**rescription in **E**veryday practice & **R**ehabilitative **T**raining (EXPERT) tool. This tool is an interactive, digital training and decision support system that assists healthcare professionals to prescribe clinically effective and medically safe exercise training programmes in CVD patients. With such a tool, we aim to optimize exercise prescription for patients with CVD (risk), and hereby to contribute to increased short- and long-term clinical benefits.

In this paper, first the activities and composition of the EXPERT working group is described, thereafter the EXPERT tool construction methodology and use. Finally, exercise training recommendations for five imaginary cases (see Appendix 1), as generated by the EXPERT tool, are compared with exercise training recommendations generated by 18 cardiologists/CV rehabilitation specialists.

#### **EAPC EXPERT working group**

A working group of dedicated and experienced rehabilitation specialists from different European countries was first composed. Not all working group members were involved in the development of the EXPERT tool from the beginning. Some members agreed to participate at a later stage of the project. All contributors were chosen based on scientific and/or clinical expertise.

#### *Contributors and collaborations within EXPERT working group*

The EXPERT working group involved 33 experts in the rehabilitation of chronic internal diseases, and three computer science experts, from 11 European countries (see author list).

#### *Specific goals of EXPERT working group*

An interactive digital training and decision support system for exercise prescription was developed by the EXPERT project working group, and was endorsed by the European Association of Preventive Cardiology (EAPC). The goal of the EAPC is to optimize the implementation of, to spread scientific knowledge of, and to educate clinicians in secondary CV prevention. The following targets in the EXPERT project were agreed:

1. To design a digital training and decision support system that assists healthcare professionals to choose and adopt the most optimal exercise training intervention for CVD (risk) patients. The tool should act as a decision support/recommendation generating system.
2. To develop, validate and implement the digital training and decision support system as a web-based application, which assists healthcare professionals to choose and implement effective exercise training interventions in CVD (risk) patients.
3. To apply the tool in an educational context. The recommendations suggested by the tool allow to train healthcare professionals to better understand state-of-the-art exercise prescription, and to promote such prescription by an e-learning platform or educational activities.
4. To update and upgrade this digital training and decision support system according to new scientific evidence and to experiences emerged from research and clinical use.
5. By the clinical use of this digital training and decision support system it is possible to collect large amounts of data concerning exercise prescription and changes in CVD risk factors from different centres. By the analysis of such data, it is possible to inventory how exercise is prescribed in CV rehabilitation, and what is the impact of different exercise prescriptions on clinical benefits.

#### *Target audience of EXPERT tool*

The EXPERT tool is made and designed for cardiologists, physiotherapists, clinical exercise physiologists and/or nurses specifically involved in CV rehabilitation. The EXPERT tool may also be used by sport- and exercise medicine specialists, family physicians or endocrinologists, although it must be guaranteed that the exercise training intervention must be implemented in the proper setting with sufficient and specialised supervision. In the end, the implementation of exercise training intervention remains the full responsibility of the healthcare professional, i.e. the generated exercise prescription by the EXPERT tool must always be evaluated by sufficiently educated physicians or allied healthcare professionals.

### **Methodology of construction of EXPERT tool**

#### *Contributor tasks*

The chronology and passed timelines of EXPERT working group activities are displayed in Appendix 2.

Working group members were allocated to specific CVD's, CVD risk factors, or other chronic non-CV co-morbidities after the first official meeting (see [author list](#)), and were requested to 1. provide definitions or diagnostic criteria, 2. define the primary goal of exercise training intervention, 3. specify exercise training recommendations, and 4. indicate exercise training safety advices. These recommendations and definitions had to be based on (preferably in following order) current clinical



guidelines and position statements, meta-analyses, systematic reviews, randomised controlled trials, cohort studies, observational studies or expert opinions. The allocation of these experts to a specific steering group was based on specific scientific/clinical expertise. These recommendations and definitions were collected by the project coordinator who collaborated with computer science experts to construct the EXPERT tool.

#### *Definitions and diagnostic criteria of diseases and risk factors*

The different CVD's, commonly present chronic non-CV diseases, and CVD risk factors were defined according to international guidelines (see Table 1). These standards and criteria are also used in the EXPERT tool.

#### *Exercise intervention goals*

For each different CVD, CVD risk factor and other chronic non-CV co-morbidity, specific exercise intervention goals were formulated (see Table 2). These goals were selected as they are known to be associated with clinical status or morbidity/mortality. Exercise training prescriptions were based on these exercise intervention goals.

### **Construction and use of the tool**

#### *Step 1: patient characteristics*

Clinicians using the EXPERT tool have to fill out the patient's name, date of birth, body height and weight (from which body mass index (BMI) is calculated automatically), systolic and diastolic blood pressure, blood total and low-density lipoprotein (LDL) cholesterol concentration, fasting glycaemia, resting and peak heart rate during exercise testing, and peak oxygen uptake capacity (from which percentage of reference value is automatically calculated).<sup>36</sup> When certain thresholds of CVD risk factors are exceeded, these risk factors are automatically activated (with their corresponding exercise prescription). Based on percentage of normal peak oxygen uptake capacity, clinicians are alerted to adjust the initial exercise intensity accordingly. Resting heart rate and heart rate during peak exercise are used for detailed exercise intensity prescription (based on Karvonen formula). If certain data are not available (e.g. from exercise testing) the EXPERT tool still functions, but does not take into account these missing values for the generation of exercise prescription.

#### *Step 2: CVD's, CVD risk factors, and other chronic non-CV co-morbidities*

Clinicians using the EXPERT tool are able to select one or more of the following CVD's and CVD risk factors: primary indications for rehabilitation (e.g. coronary artery disease (with or without percutaneous coronary intervention (PCI), coronary artery bypass graft (CABG) surgery, or

endoscopic atraumatic CABG surgery (endo-ACAB), heart failure (with preserved or lowered left ventricular ejection fraction), cardiomyopathy, intermittent claudication, implantable cardioverter defibrillator (ICD) or pacemaker, ventricular assist devices, heart transplantation, valve disease or surgery, congenital heart disease, pulmonary hypertension), CVD risk factors (e.g. type 1 and 2 diabetes, obesity, hypertension, hypercholesterolemia/dyslipidemia). In addition, clinicians could select one or more chronic non-CV diseases to fine-tune exercise training prescription, such as sarcopenia, chronic pulmonary disease or renal insufficiency/failure. The decision to divide the above-mentioned diseases into primary indications, CVD risk factors, and other chronic non-CV co-morbidities may be pragmatic, but it reflects the clinical practice in exercise prescription for CVD (risk) and increases the feasibility and user experience of the EXPERT tool.

#### *Step 3: Cardiovascular medication interactions*

Medications with significant repercussions for exercise prescription and performance were included: beta-blockers (they alter target exercise heart rate), statins (they may cause myopathy and lower exercise tolerance), and exogenous insulin administration or oral meglitinide/sulfonylurea intake (they increase the risk for hypoglycaemia during and after exercise training). Clinicians using the EXPERT tool have the opportunity to select these medications so that exercise prescription can be further adapted according to medication intake.

#### *Step 4: Adverse events during exercise testing*

Adverse events during exercise testing that significantly affect exercise prescription, were also taken into account: myocardial ischemia (in which the myocardial ischemia threshold should be preferred as upper exercise intensity threshold), exercise-induced atrial fibrillation (altering exercise heart rate or the atrial fibrillation threshold should be preferred as upper exercise intensity marker), and presence of ICD (in which 10-20 beats below the ICD firing threshold should be preferred as upper exercise intensity threshold). Clinicians have the opportunity to select these conditions and exercise prescription will be further adapted according to these selections. Furthermore, cardiopulmonary exercise testing should preferentially be performed in patients with different CVD risk factors due to increased test-sensitivity for myocardial ischemia and other co-morbidities.

#### **Exercise training recommendations and exercise safety advices**

After execution of these four steps, the EXPERT tool is ready to generate an exercise prescription aiming to optimize the clinical benefits and medical safety of exercise training (see Figure 1 and 2). In addition, contra-indications for certain types of exercise, as well as which safety precautions should be taken into account, are clearly mentioned in the advice concerning medical safety. These safety

advices include which symptoms during exercise training may be anticipated and how to monitor these, and how to adapt training modalities to prevent eliciting/worsening in these symptoms. This exercise prescription can always be individually tailored by the clinician, stored and consulted during follow-up. In addition, web links to the most recent EAPC position statements on exercise training and rehabilitation are provided.

Definitions of different ranges of exercise intensity that were used in the EXPERT tool are mentioned in Table 3.<sup>37</sup>

### **The interactive EXPERT tool: capturing user requirements and prototyping**

The EXPERT tool guides the user in bringing all contributing factors for the particular patient in perspective and proposes an adaptable exercise training recommendation. In this way, the EXPERT tool invites the user to explore possibilities and perform simulations, by showing the effect on the exercise training recommendation of changing the selections of contributing factors (CVD's, CVD risk factors, medication,...). In short, the envisioned EXPERT tool would function as a training and decision support system for the rehabilitation expert.

An interactive, semi-functional prototype of the EXPERT tool, focusing on the overall workflow supported by the tool and on the initial "look and feel" and interactivity of the tool, was realised by the HCI group of Hasselt University. A preliminary version was demonstrated for the EXPERT group in May 2015 at EuroPrevent Lisbon and was welcomed by positive comments. Based on the experts' feedback, the prototype was further elaborated upon to be discussed again with the members of the EXPERT group in August 2015 at ESC London. Following this second round of expert feedback in the EXPERT group meetings, a small scale formative user test was organised with local rehabilitation experts of Jessa hospital in Belgium and members of the EXPERT working group. In the local setting, HCI techniques such as observations and thinking aloud were used to optimally capture the user requirements. Throughout the prototyping process, attention was given to functional features of the EXPERT tool, the recommendation algorithm and user experience. Besides assessing the overall concept of the EXPERT tool as a training and decision support system recommending exercise prescriptions for CV rehabilitation, this user testing stage has allowed us to define and test an initial validation protocol for the next stages of the project.

### **Results of comparison of exercise training advices by EXPERT tool vs. cardiologists/cardiovascular rehabilitation specialists.**

Eighteen cardiologists and physiotherapists involved in CV rehabilitation agreed to propose exercise training modalities for five imaginary patient cases (see Appendix 1, leading to 81 valid case

comparisons). These exercise advices were then compared with the advices from the EXPERT tool. From this comparative study, it was generally noticed that:

- the range in prescribed endurance exercise training intensity (based on %HRmax) by the clinicians was large and in 60 patient cases (74% of all cases) the exercise intensity range did not correspond with the EXPERT tool.
- in all 81 cases the patient was required to do strength training exercises, we observed that clinicians proposed this activity in 58 cases (72% of all cases).
- in all 81 cases the patient was required to execute additional types of exercises, we observed that clinicians proposed these activities in 20 cases (25% of all cases).
- the recommended minimal programme duration by the clinicians showed a large range (from 3 up to 52 weeks) and was often shorter when compared to the EXPERT tool: in 37 patient cases (46% of all cases) this was <12 weeks.
- the proposed exercise frequency and exercise session duration corresponded well with the EXPERT tool prescriptions.

## Discussion

In the present paper, the concept, definitions and construction methodology of the EXercise Prescription in Everyday practice & Rehabilitative Training (EXPERT) tool, a digital training and decision support system for optimised exercise prescription in CVD (risk), has been explained in detail. Such description allows future users of the EXPERT tool to understand the fundamentals of its function.

The EXPERT tool was developed over a three-year period. The development phase consisted of 1. the formation of a representative working group, 2. multiple meetings and discussions in the working group to reach consensus, 3. the construction of this tool, and 4. multiple validation phases with further optimisation of the tool. Eventually, a training and decision support system for exercise prescription in patients with CVD (risk) has been developed which automatically activates CVD risk factors (with accessory exercise prescription) during input of patient characteristics, and allows clinicians to select up to ten primary indications for rehabilitation, five CVD risk factors and three chronic non-CV diseases. It also allows clinicians to select certain CV medications (with significant impact on exercise prescription) and adverse events during exercise testing. The tool then automatically calculates the most optimal exercise prescription (exercise training intensity, frequency, duration, type, session and programme duration, additional exercise training modalities) based on this input, and it generates exercise training safety advices to optimise medical safety of exercise training. This exercise prescription can be changed by the clinician anytime and it allows clinicians to collect patient data and to review exercise prescriptions during follow-up. It thus follows that the EXPERT tool is the first digital system that allows and generates such detailed and comprehensive exercise prescriptions for patients with CVD, taking so many clinical aspects into account, and combining this information within one patient. However, in this tool currently no difference in exercise prescription is being made between inpatient and outpatient settings, or between supervised and unsupervised programs. It thus follows that clinicians who prescribe exercise should take these factors and circumstances into account to optimize medical safety and practical implementation. Despite the automatic calculation of exercise prescription by the EXPERT tool, it remains the full responsibility of the clinician to guarantee optimal medical safety and feasibility of exercise intervention.

The need for the standardisation of exercise prescription in CV rehabilitation throughout Europe was further confirmed by our own study in which exercise prescriptions by 18 CV rehabilitation experts for five imaginary patient cases were compared with exercise prescriptions generated by the EXPERT tool. The EXPERT tool interprets current European exercise recommendations and expert opinions. It was noticed that the prescribed exercise intensities by the clinicians were very often higher or lower, strength training exercises and additional exercise training strategies were prescribed less frequent,

and the rehabilitation programme duration was often shorter, when compared to the EXPERT tool advices. It is thus felt that by the implementation and use of the EXPERT tool, many clinicians will be stimulated to reconsider their exercise prescriptions.

The next step in this project is the clinical implementation of the EXPERT tool in CV rehabilitation settings and hospitals throughout Europe. This will allow the EXPERT working group to collect a large amount of data of numerous CVD (risk) patients in rehabilitation programmes to contribute to a further understanding of current exercise training prescription in Europe and the expected benefits of the selection of different exercise training modalities on short- and long-term clinical outcomes or exercise training adherence/drop-out. As such, these data may lead to refinements of current exercise training recommendations. Moreover, it is speculated that the use of the EXPERT tool in exercise prescription may lead to significantly greater clinical benefits, cost savings and innovative approaches to exercise prescription in clinical practice. Since the last decade, technological progress has led to a 'revolution' in rehabilitation medicine: tele-rehabilitation of heart disease patients is a nice example of how the use and implementation of these new technologies in clinical medicine leads to better treatment and outcomes.<sup>38,39</sup> Another potential opportunity is thus to implement the EXPERT tool in such tele-rehabilitation programmes.

Future activities within the EXPERT working group are anticipated to continue to adhere to the EXPERT working group goals, such as: 1. Further refinement of the EXPERT tool and implementation throughout the cardiology community. To provide a state-of-the-art digital tool for exercise prescription, it is mandatory to regularly update exercise training recommendations, 2. Epidemiological European study on i. Current exercise prescription in clinical practice and its agreement with clinical guidelines (within different centres, regions and countries), and ii. The clinical impact of the EXPERT tool-based cardiac rehabilitation vs. usual cardiac rehabilitation. Such studies are needed to further optimise the construct and design of the EXPERT tool, but also to be able to examine relations between exercise prescription and clinical benefits or therapy adherence in various CVD risk factors and diseases, and to examine whether a digital supported exercise prescription eventually leads to significantly greater clinical benefits and cost savings, as opposed to current exercise prescription throughout Europe. Such data can also contribute to a further refinement of clinical exercise training recommendations.

One current limitation of the EXPERT tool may be that it has not yet been thoroughly validated in clinical practice, although we have compared exercise prescriptions as generated by eighteen clinicians with exercise prescriptions as generated by the EXPERT tool. As a result, efforts should be made to continue executing such studies with this tool.

In conclusion, optimal exercise prescription remains a challenge due to the complexity of the combination of different CVD's or CVD risk factors, the influence of pharmacological treatment and

the presence of chronic non-CV diseases or adverse events during exercise testing. In this project, an interactive training and decision support system (EXPERT tool) was developed aiming to assist healthcare providers to better achieve this goal. The current report gives a detailed overview of the concept, definitions and construction methodology of this tool as well as the results of the testing in order to provide a clear understanding of its rationale and function.

**Conflicts of interest**

The Authors declare that there is no conflict of interest.

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**Authorship**

DH, PD, KC, LV, MFP, JN, VC, RP, EG, GRR, UC, JPS, EG, CHD, FE, AA, BR, MA, SSB, OB, PB, MB, RF, PF, EGP, EK, ML, DN, RR, MAS, CS, TT, CT, CV, HV, and PD contributed to the conception or design of the work. DH, PD, KC, LV, MFP, JN, VC, RP, EG, GRR, UC, JPS, EG, CHD, FE, AA, BR, MA, SSB, OB, PB, MB, RF, PF, EGP, EK, ML, DN, RR, MAS, CS, TT, CT, CV, HV and PD contributed to the acquisition, analysis, or interpretation of data for the work. DH, PD and KC drafted the manuscript. LV, MFP, JN, VC, RP, EG, GRR, UC, JPS, EG, CHD, FE, AA, BR, MA, SSB, OB, PB, MB, RF, PF, EGP, EK, ML, DN, RR, MAS, CS, TT, CT, CV, HV, and PD critically revised the manuscript. All gave final approval and agree to be accountable for all aspects of work ensuring integrity and accuracy.



## References

1. Rauch B, Davos CH, Doherty P. et al. The prognostic effect of cardiac rehabilitation in the era of acute revascularisation and statin therapy: A systematic review and meta-analysis of randomized and non-randomized studies - The Cardiac Rehabilitation Outcome Study (CROS). *Eur J Prev Cardiol* 2016 Oct 24. pii: 2047487316671181. [Epub ahead of print]
2. Lewinter C, Doherty P, Gale CP, et al. Exercise-based cardiac rehabilitation in patients with heart failure: a meta-analysis of randomised controlled trials between 1999 and 2013. *Eur J Prev Cardiol* 2015; 22: 1504-1512.
3. Sibilitz KL, Berg SK, Tang LH, et al. Exercise-based cardiac rehabilitation for adults after heart valve surgery. *Cochrane Database Syst Rev* 2016; 3: CD010876.
4. Lane R, Ellis B, Watson L, et al. Exercise for intermittent claudication. *Cochrane Database Syst Rev* 2014; 7: CD000990.
5. Piepoli MF, Hoes AW, Agewall S, et al. 2016 European Guidelines on cardiovascular disease prevention in clinical practice. *Eur J Prev Cardiol* 2016; 23: NP1-96.
6. Hansen D, Dendale P, van Loon LJ, et al. The impact of training modalities on the clinical benefits of exercise intervention in patients with cardiovascular disease risk or type 2 diabetes mellitus. *Sports Med* 2010; 40: 921-940.
7. Umpierre D, Ribeiro PA, Schaan BD, et al. Volume of supervised exercise training impacts glycaemic control in patients with type 2 diabetes: a systematic review with meta-regression analysis. *Diabetologia* 2013; 56: 242-251.
8. Sanderson B, Askew C, Stewart I, et al. Short-term effects of cycle and treadmill training on exercise tolerance in peripheral arterial disease. *J Vasc Surg* 2006; 44: 119-127.
9. Bjarnasons-Wherens B, McGee H, Zwisler AD, et al. Cardiac rehabilitation in Europe: results from the European cardiac rehabilitation inventory survey. *Eur J Cardiovasc Prev Rehabil* 2010; 17: 410-418.
10. Vromen T, Spee RF, Kraal JJ, et al. Exercise training programs in Dutch cardiac rehabilitation centres. *Neth Heart J* 2013; 21: 138-143.
11. Brodie D, Bethell H, and Breen S. Cardiac rehabilitation in England: a detailed national survey. *Eur J Cardiovasc Prev Rehabil* 2006; 13: 122-128.
12. Thompson DR, Bowman GS, Kitson AL, et al. Cardiac rehabilitation services in England and Wales: a national survey. *Int J Cardiol* 1997; 59: 299-304.
13. McGee HM, Hevey D, and Horgan JH. Cardiac rehabilitation service provision in Ireland: the Irish Association of Cardiac Rehabilitation survey. *Ir J Med Sci* 1998; 170: 159-162.
14. Abell B, Glasziou P, Briffa T, et al. Exercise training characteristics in cardiac rehabilitation programmes: a cross-sectional survey of Australian practice. *Open Heart J* 2016; 3: e000374.

15. Tramarin R, Ambrosetti M, De Feo S, et al. The Italian Survey on Cardiac Rehabilitation-2008 (ISYDE-2008). Part 3. National availability and organization of cardiac rehabilitation facilities. *Monaldi Arch Chest Dis* 2008; 70: 175-205.
16. Ambrosetti M, Doherty P, Faggiano P, et al. Characteristics of structured physical training currently provided in cardiac patients: insights from the Exercise Training in Cardiac Rehabilitation (ETCR) Italian survey. *Mon Arch Chest Dis* 2017; in press.
17. Vanhees L, Geladas N, Hansen D, et al. Importance of characteristics and modalities of physical activity and exercise in the management of cardiovascular health in individuals with cardiovascular risk factors. Recommendations from the European Association for Cardiovascular Prevention and Rehabilitation (Part II). *Eur J Prev Cardiol* 2012; 19: 1005-1033.
18. Vanhees L, Rauch B, Piepoli M, et al. Importance of characteristics and modalities of physical activity and exercise in the management of cardiovascular health in individuals with cardiovascular disease (Part III). *Eur J Prev Cardiol* 2012; 19: 1333-1356.
19. Achttien RJ, Vromen T, Staal JB, et al. Development of evidence-based clinical algorithms for prescription of exercise-based cardiac rehabilitation. *Neth Heart J* 2015; 23: 563-575.
20. Windecker S, Kolh P, Alfonso F, et al. 2014 ESC/EACTS Guidelines on myocardial revascularization. *Eur Heart J* 2014; 35: 2541-2619.
21. Montalescot G, Sechtem U, Achenbach S, et al. 2013 ESC guidelines on the management of stable coronary artery disease. *Eur Heart J* 2013; 34: 2949-3003.
22. Ponikowski P, Voors AA, Anker SD, et al. 2016 ESC Guidelines for the diagnosis and treatment of acute and chronic heart failure. *Eur Heart J* 2016; 37: 2129-2200.
23. Elliott PM, Anastakis A, Borger MA, et al. 2014 ESC Guidelines on diagnosis and management of hypertrophic cardiomyopathy. *Eur Heart J* 2014; 35: 2733-2779.
24. Rydén L, Grant PJ, Anker SD, et al. ESC Guidelines on diabetes, pre-diabetes, and cardiovascular diseases developed in collaboration with the EASD. *Eur Heart J* 2013; 34: 3035-3087.
25. Mancia G, Fagard R, Narkiewicz K, et al. 2013 ESH/ESC guidelines for the management of arterial hypertension. *Eur Heart J* 2013; 34: 2159-2219.
26. Catapano AL, Graham I, De Backer G, et al. 2016 ESC/EAS Guidelines for the Management of Dyslipidaemias. *Eur Heart J* 2016 Aug 27; Epub ahead of print.
27. Galiè N, Humbert M, Vachiery JL, et al. 2015 ESC/ERS Guidelines for the diagnosis and treatment of pulmonary hypertension. *Eur Heart J* 2016; 37: 67-119.
28. Tendera M, Aboyans V, Bartelink ML, et al. ESC Guidelines on the diagnosis and treatment of peripheral artery diseases: Document covering atherosclerotic disease of extracranial carotid and vertebral, mesenteric, renal, upper and lower extremity arteries. *Eur Heart J* 2011; 32: 2851-906.

29. Fielding RA, Vellas B, Evans WJ, et al. Sarcopenia: an undiagnosed condition in older adults— Current consensus definition: prevalence, etiology, and consequences. international working group on Sarcopenia. *J Am Med Dir Assoc* 2011; 12: 249-256.
30. Vestbo J, Hurd SS, Agustí AG, et al. Global strategy for the diagnosis, management, and prevention of chronic obstructive pulmonary disease: GOLD executive summary. *Am J Respir Crit Care Med* 2013; 187: 347-365.
31. Pellegrino R, Viegi G, Brusasco V, et al. Interpretative strategies for lung function tests. *Eur Respir J* 2005; 26: 948-968.
32. Raghu G, Collard HR, Egan JJ, et al. An official ATS/ERS/JRS/ALAT statement: idiopathic pulmonary fibrosis: evidence-based guidelines for diagnosis and management. *Am J Respir Crit Care Med* 2011; 183: 788-824.
33. National Kidney Foundation. KDOQI Clinical Practice Guideline for Diabetes and CKD: 2012 Update. *Am J Kidney Dis* 2012; 60: 850-886.
34. Vahanian A, Alfieri O, Andreotti F, et al. Guidelines on the management of valvular heart disease (version 2012). *Eur Heart J* 2012; 33: 2451-2496.
35. Baumgartner H, Bonhoeffer P, De Groot NM, et al. ESC Guidelines for the management of grown-up congenital heart disease (new version 2010). *Eur Heart J* 2010; 31: 2915-2957.
36. Gläser S, Koch B, Ittermann T, et al. Influence of age, sex, body size, smoking, and beta blockade on key gas exchange exercise parameters in an adult population. *Eur J Cardiovasc Prev Rehabil* 2010; 17: 469-476.
37. Vanhees L, De Sutter J, Geladas N, et al. Importance of characteristics and modalities of physical activity and exercise in defining the benefits to cardiovascular health within the general population: recommendations from the EACPR (Part I). *Eur J Prev Cardiol* 2012; 19: 670-686.
38. Frederix I, Hansen D, Coninx K, et al. Effect of comprehensive cardiac telerehabilitation on one-year cardiovascular rehospitalization rate, medical costs and quality of life: A cost-effectiveness analysis. *Eur J Prev Cardiol* 2016; 23: 674-682.
39. Frederix I, Hansen D, Coninx K, et al. Medium-Term Effectiveness of a Comprehensive Internet-Based and Patient-Specific Telerehabilitation Program With Text Messaging Support for Cardiac Patients: Randomized Controlled Trial. *J Med Internet Res* 2015; 17: e185.

## Tables and figures

**Table 1** Definition and diagnostic criteria for diseases and risk factors

| REHABILITATION INDICATION  | Diagnosis definition or criteria  |
|--|---|
| <b>Stable coronary artery disease (with indication for percutaneous coronary intervention or coronary artery bypass graft)<sup>20,21</sup></b> | Significant coronary stenosis in one or more coronary arteries ( $\geq 50\%$ stenosis), or patients with symptoms of angina pectoris during exercise, with or without coronary revascularisation by percutaneous coronary intervention or coronary artery bypass graft.   |
| <b>Heart failure<sup>22</sup></b>  | Typical symptoms (e.g. breathlessness, ankle swelling, and fatigue) and signs (e.g. elevated jugular venous pressure, pulmonary crackles, and displaced apex beat) resulting from an abnormality of cardiac structure or function (diminished cardiac output, diagnosed by echocardiography) due to long-standing hypertension, myocardial ischemia/infarction, valve disease, obesity, and/or diabetes. Both diastolic (preserved left-ventricular ejection fraction) and systolic (reduced left ventricular ejection fraction) heart failure is included.   |
| <b>Cardiomyopathy<sup>23</sup></b>   | In an adult, hypertrophic cardiomyopathy is defined by a wall thickness $\geq 15$ mm in one or more left ventricular myocardial segments—as measured by any imaging technique (echocardiography, cardiac magnetic resonance imaging or computed tomography), that is not explained solely by loading conditions. Genetic and non-genetic disorders can present with lesser degrees of wall thickening (13–14 mm); in these cases, the diagnosis of hypertrophic cardiomyopathy requires evaluation of other features including family history, non-cardiac symptoms and signs, electrocardiogram abnormalities, laboratory tests and multi-modality cardiac imaging.                          |
| <b>Obesity<sup>24</sup></b>  | Body mass index $>30$ kg/m <sup>2</sup> or (preferentially) a waist circumference $>94$ cm for males and $>80$ cm for females.  |
| <b>Type 1 diabetes<sup>24</sup></b>  | Type 1 diabetes: fasting blood glucose level $\geq 125$ mg/dl (7.0 mmol/l), 2-hour glycaemia $\geq 200$ mg/dl ( $\geq 11.1$ mmol/l) during oral glucose tolerance test, or glycated haemoglobin $\geq 6.5\%$ (48 mmol/mol).<br>Hyperglycaemia is due to (sudden) pancreatic beta-cell destruction leading to absolute insulin deficiency.   |
| <b>Type 2 diabetes<sup>24</sup></b>  | Type 2 diabetes: fasting blood glucose level $\geq 125$ mg/dl (7.0 mmol/l) 2-hour glycaemia $\geq 200$ mg/dl ( $\geq 11.1$ mmol/l) during oral glucose tolerance test, or glycated haemoglobin $\geq 6.5\%$ (48 mmol/mol).<br>Type 2 diabetes is characterized by a combination of insulin resistance and beta-cell failure, in association with obesity (typically with an abdominal distribution) and sedentary lifestyle. Insulin resistance and an impaired first-phase insulin secretion causing postprandial hyperglycaemia characterize the early stage of T2DM. This is followed by a deteriorating second-phase insulin response and persistent hyperglycaemia in the fasting state. |

|  |  |
|--|--|
| <b>Hypertension<sup>25</sup></b>   | Systolic blood pressure $\geq 140$ mmHg or diastolic blood pressure $\geq 90$ mmHg.  |
| <b>Hypercholesterolemia/Dyslipidaemia<sup>26</sup></b>                           | Blood low-density lipoprotein cholesterol content $\geq 100$ mg/dl (2.5 mmol/l) for high risk patients or $>70$ mg/dl ( $<1.8$ mmol/l) for very high risk patients.  |
| <b>Pulmonary hypertension<sup>27</sup></b>                                       | An increase in mean pulmonary arterial pressure $\geq 25$ mmHg at rest as assessed by right heart catheterization.   |
| <b>Intermittent claudication<sup>28</sup></b>                                    | The development of symptoms (reduced walking capacity and intermittent leg pain that is provoked by walking) related to peripheral arterial disease: an ankle-brachial index of $\leq 0.8$ or the mean of three ankle-brachial indexes of $\leq 0.90$ , or having undergone peripheral arterial revascularization.   |
| <b>Pacemaker &amp; implantable cardioverter defibrillator</b>                    | Presence of pacemaker or implantable cardioverter defibrillator.   |
| <b>Ventricular assist devices</b>  | Presence of ventricular assist device.   |
| <b>Cardiac transplantation</b>   | Presence of transplanted heart.  |
| <b>Sarcopenia<sup>29</sup></b>   | Lean tissue mass is less than 20%tile of adult reference values or an appendicular lean mass/height <sup>2</sup> of $\leq 7.23$ kg/m <sup>2</sup> in men and at $\leq 5.67$ kg/m <sup>2</sup> in women.  |
| <b>Chronic lung disease<sup>30-32</sup></b>                                      | Chronic obstructive pulmonary disease: people with a post-bronchodilator FEV <sub>1</sub> /FVC $< 0.70$ and reduced FEV.<br>Restrictive lung disease: total lung capacity $\leq 5^{\text{th}}$ percentile and normal FEV <sub>1</sub> /FVC.<br>Idiopathic interstitial lung disease: is a specific form of chronic, progressive fibrosing interstitial pneumonia of unknown cause, occurring primarily in older adults, limited to the lungs, and associated with the histopathologic and/or radiologic pattern of a usual interstitial pneumonia. It requires exclusion of other known causes of interstitial lung disease (e.g., domestic and occupational environmental exposures, connective tissue disease, and drug toxicity), the presence of a usual interstitial pneumonia pattern on high-resolution computed tomography in patients not subjected to surgical lung biopsy, and specific combinations of high-resolution computed tomography and surgical lung biopsy pattern in patients subjected to surgical lung biopsy. |
| <b>Renal failure (patients on dialysis)<sup>33</sup></b>                         | A glomerular filtration rate level less than 60 mL/min per 1.73 m <sup>2</sup> represents loss of half or more of the adult level of normal kidney function (renal insufficiency). A glomerular filtration rate less than 15 mL/min per 1.73 m <sup>2</sup> equals renal failure.  |
| <b>Valve disease/surgery (without coronary artery bypass graft)<sup>34</sup></b> | Aortic valve stenosis: valve area $< 1.0$ cm <sup>2</sup> , indexed valve area $< 0.6$ cm <sup>2</sup> /m <sup>2</sup> body surface area, mean gradient $> 40$ mmHg, maximum jet velocity $> 4.0$ m/s, velocity ratio $< 0.25$ .   |

Mitral valve stenosis: valve area  $<1.0 \text{ cm}^2$ , mean gradient  $>10 \text{ mmHg}$ .

Tricuspid valve stenosis: mean gradient  $\geq 5 \text{ mmHg}$ .

Valve regurgitation is based on qualitative (valve morphology, colour flow regurgitant jet, continuous wave signal of regurgitant jet, and other features), semi-quantitative (vena contracta width, upstream vein flow, inflow, and other features) and quantitative (effective regurgitant orifice area, regurgitant volume, and enlargement of cardiac chambers/vessels) criteria.

#### **Congenital heart disease<sup>35</sup>**

Atrial septal defect, ventricular septal defect, atrioventricular septal defect, patent ductus arteriosus, left ventricular outflow tract obstruction, coarctation of the aorta, Marfan syndrome, right ventricular outflow tract obstruction, Ebstein's anomaly, tetralogy of Fallot, pulmonary atresia with ventricular septal defect, transposition of the great arteries, congenitally corrected transposition of the great arteries, univentricular heart, patients after Fontan operation, right ventricular to pulmonary artery conduit, Eisenmenger syndrome and severe pulmonary arterial hypertension.

#### **In-hospital phase**

Being hospitalised for at least three consecutive days.

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Abbreviations: FEV, forced expiratory volume; FVC, forced vital capacity.

**Table 2** Exercise intervention goals in the EAPC EXPERT tool

| REHABILITATION INDICATION                                      | Goal of exercise intervention  |
|--|--|
| <b>Stable CAD (with clarification for PCI, CABG/endo ACAB)</b> | increase $VO_{2peak}$ up to 100% of normal value   |
| <b>Heart failure</b>   | increase $VO_{2peak}$ up to 100% of normal value   |
| <b>Cardiomyopathy</b>  | increase LVEF >60% or $VO_{2peak}$ up to 100% of normal value  |
| <b>Obesity</b>   | lower adipose tissue mass (BMI<25.0 kg/m <sup>2</sup> or (preferentially) a waist circumference <94 cm for males and <80 cm for females)   |
| <b>Type 1 diabetes</b>   | improve glycaemic control (HbA1c <7.0%)  |
| <b>Type 2 diabetes</b>   | improve glycaemic control (HbA1c <7.0%)  |
| <b>Hypertension</b>  | lower blood pressure (<140/90 mmHg)  |
| <b>Hypercholesterolemia/dyslipidaemia</b>                      | improve blood lipid profile (blood low-density lipoprotein cholesterol content <100 mg/dl (2.5 mmol/l) in high-risk patients or <70 mg/dl (<1.8 mmol/l) for very high risk patients. |
| <b>Pulmonary hypertension</b>                                  | lower pulmonary blood pressure (increase in mean pulmonary arterial pressure <25 mmHg at rest)   |
| <b>Intermittent claudication</b>                               | increase walking tolerance up to a normal walking capacity during 6-min walking test   |
| <b>Pacemaker &amp; ICD</b>                                     | improve functional capacity up to a normal walking capacity during 6-min walking test  |
| <b>Assist devices</b>  | improve functional capacity up to a normal walking capacity during 6-min walking test  |
| <b>Cardiac transplantation</b>                                 | increase $VO_{2peak}$ up to 100% of normal value   |
| <b>Sarcopenia</b>  | increase muscle mass up to an appendicular lean mass/height <sup>2</sup> of >7.23 kg/m <sup>2</sup> in men and >5.67 kg/m <sup>2</sup> in women                                      |
| <b>Chronic lung disease</b>                                    | improve functional capacity up to a normal walking capacity during 6-min walking test  |
| <b>Renal failure (patients on dialysis)</b>                    | improve functional capacity up to a  |

|   |   |
|---|---|
|   | normal walking capacity during 6-min walking test                                     |
| <b>Valve disease/surgery (without CABG)</b> | improve functional capacity up to a normal walking capacity during 6-min walking test |
| <b>Congenital heart disease</b>             | improve functional capacity up to a normal walking capacity during 6-min walking test |
| <b>In-hospital phase</b>                    | improve functional capacity up to a normal walking capacity during 6-min walking test |

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Abbreviations: CAD, coronary artery disease; PCI, percutaneous coronary intervention; CABG, coronary artery bypass graft; endo ACAB, endoscopic atraumatic bypass graft; COPD, chronic obstructive pulmonary disease; LVEF, left ventricular ejection fraction;  $VO_{2peak}$ , peak oxygen uptake capacity.



**Table 3** Definitions and criteria for different ranges of exercise intensity as used in the EXPERT tool

| Intensity                           | Lactate (mmol/l) | METs | VO2peak (%) | HRR (%) | HRmax (%) | RPE scale (/20) | Training zone               |
|-------------------------------------|------------------|------|-------------|---------|-----------|-----------------|-----------------------------|
| Low intensity, light effort         | 2-3              | 2-4  | 28-39       | 30-39   | 45-54     | 10-11           | Aerobic                     |
| Moderate intensity, moderate effort | 4-5              | 4-6  | 40-59       | 40-59   | 55-69     | 12-13           | Aerobic                     |
| High intensity, vigorous effort     | 6-8              | 6-8  | 60-79       | 60-84   | 70-89     | 14-16           | Lactate, aerobic, anaerobic |
| Very hard effort                    | 8-10             | 8-10 | >80         | >84     | >89       | 17-19           | Lactate, aerobic, anaerobic |

Abbreviations: METs, metabolic equivalents; VO2peak, peak oxygen uptake; HRR, heart rate reserve; HRmax, maximal heart rate; RPE, ratings of perceived exertion.

Based on reference 37.

**Figure 1** Conceptual representation of the general functioning of the EXPERT tool

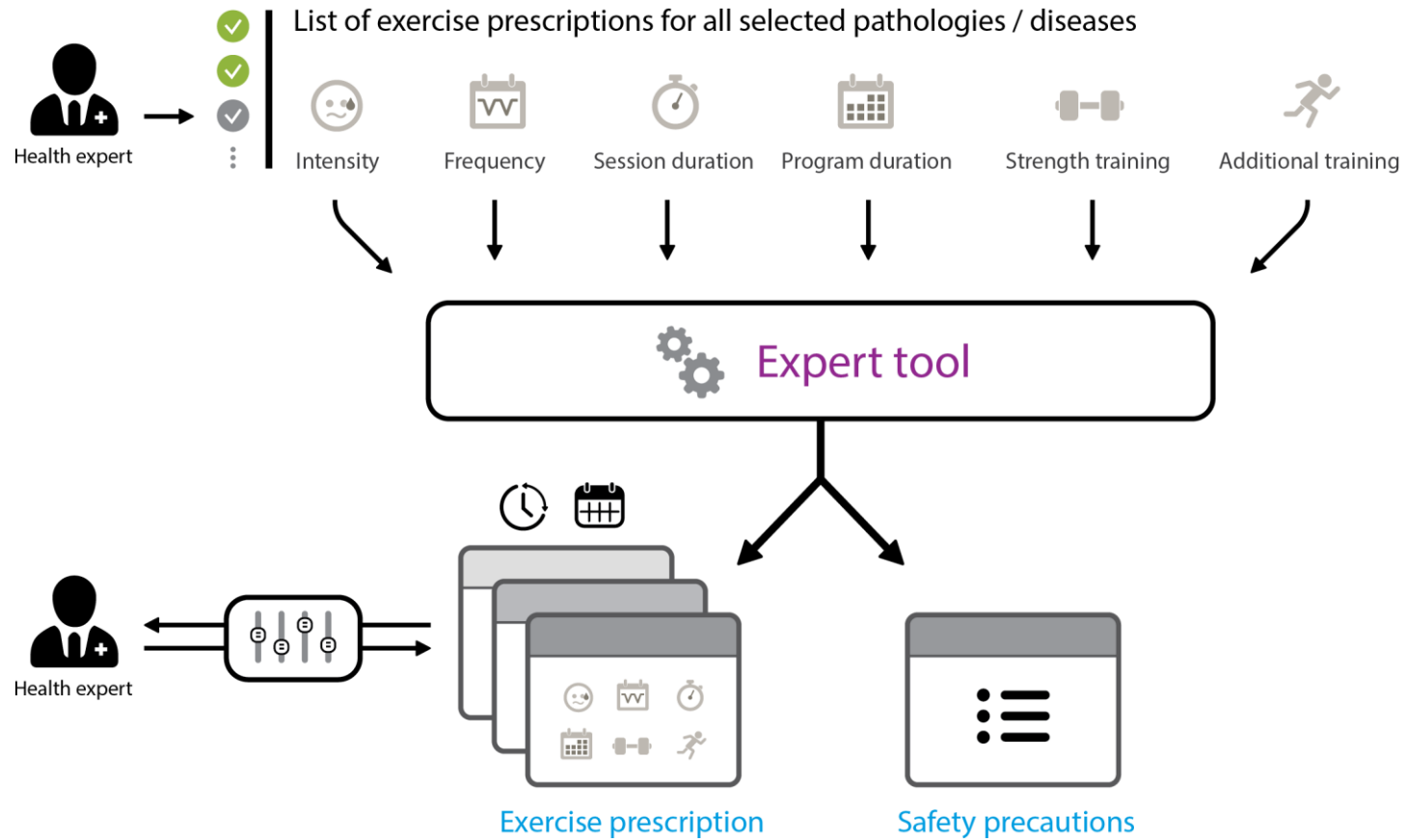


Figure 2 Screenshot of EXPERT tool working page

The screenshot shows a web browser window with the URL <https://expert-tool.edm.uhasselt.be/expert2.php>. The patient information bar at the top includes: case1 case1 26/02/1950, Male, 66 years; VO2 26.32 ml/kg/min, 2.5 L/min 116%; rest: 55 bpm, max: 123 bpm; 32.49; 95 kg; 171 cm; 145/82; glucose 85 mg/dl; cholesterol Total: 180 mg/dl. The main interface features several sections for selecting exercise parameters:

- Primary Indication:** CAD, PCI, CABG, and endo-ACAB. Options include L up to M, 3-5, 20-45, >8 weeks, and yes.
- Key Risk Factor:** Hypertension. Options include M up to H, daily, 30-60, >6 weeks, and yes.
- Exercise Modifier:** Not selected.
- Anomalies:** Not selected.
- Medication:** Beta Blocker.
- Recommendation:** Moderate HR: 82-95, daily, 20-60 min, >40 weeks, Yes. Includes a note: "In case of CABG surgery, strength training for the arm muscles are only allowed".

At the bottom, there are three buttons: "History of recommendations", "Safety Precautions", and "Links to ESC exercise training guidelines".

**Appendix 1** Imaginary cases for comparison of exercise prescription between EXPERT tool and cardiologists/CV rehabilitation specialists

| Case 1  | Case 2  | Case 3   | Case 4  | Case 5  |
|---|---|--|---|---|
| <p>Age: 65 years<br/>           Body height: 171 cm<br/>           Body weight: 65 kg<br/>           Sex: male<br/>           VO<sub>2</sub>max: 2500 ml/min (116% of predicted normal value)<br/>           Resting HR: 55 bts/min<br/>           Peak exercise HR: 123 bts/min<br/>           Total cholesterol: 180 mg/dl<br/>           Fasting glycaemia: 92 mg/dl<br/>           Blood pressure: 145/82 mmHg<br/>           Medication intake: beta-blocker, nitrate, statin, antiplatelet.<br/>           Referred to rehabilitation for: acute myocardial infarction with PCI.<br/>           Co-morbidities: None.</p> | <p>Age: 55 years<br/>           Body height: 160 cm<br/>           Body weight: 85 kg<br/>           Sex: female<br/>           VO<sub>2</sub>max: 1600 ml/min (108% of predicted normal value)<br/>           Resting HR: 102 bts/min<br/>           Peak exercise HR: 151 bts/min<br/>           Total cholesterol: 267 mg/dl<br/>           Fasting glycaemia: 108 mg/dl<br/>           Blood pressure: 115/72 mmHg<br/>           Medication intake: statin, ACE-inhibitor, orlistat, antiplatelet, metformin, sulfonylurea.<br/>           Referred to rehabilitation for: obesity.<br/>           Co-morbidities: type 2 diabetes.<br/>           Additional information: gonarthrosis present.</p> | <p>Age: 70 years<br/>           Body height: 182 cm<br/>           Body weight: 80 kg<br/>           Sex: male<br/>           VO<sub>2</sub>max: 1500 ml/min (73% of predicted normal value)<br/>           Resting HR: 52 bts/min<br/>           Peak exercise HR: 112 bts/min<br/>           Total cholesterol: 189 mg/dl<br/>           Fasting glycaemia: 102 mg/dl<br/>           Blood pressure: 125/80 mmHg<br/>           Medication intake: statin, antiplatelet, beta-blocker, digitalis, mucolytics, bronchodilators.<br/>           Referred to rehabilitation for: AMI with CABG.<br/>           Co-morbidities: Heart failure with preserved ejection fraction, mild COPD.</p> | <p>Age: 65 years<br/>           Body height: 165 cm<br/>           Body weight: 90 kg<br/>           Sex: female<br/>           VO<sub>2</sub>max: 1450 ml/min (90% of predicted normal value)<br/>           Resting HR: 52 bts/min<br/>           Peak exercise HR: 100 bts/min<br/>           Total cholesterol: 234 mg/dl<br/>           Fasting glycaemia: 115 mg/dl<br/>           Blood pressure: 135/75 mmHg<br/>           Medication intake: beta-blocker, statin, exogenous insulin, nitrate, erythropoietin.<br/>           Referred to rehabilitation for: stable myocardial ischemia (threshold at 87 bts/min)<br/>           Co-morbidities: renal failure, type 1 diabetes.<br/>           Additional information: chronic aspecific low back pain present.</p> | <p>Age: 79 years<br/>           Body height: 170 cm<br/>           Body weight: 59 kg<br/>           Sex: male<br/>           VO<sub>2</sub>max: 1250 ml/min (88% of predicted normal value)<br/>           Resting HR: 56 bts/min<br/>           Peak exercise HR: 111 bts/min<br/>           Total cholesterol: 178 mg/dl<br/>           Fasting glycaemia: 125 mg/dl<br/>           Blood pressure: 135/87 mmHg<br/>           Medication intake: beta-blocker, bronchodilator, antiplatelet.<br/>           Referred to rehabilitation for: peripheral vascular disease.<br/>           Co-morbidities: cachexia and frailty, COPD.</p> |
| EXPERT Exercise recommendation  |   |  |   |   |
| <p>INTENSITY<br/>           Moderate<br/>           HR 82-95 bts/min</p> <p>SESSION DURATION<br/>           20 up to 60 min</p> <p>FREQUENCY<br/>           5 days/week</p>   | <p>INTENSITY<br/>           Moderate<br/>           HR 122-131 bts/min</p> <p>SESSION DURATION<br/>           30 up to 60 min</p> <p>FREQUENCY<br/>           5 days/week</p>   | <p>INTENSITY<br/>           Moderate<br/>           HR 76-87 bts/min</p> <p>SESSION DURATION<br/>           20 up to 60 min</p> <p>FREQUENCY<br/>           5 days/week</p>  | <p>INTENSITY<br/>           Moderate<br/>           HR 71-80 bts/min</p> <p>SESSION DURATION<br/>           30 up to 60 min</p> <p>FREQUENCY<br/>           5 days/week</p>   | <p>INTENSITY<br/>           Up to claudication threshold</p> <p>SESSION DURATION<br/>           20 up to 60 min</p> <p>FREQUENCY<br/>           5 days/week</p>   |

|   |   |   |   |   |
|---|---|---|---|---|
| <p>MINIMAL DURATION<br/>40 weeks</p> <p>STRENGTH TRAINING<br/>yes</p> <p>ADDITIONAL TRAINING STRATEGIES<br/>Additional isometric handgrip exercise training is advised.</p> | <p>MINIMAL DURATION<br/>40 weeks</p> <p>STRENGTH TRAINING<br/>yes</p> <p>ADDITIONAL TRAINING STRATEGIES<br/>Additional isometric handgrip exercise training is advised. &gt;900 kcal/week of energy expenditure should be achieved.</p> | <p>MINIMAL DURATION<br/>40 weeks</p> <p>STRENGTH TRAINING<br/>yes</p> <p>ADDITIONAL TRAINING STRATEGIES<br/>In case of CABG surgery, strength training for the arm muscles are only allowed when the sternum is stabilized.<br/>Add inspiratory muscle training (IMT).<br/>Additional isometric handgrip exercise training is advised. &gt;900 kcal/week of energy expenditure should be achieved.<br/>Breathing exercises should be added.</p> | <p>MINIMAL DURATION<br/>40 weeks</p> <p>STRENGTH TRAINING<br/>yes</p> <p>ADDITIONAL TRAINING STRATEGIES<br/>Ending an exercise bout with HIT training is advised to prevent post-exercise hypoglycaemia.<br/>Additional isometric handgrip exercise training is advised. &gt;900 kcal/week of energy expenditure should be achieved.<br/>Flexibility and balance exercises should be added.</p> | <p>MINIMAL DURATION<br/>12 weeks</p> <p>STRENGTH TRAINING<br/>Yes</p> <p>ADDITIONAL TRAINING STRATEGIES<br/>Nordic walking and arm cranking exercises may be promoted.<br/>Additional isometric handgrip exercise training is advised.<br/>Muscle electrostimulation, balance training, or tai chi may be added.<br/>Breathing exercises should be added.</p> |
|---|---|---|---|---|

**Appendix 2** Chronology and timelines of EXPERT working group activities.

In the working group activities, the following chronology was respected:

1. Project proposal official presentation (EuroPrevent Rome, May 2013).
2. Steering group formation (June-August 2013).
3. Critical review analysis of the evidences by the group members (September 2013-February 2014).  
Working group members first consulted existing clinical exercise training guidelines or position statements, and further considered specific studies (preferentially meta-analyses, systematic reviews or randomised controlled trials) analysing the impact of different exercise modalities on CVD's or CVD risk factors. When no evidence was found, the working group relied on expert opinions.
4. Summary of literature outcomes, as delivered by working group members, by project leader (discussed during EuroPrevent Amsterdam, May 2014, and ESC Barcelona, August 2014).
5. Design and development of a preliminary, web-based, interactive training and decision support system (by UHasselt research institutes Biomed-Reval and EDM-HCI) (September 2014-February 2015).
6. Presentation of first EXPERT tool prototype to group members (EuroPrevent Lisbon, May 2015).
7. Pilot test phase of implementation and usability of the first prototype by steering group members: data on feasibility was collected (June-July 2015).
8. Presentation of updated EXPERT tool to group members (ESC London, August 2015).
9. Design of a more advanced version of the web-based, interactive EXPERT tool, developed as a digital training and decision support system for students and healthcare professionals in exercise training of CVD (September-December 2015).
10. Update of exercise training recommendations (January-March 2016).
11. Pilot test phase of implementation and usability of the updated EXPERT tool by cardiologists and physiotherapists involved in CV rehabilitation at Jessa hospital, Belgium, and by EXPERT working group members: data on feasibility and exercise recommendations for imaginary patient cases were collected (April-June 2016).
12. Update of the EXPERT-tool, based on feedback (July-October 2016).