

RESEARCH

Open Access



# Short term high-intensity interval training in patients scheduled for major abdominal surgery increases aerobic fitness

Anna Michel<sup>1</sup>, Vincent Gremeaux<sup>2,3</sup>, Guillaume Muff<sup>4</sup>, Basile Pache<sup>5</sup>, Sandrine Geinoz<sup>5</sup>, Ana Larcinese<sup>6</sup>, Charles Benaim<sup>4</sup>, Bengt Kayser<sup>3</sup>, Nicolas Demartines<sup>5</sup>, Martin Hübner<sup>5</sup>, David Martin<sup>5\*</sup> and Cyril Besson<sup>2,3</sup>

## Abstract

**Background:** Prehabilitation may improve postoperative clinical outcomes among patients undergoing major abdominal surgery. This study evaluated the potential effects of a high-intensity interval training (HIIT) program performed before major abdominal surgery on patients' cardiorespiratory fitness and functional ability (secondary outcomes of pilot trial NCT02953119).

**Methods:** Patients were included before surgery to engage in a low-volume HIIT program with 3 sessions per week for 3 weeks. Cardiopulmonary exercise and 6-min walk (6MWT) testing were performed pre- and post-prehabilitation.

**Results:** Fourteen patients completed an average of  $8.6 \pm 2.2$  (mean  $\pm$  SD) sessions during a period of  $27.9 \pm 6.1$  days. After the program,  $\dot{V}O_2$  peak ( $+ 2.4 \text{ ml min}^{-1} \text{ kg}^{-1}$ , 95% CI 0.8–3.9,  $p = 0.006$ ), maximal aerobic power ( $+ 16.8 \text{ W}$ , 95% CI 8.2–25.3,  $p = 0.001$ ),  $\dot{V}O_2$  at anaerobic threshold ( $+ 1.2 \text{ ml min}^{-1} \text{ kg}^{-1}$ , 95% CI 0.4–2.1,  $p = 0.009$ ) and power at anaerobic threshold ( $+ 12.4 \text{ W}$ , 95% CI 4.8–20,  $p = 0.004$ ) were improved. These changes were not accompanied by improved functional capacity (6MWT:  $+ 2.6 \text{ m}$ , 95% CI  $(- 19.6)$  to 24.8,  $p = 0.800$ ).

**Conclusion:** A short low-volume HIIT program increases cardiorespiratory fitness but not walking capacity in patients scheduled for major abdominal surgery. These results need to be confirmed by larger studies.

**Keywords:** Prehabilitation, CPET, Major abdominal surgery, Exercise, Aerobic capacity

## Background

Postoperative complications after major abdominal surgery are of public health and economic concern [1, 2]. The concept of Enhanced Recovery After Surgery (ERAS) contributes to reducing postoperative complications and improving patient comfort by implementing multimodal measures, starting in the preoperative period [3, 4]. Several surgical specialties now have started implementing training protocols

in the preoperative period [5–8]. Prehabilitation, as a principle of preoperative training, for example through adapted physical activity, may improve the general condition of patients prior to surgery [9]. Preoperative training protocols, as well as their results, vary widely between studies. For abdominal surgery, several reviews summarized the effects of chest physiotherapy, strength and/or endurance training, or multimodal programs that combine exercise, and nutritional and psychological support, showing promising results [10–13]. Among exercise modalities, short high-intensity interval training (HIIT) (e.g. 15-s periods of intense exercise interspersed with 15-s recoveries) is considered a safe, time-efficient and effective mean to

\*Correspondence: david.martin@chuv.ch

<sup>5</sup> Department of Visceral Surgery, Lausanne University Hospital CHUV, University of Lausanne (UNIL), Rue du Bugnon 46, 1011 Lausanne, Switzerland

Full list of author information is available at the end of the article



improve cardiorespiratory fitness in clinical populations [14–17]. Based on the protocols used in the initiation phase of cardiac rehabilitation patients with low exercise capacity, low-volume HIIT protocols appear to be more optimal [18]. These low-volume programs, performed at 80% of maximal aerobic power (MAP), are also already widely used and proved effective in patients with metabolic syndrome [19, 20].

Identifying the population at risk for complications post-surgery can be done in different ways [9]. Maximum oxygen consumption ( $\dot{V}O_{2\text{peak}}$ ) and oxygen consumption at anaerobic threshold ( $\dot{V}O_{2\text{AT}}$ ), which are measures of cardiorespiratory fitness, can be evaluated by Cardiopulmonary Exercise Testing (CPET). These measures are good predictors of all-cause mortality and cardiovascular events, and can also be used to predict morbidity risk after abdominal surgery [21–23]. In patients scheduled for resection of benign or malignant colorectal disease,  $\dot{V}O_{2\text{peak}}$  correlated well with functional effort capacity (6-min walk test (6MWT)), suggesting that pre-operative training may also improve functional capacity [24].

Prehabilitation's challenge is to improve the cardiorespiratory fitness of patients in a limited time frame, in order to positively impact the postoperative outcomes. In preparation of a controlled clinical trial, a prospective study of the effects of a 3-week HIIT prehabilitation program in patients scheduled for elective major abdominal surgery was designed [25]. The present article reports the results of this pilot study on the efficacy of the training modality on cardiorespiratory fitness and walking performance.

## Methods

### Study design

This article reports secondary outcomes of a prospective pilot study in preparation of a clinical trial in patients undergoing elective major abdominal surgery at the Lausanne University Hospital (CHUV) between May 2017 and January 2020 [25]. The ethics committee of the Canton de Vaud (#469/15) approved the study. The study was registered on [www.clinicaltrials.gov](http://www.clinicaltrials.gov) registry (NCT02953119) and was conducted in accordance with ethical standards of the Helsinki declaration. Written informed consent was obtained from all participants to the study.

Patients were included at the preoperative consultation by the operating surgeons, according to inclusion and exclusion criteria (supplementary material). Each patient gave written informed consent to participate. There was no extra surgery delay from participation to the study.

Patients were then addressed at the Sports and Exercise Medicine Department for medical clearance and CPET.

### Cardiopulmonary exercise testing

The clinical check-up upon inclusion included complete clinical history and examination, resting electrocardiogram (ECG), and the measurement of blood pressure, weight and height. Participants then completed a maximal CPET on an ergocycle (Corival CPET, Lode, Netherlands) to determine maximal aerobic power (MAP) and peak oxygen consumption ( $\dot{V}O_{2\text{peak}}$ , highest value of 20-s average [26]). After a 3 min rest, participants started 3 min of unloaded pedaling at 60 rpm (revolutions per minute). Power was increased with a ramp protocol of 10 to 25 W per min according to Wasserman's equation for exercise workload increments [27]. Oxygen consumption ( $\dot{V}O_2$ ), expired carbon dioxide ( $\dot{V}CO_2$ ) and minute ventilation were measured using a Cortex Metalyzer 3B gas exchange analyzer (Cortex Biophysik GmbH, Leipzig, Germany), which was calibrated for flow and gas concentrations before every procedure according to manufacturer recommendations. Stress ECG was monitored with a Custo Cardio 200 (Custo Med GmbH, Otterbrunn, Germany). The following maximum criteria were checked for each test: voluntary exhaustion, plateauing of the  $\dot{V}O_2$ -Work rate relationship ( $\dot{V}O_2$  increasing by less than 2 ml min<sup>-1</sup> kg<sup>-1</sup> following a power increment), peak heart rate (HR) within 10 beats·min<sup>-1</sup> of the age-predicted maximum, and peak RER above 1.10. CPET was considered as maximal if patients stopped because of exhaustion and if at least one of the other maximum criteria was met. Data on  $\dot{V}O_{2\text{peak}}$ ,  $\dot{V}O_{2\text{AT}}$ , MAP, relative MAP and peak heart rate ( $HR_{\text{peak}}$ ) were excluded from analysis if those criteria were not met.

Two experienced exercise physiologists blindly determined  $\dot{V}O_2$  and power at the anaerobic threshold ( $\dot{V}O_{2\text{AT}}$  and  $P_{\text{AT}}$ ) with established criteria [26]: (1) excess  $\dot{V}CO_2$  relative to  $\dot{V}O_2$  above the AT with the modified V-slope method; (2) identifying hyperventilation relative to oxygen; and (3) excluding hyperventilation relative to  $CO_2$  at the AT inflection point identified by criteria 1 and 2 [26]. If the difference between the physiologists was  $\leq 3\%$ , the results were averaged. When the difference was  $> 3\%$ , they each analyzed the test again and discussed until consensus. A sport physician and a cardiologist systematically interpreted CPET and patients were excluded in case of abnormal response to exercise [26]. Heart rate was extracted at rest, anaerobic threshold and peak. CPET was performed pre- and post-prehabilitation, for every patient according to the same standard procedures [26]. On the first and last day of the program, functional capacity was measured using the 6MWT [24]. Main variables were maximal aerobic power (MAP), aerobic

capacity ( $\dot{V}O_{2peak}$ ,  $\dot{V}O_{2AT}$ ), and functional capacity assessed by the 6MWT.

### High-intensity interval training

Patients performed the prehabilitation program supervised by physiotherapists until the day of surgery. The training protocol was based on a model used in a comparable study in lung cancer patients [5]. The work-out, based on the patients' individual CPET results, consisted of a 5-min warm-up at 50% of MAP, followed by 2 series of 10 min of 15 s of high-intensity intervals at 80% of MAP interspersed by 15 s at 35% of MAP (active pedaling), with a 4-min break of unloaded pedaling in between. The work-out ended with a 5-min cool-down at 30% of MAP. This represented a short interval low-volume protocol, as previously described [19]. Finally, stretching exercises were performed with the patient: stretching of the sural triceps, the quadriceps, the hamstrings and the back. No resistance training exercises were performed. Session duration was approximately 1 h and was adapted to each patient according to the results of their CPET. This training was performed 3 times a week for 3 weeks before surgery.

### Statistical analyses

Normality was assessed with Kolmogorov–Smirnov test. If normality passed, parametric statistics were used, and data are presented as mean, standard deviation (SD) and confidence interval (95% CI). When normality failed, non-parametric statistics were used, and data are presented as medians (interquartile range (IQR)). For comparisons, two-tailed paired t-tests were used for normally distributed data and Wilcoxon sign-rank tests for non-normal distributions. Statistical significance was set at  $p < 0.05$ . Correlations were assessed using Pearson correlation. GraphPad Prism, version 9.0.0 (86) and Excel, version 16.16.2 (180910) were used for analysis. Missing data were omitted based on the available case analysis (pairwise).

## Results

### Patients

Participation in the study was proposed to 44 patients fulfilling the inclusion criteria. Twenty of them agreed to participate, 3 were excluded for clinical reasons (abnormal CPET) and were referred for cardiology follow-up, and 1 patient had his surgery earlier. Two participants abandoned, finding the program too hard for their condition and lacking motivation. Fourteen patients completed the HIIT program. Their mean age was  $64 \pm 13.9$  years with 8 male and 6 female patients. The mean BMI (Body Mass Index) was  $28.4 \pm 5.9$  kg m<sup>-2</sup>. The mean number of completed training sessions was  $8.6 \pm 2.2$  over a period

of  $27.9 \pm 6.1$  days between CPETs. Full adherence to the training program was 88% (i.e. no missed training sessions). After prehabilitation, one patient did not achieve maximal effort on the second CPET due to fatigue, dyspnea and mask discomfort. Another took off his mask during the second CPET due to discomfort and his  $\dot{V}O_{2peak}$  values are missing. There were no adverse events observed during prehabilitation.

### Effects of prehabilitation

There were significant improvements in aerobic capacity and power output after prehabilitation, but not in functional testing and heart rate measures. Descriptive analyses of CPET results before and after the prehabilitation are shown in Table 1. Individual responses and absolute means of differences during CPET and 6MWT are shown in Figs. 1, 2 and 3. Patients had a significant increase in  $\dot{V}O_{2peak}$  of 13% (mean difference  $2.4$  ml min<sup>-1</sup> kg<sup>-1</sup>, 95% CI 0.8–3.9,  $p = 0.006$ ) as well as in  $\dot{V}O_{2AT}$  of 13% (mean difference  $1.2$  ml min<sup>-1</sup> kg<sup>-1</sup>, 95% CI 0.4–2.1,  $p = 0.009$ ).

Power at AT was significantly increased by 26% (mean difference  $12.4$  W, 95% CI 4.8–20,  $p = 0.004$ ). MAP increased by 14% (mean difference  $16.8$  W, 95% CI 8.2–25.3,  $p = 0.001$ ). The maximal relative aerobic power (MAP relative to body mass) increase was also significant (median difference  $0.2$  W kg<sup>-1</sup>, 97.95% CI 0.09–0.2,  $p = 0.007$ ) (Fig. 1).

Heart rate at rest, at anaerobic threshold and at peak increased by 1.1 bpm (mean difference, 95% CI (–5.9) to 8.0,  $p = 0.745$ ), 2.3 bpm (mean difference, 95% CI (–2.1) to 6.8,  $p = 0.281$ ) and 4.8 bpm (mean difference, 95% CI (–0.2) to 9.8,  $p = 0.060$ ) respectively, but none of these differences reached statistical significance (Fig. 2).

There was no significant difference between the first 6MWT (baseline) and the second 6MWT (after prehabilitation, before surgery) (mean  $539$  m  $\pm$  70 vs.  $542$  m  $\pm$  76; mean difference +3 m, 95% CI (–20) to 25,  $p = 0.806$ ) (Fig. 3). A correlation between the baseline  $\dot{V}O_{2peak}$  and the walking distance measured (6MWT 1) before prehabilitation was found but was not significant ( $r = 0.55$ , 95% CI (–0.03) to 0.9, R squared = 0.303,  $p = 0.063$ ), see Fig. 4. After prehabilitation (6MWT 2), the correlation was less and not significant either ( $r = 0.44$ , 95% CI (–0.2) to 0.8, R squared = 0.193,  $p = 0.153$ ).

## Discussion

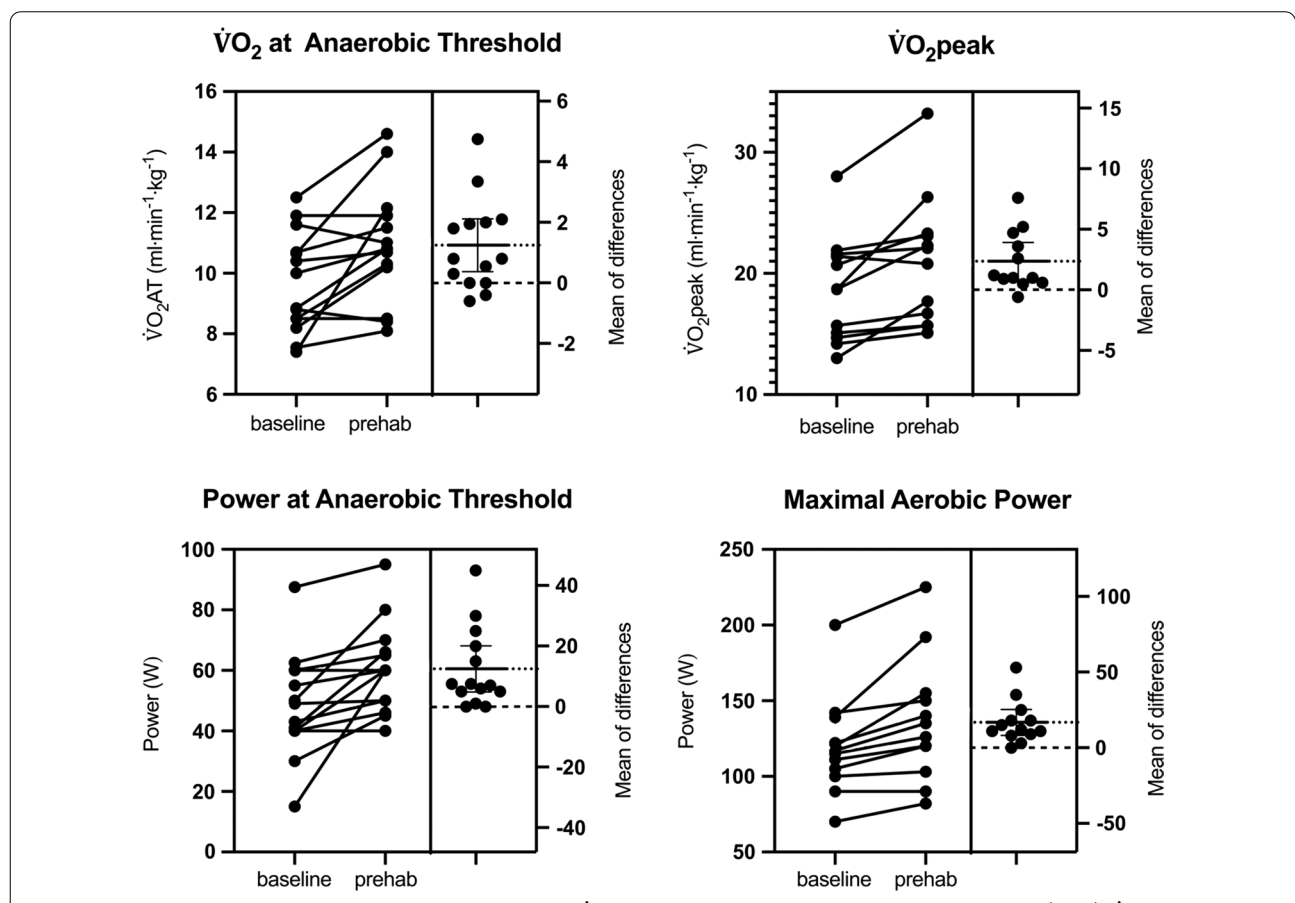
The main findings of the present study on the effects of a 3-week HIIT prehabilitation program in patients scheduled for major abdominal surgery were an increase in maximal and submaximal aerobic capacities, without any adverse effects. It thus proved possible to safely enhance exercise capacity of surgical patients scheduled for major

**Table 1** Descriptive analysis of cardiopulmonary exercise test results

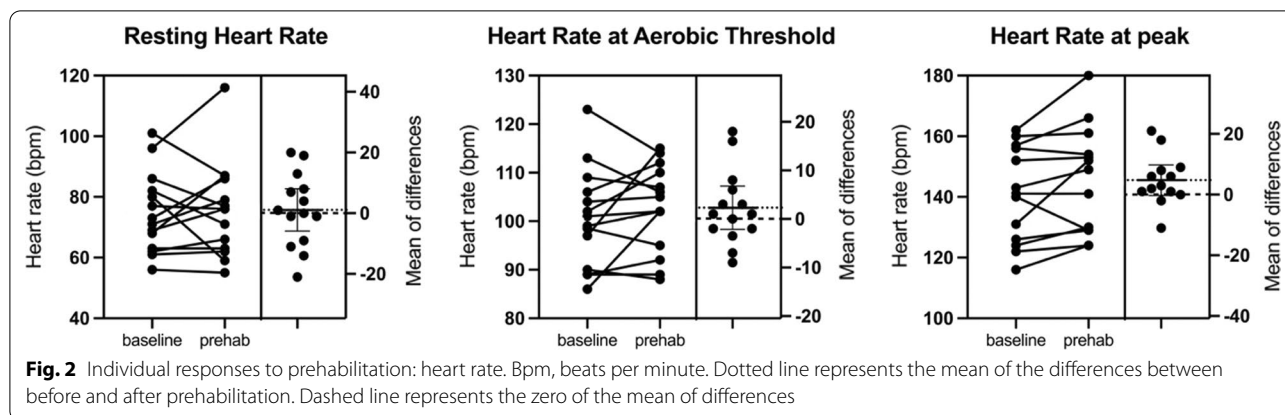
	Baseline (n = 14)	Prehabilitation (n = 14)	P value
HR <sub>rest</sub> (bpm)	74.6 (13.3)	75.7 (15.6)	0.745
HR <sub>AT</sub> (bpm)	100.5 (10.3)	102.8 (8.9)	0.281
HR <sub>peak</sub> (bpm)	140.8 (15.8)	145.5 (17.7)	0.060
$\dot{V}O_2AT$ (ml min <sup>-1</sup> kg <sup>-1</sup> )	9.7 (1.6)	10.9 (1.9)	0.009
$\dot{V}O_2AT$ (l min <sup>-1</sup> ) median, IQR	0.73 (0.2)	0.76 (0.2)	0.004
$\dot{V}O_2$ peak (ml min <sup>-1</sup> kg <sup>-1</sup> )	18.6 (4.3)	21 (5.3)	0.006
$\dot{V}O_2$ peak (l min <sup>-1</sup> )	1.47 (0.5)	1.66 (0.6)	0.007
P AT (W)	48.1 (18.1)	65.5 (14.7)	0.004
MAP (W)	118.9 (30.8)	135.7 (39.2)	0.001
MAP relative (W kg <sup>-1</sup> ) median, IQR	1.46 (0.4)	1.67 (0.5)	< 0.001
METS max	5.5 (1.2)	6.3 (1.4)	0.006

Data are presented in mean (SD). N = 14, unless clarified

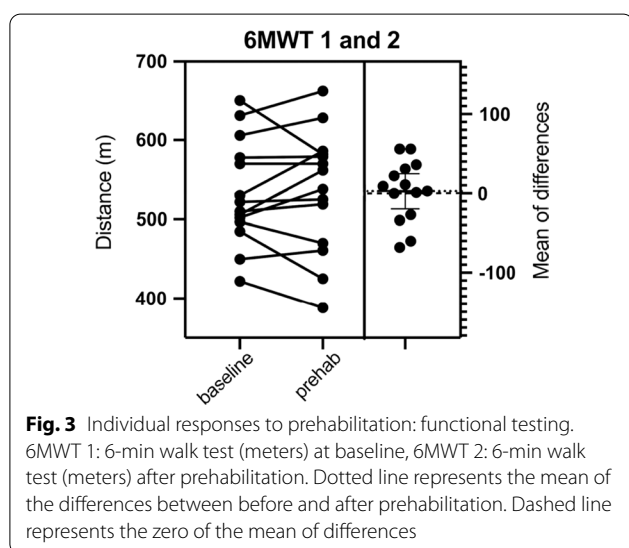
CPET: cardiopulmonary exercise testing; HR<sub>rest</sub>: heart rate before CPET (beats per minute); HR<sub>AT</sub>: heart rate at anaerobic threshold (beats per minute); HR<sub>peak</sub>: heart rate at maximal oxygen uptake (beats per minute) (n = 13),  $\dot{V}O_{2peak}$  (ml min<sup>-1</sup> kg<sup>-1</sup>): relative maximal oxygen uptake (n = 12, a patient took off his mask due to discomfort),  $\dot{V}O_{2peak}$  (l min<sup>-1</sup>): absolute maximal oxygen uptake (n = 12, a patient took off his mask due to discomfort);  $\dot{V}O_2AT$  (ml min<sup>-1</sup> kg<sup>-1</sup>): relative oxygen uptake at anaerobic threshold,  $\dot{V}O_2AT$  (l min<sup>-1</sup>): absolute oxygen uptake at anaerobic threshold; PAT: power at anaerobic threshold (W); MAP: maximal aerobic power (W) (n = 13); MAP relative: maximal aerobic power according to weight (W kg<sup>-1</sup>) (n = 13); METS: metabolic equivalent of task



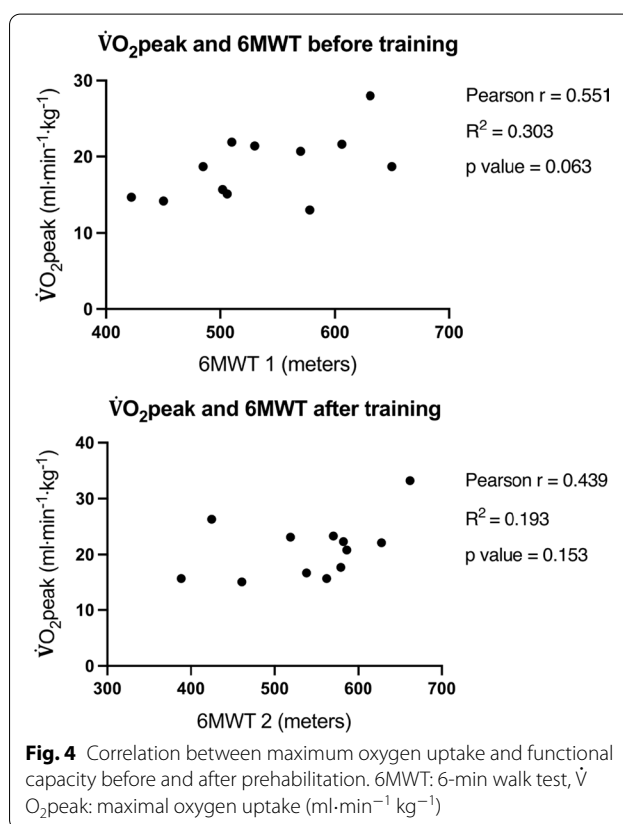
**Fig. 1** Individual responses to prehabilitation: aerobic capacities.  $\dot{V}O_2AT$ : oxygen uptake at anaerobic threshold (ml min<sup>-1</sup> kg<sup>-1</sup>),  $\dot{V}O_{2peak}$ : maximal oxygen uptake (ml min<sup>-1</sup> kg<sup>-1</sup>), Power at anaerobic threshold (P AT, watts), Maximal aerobic power (MAP, watts). Dotted line represents the mean of the differences between before and after prehabilitation. Dashed line represents the zero of the mean of differences



**Fig. 2** Individual responses to prehabilitation: heart rate. Bpm, beats per minute. Dotted line represents the mean of the differences between before and after prehabilitation. Dashed line represents the zero of the mean of differences



**Fig. 3** Individual responses to prehabilitation: functional testing. 6MWT 1: 6-min walk test (meters) at baseline, 6MWT 2: 6-min walk test (meters) after prehabilitation. Dotted line represents the mean of the differences between before and after prehabilitation. Dashed line represents the zero of the mean of differences



**Fig. 4** Correlation between maximum oxygen uptake and functional capacity before and after prehabilitation. 6MWT: 6-min walk test,  $\dot{V}O_{2peak}$ : maximal oxygen uptake ( $ml \cdot min^{-1} \cdot kg^{-1}$ )

abdominal surgery with a short-interval HIIT program over a limited time period.

Prehabilitation may enhance fitness levels and prepare patients to better cope with the stress caused by surgery [28]. The concept is to increase cardiorespiratory fitness and enhance functional reserve (i.e. a patient's functional capacities engaged in case of effort or disease-caused stress [29]), and thus decrease pre- and postoperative complications [30]. While there are encouraging results for several types of scheduled surgery, there still is limited literature reporting the efficacy of short-term training programs aiming at increasing fitness levels in patients prior to major abdominal surgery. There are various forms and volumes of HIIT, and this could represent a key variable of how successful a prehabilitation program may be. We therefore tested the hypotheses that in such patients, a low-volume HIIT program enhances aerobic capacity ( $\dot{V}O_{2peak}$  and  $\dot{V}O_{2AT}$ ) and maximal aerobic power (MAP), and secondarily, improves their functional performance as estimated by a walking test

(6MWT). The program had to be effective and time-efficient (e.g. meaningful gains in a short period) as many surgical acts cannot be delayed.

**Improvement in physiological parameters**

The significant increases in both  $\dot{V}O_{2AT}$  and  $\dot{V}O_{2peak}$  indicate a positive training response in these patients. These findings align with previous studies, despite the use of different interval protocols, either in volume and/or intensity [31]. Recent studies on patients scheduled



for major abdominal surgery, liver resection of colorectal liver metastasis, or lung cancer patients, found that after about 4 weeks of HIIT,  $\dot{V}O_{2peak}$  had increased similarly, between 2 and 3 ml min<sup>-1</sup> kg<sup>-1</sup> [5, 9, 32], or led to an improvement in cycling endurance at 80% of peak aerobic power [33]. In comparison, a recent review on gastrointestinal and thoracic surgery also reported significant increases in  $\dot{V}O_{2peak}$ , up to 2.8 ml min<sup>-1</sup> kg<sup>-1</sup>, using continuous exercise programs for at least 4 weeks [34]. HIIT may be more, or at least equally efficient, in terms of improvement in aerobic capacity among deconditioned patients who might have more difficulties maintaining longer efforts, and may be perceived as less difficult, compared to moderate continuous exercise programs [14–16]. Short-interval HIIT seems to be one of the most effective and safe training modalities, making it particularly suitable for the type of patients in the present study [5, 15, 17, 18, 35]. A recent review on cardiac rehabilitation for older patients with low functional capacity recommended to begin with short intervals, to then progress to medium- and long-interval HIIT, to amplify the accumulation of benefits from each protocol and thereby further increasing exercise and stress tolerance [16]. The present results' magnitude, 2.4 ml min<sup>-1</sup> kg<sup>-1</sup> increase in  $\dot{V}O_{2peak}$ , seems clinically relevant, as a 2 ml min<sup>-1</sup> kg<sup>-1</sup> is suggested by another on-going major abdominal surgery rehabilitation randomized controlled trial [36], and the finding that a 6% increase reduces time to all-cause mortality in chronic heart failure [37]. With regard to submaximal exercise, the clinical impact of an improved  $\dot{V}O_{2AT}$  was shown to be relevant from 1.5 ml min<sup>-1</sup> kg<sup>-1</sup> [32]. The present protocol elicited a significant 1.2 ml min<sup>-1</sup> kg<sup>-1</sup> improvement, slightly lower, suggesting room for improvement.

Along with enhancing aerobic capacities, maximal aerobic power (MAP) and power at anaerobic threshold also increased significantly. Bhatia et al. reported a significant increase in peak power output, along with an increase of  $HR_{peak}$ , suggesting that part of the observed increase in aerobic capacity may have come from their patients having pushed themselves further after completing a HIIT program [5]. In the present results,  $HR_{peak}$  showed a tendency to increase, as shown in Fig. 2. An average 3.5% increase in  $HR_{peak}$  was observed during the second CPET compared to the first. It is, therefore, possible that a part of the 13% increase observed in aerobic capacity was due to patients being able to push themselves somewhat further even though CPET maximality was reached according to the criteria used.

#### Functional data

Previous studies have supported that a small distance accomplished during 6MWT is a strong predictor of

postoperative morbidity and, according to Lee et al., provides an alternative to CPET if not available [24]. That study also reported a positive correlation between walking distance and  $\dot{V}O_{2peak}$  ( $R^2=0.52$ ,  $p<0.001$ ). Despite the small number of participants in the present study, a similar trend between walking distance and  $\dot{V}O_{2peak}$  before training could be observed, although not reaching significance (Fig. 4). It is possible that increasing walking distance preoperatively with specific training could further contribute to reducing postoperative morbidity risk. However, direct impact of prehabilitation on postoperative complications remains debated with discordant results [12, 33, 38]. Bhatia et al. [5], using a similar training protocol as ours, showed a median increase of 20% (14–26%) of 6-min walking distance in patients with lung cancer and suggested that patients translated their increased aerobic power into better exercise capacities in daily life settings. Apart from following a HIIT program their patients were also actively encouraged to walk and carried a pedometer. Our protocol did not include any walking exercises, which potentially could explain why we did not find any significant improvement in 6MWT distance.

#### Aerobic capacity and postoperative outcomes

Previous studies found that  $\dot{V}O_{2peak}$  and  $\dot{V}O_{2AT}$  are not only prime predictors for cardiovascular events and all-cause mortality [21, 23, 26], but also of morbidity of rectal cancer [22]. Prehabilitation prior to surgery favorable impacts on overall postoperative morbidity and pulmonary morbidity [6, 9, 10, 38]. A meta-analysis concluded that an increase of  $\dot{V}O_{2peak}$  by 3.5 ml min<sup>-1</sup> kg<sup>-1</sup> equals a 13–15% lower risk of all-cause mortality and cardiovascular mortality [21, 39]. Optimal CPET cut-offs to discriminate patients with potential greater postoperative morbidity were identified as <18.6 ml·min<sup>-1</sup>·kg<sup>-1</sup> of  $\dot{V}O_{2peak}$  and <10.6 ml·min<sup>-1</sup>·kg<sup>-1</sup> of  $\dot{V}O_{2AT}$  [22]. Depending on the type of pathology, those cut-offs may vary [23]. Along such cut-offs the patients of the present study could be considered low cardiorespiratory fit and at increased risk at baseline. Attesting to the relevance of training modalities such as used in the present study, the included patients who completed the program increased their  $\dot{V}O_2$  above these cut-offs, underlining the potential clinical relevance of such programs.

#### Limitations

Several limitations should be taken into account considering the results of this study. First, the number of included participants who finished the HIIT program was low. Second, in this pilot phase in preparation of a controlled trial, there was no control group receiving standard care but no training. Third, the training

modality was based on stationary cycling and did not include any other types of exercise such as walking. Future studies could propose multi-modality programs complemented with general life-style advice and counseling [12, 13, 28]. Fourth, the subjective experience of the patients and any musculoskeletal issues for the 6MWT were not evaluated. Grading of rate of perceived exertion and dyspnea during HIIT should be included in future studies to study their evolution along the training sessions over time. Fifth, the age distribution of the present population, with 10 out of 14 patients over 65 years old, limits any conclusions to the effects of HIIT on the age-related fitness physiological decline [33]. Considering that the incidence and mortality rate of cancer is increasing in younger patients [40], prehabilitation may also be beneficial for younger patients as well, but remains to be studied specifically.

## Conclusion

A short (3 week) low-volume HIIT program before major elective abdominal surgery is safe and enhances aerobic capacities of patients with low baseline fitness but does not improve functional ability as quantified with the six-minute walking test. These results need to be confirmed by larger studies, and such programs need to be integrated more systematically in treatment plans.

## Practical implications

- A single modality preoperative stationary cycling HIIT program of 3 weeks before major elective abdominal surgery is safe and improves aerobic capacity.
- Such a short HIIT program does not confer improved functional ability as quantified with the 6-min walking test.

## Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s13102-022-00454-w>.

**Additional file 1.** Inclusion and exclusion criteria.

## Acknowledgements

The authors would like to thank all PISO collaborators who made it possible to carry out this study (25). The authors also thank the physiotherapy team (Caroline Botteau, Joel Rossière, Fabrice Giordano) and Dr. Mathieu Saubade and Dr. Vincent Gabus for their help in patients' evaluations.

## Author contributions

BP, CB, BK, ND, MH and DM designed the study. DM, BP and AM did the inclusion visits. CB, GM and CB performed and analyzed CPET. AL was the head of the team supervising the training sessions. AM, DM and CB analyzed the data.

AM, VG, BK and CB wrote the manuscript. All authors read and approved the final manuscript.

## Funding

This study was supported by the Centre Hospitalier Universitaire Vaudois (CHUV).

## Availability of data and materials

The datasets generated and/or analysed during the current study are not publicly available because these data are protected by the institution (CHUV), under cover of an ethical protocol (CER-VD), but are available from the corresponding author on reasonable request. The results of the feasibility of the program were presented in another article [25].

## Declarations

### Ethics approval and consent to participate

The ethics committee of the Canton de Vaud (#469/15) approved the study. It was conducted in accordance with ethical standards of the Helsinki declaration. All participants signed an informed consent form.

### Consent for publication

Not applicable.

### Competing interests

The authors declare that they have no competing interests.

### Author details

<sup>1</sup>Faculty of Biology and Medicine, University of Lausanne (UNIL), Lausanne, Switzerland. <sup>2</sup>Department of Sports Medicine, Swiss Olympic Medical Center, Lausanne University Hospital CHUV, University of Lausanne (UNIL), Lausanne, Switzerland. <sup>3</sup>Institute of Sport Sciences, University of Lausanne (UNIL), Lausanne, Switzerland. <sup>4</sup>Department of Physical Medicine and Rehabilitation, Lausanne University Hospital CHUV, University of Lausanne (UNIL), Lausanne, Switzerland. <sup>5</sup>Department of Visceral Surgery, Lausanne University Hospital CHUV, University of Lausanne (UNIL), Rue du Bugnon 46, 1011 Lausanne, Switzerland. <sup>6</sup>Department of Physiotherapy, Lausanne University Hospital CHUV, Lausanne, Switzerland.

Received: 10 January 2022 Accepted: 31 March 2022

Published online: 07 April 2022

## References

1. Straatman J, Cuesta MA, de Lange-de Klerk ESM, van der Peet DL. Hospital cost-analysis of complications after major abdominal surgery. *Dig Surg*. 2015;32(2):150–6.
2. Roulin D, Donadini A, Gander S, Griesser A-C, Blanc C, Hübner M, et al. Cost-effectiveness of the implementation of an enhanced recovery protocol for colorectal surgery: cost-effectiveness of enhanced recovery protocol for colorectal surgery. *Br J Surg*. 2013;100(8):1108–14.
3. Gustafsson UO, Scott MJ, Hubner M, Nygren J, Demartines N, Francis N, et al. Guidelines for perioperative care in elective colorectal surgery: enhanced recovery after surgery (ERAS<sup>®</sup>) society recommendations: 2018. *World J Surg*. 2019;43(3):659–95.
4. Engelman DT, Ben Ali W, Williams JB, Perrault LP, Reddy VS, Arora RC, et al. Guidelines for perioperative care in cardiac surgery: enhanced recovery after surgery society recommendations. *JAMA Surg*. 2019;154(8):755–66.
5. Bhatia C, Kayser B. Preoperative high-intensity interval training is effective and safe in deconditioned patients with lung cancer: a randomized clinical trial. *J Rehabil Med*. 2019;51(9):712–8.
6. Heger P, Probst P, Wiskemann J, Steindorf K, Diener MK, Mihaljevic AL. A systematic review and meta-analysis of physical exercise prehabilitation in major abdominal surgery (PROSPERO 2017 CRD42017080366). *J Gastrointest Surg*. 2020;24(6):1375–85.
7. Trépanier M, Minnella EM, Paradis T, Awasthi R, Kaneva P, Schwartzman K, et al. Improved disease-free survival after prehabilitation for colorectal cancer surgery. *Ann Surg*. 2019;270(3):493–501.

8. Hulzebos EH, Smit Y, Helders PP, van Meeteren NL. Preoperative physical therapy for elective cardiac surgery patients. In: The Cochrane Collaboration, editor. Cochrane database of systematic reviews [Internet]. Chichester, UK: Wiley; 2012 [cited 2021 Mar 4]. p. CD010118. <https://doi.org/10.1002/14651858.CD010118>.
9. Assouline B, Cools E, Schorer R, Kayser B, Elia N, Licker M. Preoperative exercise training to prevent postoperative pulmonary complications in adults undergoing major surgery: a systematic review and meta-analysis with trial sequential analysis. *Ann Am Thorac Soc*. 2020.
10. Pouwels S, Stokmans RA, Willigendael EM, Nienhuijs SW, Rosman C, van Ramshorst B, et al. Preoperative exercise therapy for elective major abdominal surgery: a systematic review. *Int J Surg*. 2014;12(2):134–40.
11. Luther A, Gabriel J, Watson RP, Francis NK. The impact of total body prehabilitation on post-operative outcomes after major abdominal surgery: a systematic review. *World J Surg*. 2018;42(9):2781–91.
12. Bolshinsky V, Li MHG, Ismail H, Burbury K, Riedel B, Heriot A. Multimodal prehabilitation programs as a bundle of care in gastrointestinal cancer surgery: a systematic review. *Dis Colon Rectum*. 2018;61(1):124–38.
13. Carli F, Bousquet-Dion G, Awasthi R, Elsherbini N, Liberman S, Boutros M, et al. Effect of multimodal prehabilitation vs postoperative rehabilitation on 30-day postoperative complications for frail patients undergoing resection of colorectal cancer: a randomized clinical trial. *JAMA Surg*. 2020;155(3):233.
14. Milanović Z, Sporiš G, Weston M. Effectiveness of high-intensity interval training (HIT) and continuous endurance training for VO<sub>2</sub>max improvements: a systematic review and meta-analysis of controlled trials. *Sports Med*. 2015;45(10):1469–81.
15. Guiraud T, Nigam A, Gremeaux V, Meyer P, Juneau M, Bosquet L. High-intensity interval training in cardiac rehabilitation. *Sports Med*. 2012;42(7):587–605.
16. Dun Y, Smith JR, Liu S, Olson TP. High-intensity interval training in cardiac rehabilitation. *Card Rehabil Older Adults*. 2019;35(4):469–87.
17. Weston M, Weston KL, Prentis JM, Snowden CP. High-intensity interval training (HIT) for effective and time-efficient pre-surgical exercise interventions. *Periop Med*. 2016;5(1):2.
18. Ribeiro PAB, Boidin M, Juneau M, Nigam A, Gayda M. High-intensity interval training in patients with coronary heart disease: prescription models and perspectives. *Ann Phys Rehabil Med*. 2017;60(1):50–7.
19. Gremeaux V, Drigny J, Nigam A, Juneau M, Guilbeault V, Latour E, et al. Long-term lifestyle intervention with optimized high-intensity interval training improves body composition, cardiometabolic risk, and exercise parameters in patients with abdominal obesity. *Am J Phys Med Rehabil*. 2012;91(11):941–50.
20. Boidin M, Nigam A, Guilbeault V, Latour E, Langeard A, Juneau M, et al. Eighteen months of combined Mediterranean diet and high-intensity interval training successfully maintained body mass loss in obese individuals. *Ann Phys Rehabil Med*. 2020;63(3):245–8.
21. Kodama S, Saito K, Tanaka S, Maki M, Yachi Y, Asumi M, et al. Cardiorespiratory fitness as a quantitative predictor of all-cause mortality and cardiovascular events in healthy men and women: a meta-analysis. *JAMA*. 2009;301(19):2024–35.
22. West MA, Parry MG, Lythgoe D, Barben CP, Kemp GJ, Grocott MPW, et al. Cardiopulmonary exercise testing for the prediction of morbidity risk after rectal cancer surgery. *Br J Surg*. 2014;101(9):1166–72.
23. Moran J, Wilson F, Guinan E, McCormick P, Hussey J, Moriarty J. Role of cardiopulmonary exercise testing as a risk-assessment method in patients undergoing intra-abdominal surgery: a systematic review. *Br J Anaesth*. 2016;116(2):177–91.
24. Lee L, Schwartzman K, Carli F, Zavorsky GS, Li C, Charlebois P, et al. The association of the distance walked in 6 min with pre-operative peak oxygen consumption and complications 1 month after colorectal resection. *Anaesthesia*. 2013;68(8):811–6.
25. Martin D, Besson C, Pache B, Michel A, Geinoz S, Gremeaux-Bader V, et al. Feasibility of a prehabilitation program before major abdominal surgery: a pilot prospective study. *J Int Med Res*. 2021;49(11):03000605211060196.
26. Levett DZH, Jack S, Swart M, Carlisle J, Wilson J, Snowden C, et al. Perioperative cardiopulmonary exercise testing (CPET): consensus clinical guidelines on indications, organization, conduct, and physiological interpretation. *Br J Anaesth*. 2018;120(3):484–500.
27. Wasserman K, editor. Principles of exercise testing and interpretation: including pathophysiology and clinical applications, 5th edn. Philadelphia: Wolters Kluwer Health/Lippincott Williams & Wilkins; 2012. 572 p.
28. Carli F, Bessissow A, Awasthi R, Liberman S. Prehabilitation: finally utilizing frailty screening data. *Eur J Surg Oncol*. 2020;46(3):321–5.
29. Belloni G, Cesari M. Frailty and intrinsic capacity: two distinct but related constructs. *Front Med*. 2019;18(6):133.
30. Hooeboom TJ, Dronkers JJ, Hulzebos EHJ, van Meeteren NLU. Merits of exercise therapy before and after major surgery. *Curr Opin Anaesthesiol*. 2014;27(2):161–6.
31. Wallen MP, Hennessy D, Brown S, Evans L, Rawstorn JC, Wong Shee A, et al. High-intensity interval training improves cardiorespiratory fitness in cancer patients and survivors: a meta-analysis. *Eur J Cancer Care (Engl)*. 2020. <https://doi.org/10.1111/ecc.13267>.
32. Dunne DFJ, Jack S, Jones RP, Jones L, Lythgoe DT, Malik HZ, et al. Randomized clinical trial of prehabilitation before planned liver resection. *Br J Surg*. 2016;103(5):504–12.
33. Barberan-Garcia A, Ubré M, Roca J, Lacy AM, Burgos F, Risco R, et al. Personalised prehabilitation in high-risk patients undergoing elective major abdominal surgery: a randomized blinded controlled trial. *Ann Surg*. 2018;267(1):50–6.
34. O'Doherty AF, West M, Jack S, Grocott MPW. Preoperative aerobic exercise training in elective intra-cavity surgery: a systematic review. *Br J Anaesth*. 2013;110(5):679–89.
35. Astorino TA, Edmunds RM, Clark A, King L, Gallant RA, Namm S, et al. High-intensity interval training increases cardiac output and VO<sub>2</sub>max. *Med Sci Sports Exerc*. 2017;49(2):265–73.
36. Woodfield J, Zacharias M, Wilson G, Munro F, Thomas K, Gray A, et al. Protocol, and practical challenges, for a randomised controlled trial comparing the impact of high intensity interval training against standard care before major abdominal surgery: study protocol for a randomised controlled trial. *Trials*. 2018;19(1):331–331.
37. Swank AM, Horton J, Fleg JL, Fonarow GC, Keteyian S, Goldberg L, et al. Modest increase in peak VO<sub>2</sub> is related to better clinical outcomes in chronic heart failure patients: results from heart failure and a controlled trial to investigate outcomes of exercise training. *Circ Heart Fail*. 2012;5(5):579–85.
38. Hughes MJ, Hackney RJ, Lamb PJ, Wigmore SJ, Christopher Deans DA, Skipworth RJE. Prehabilitation before major abdominal surgery: a systematic review and meta-analysis. *World J Surg*. 2019;43(7):1661–8.
39. Myers J, Prakash M, Froelicher V, Do D, Partington S, Atwood J. Exercise capacity and mortality among men referred for exercise testing. *N Engl J Med*. 2002;346:793–801.
40. Inra JA, Syngal S. Colorectal cancer in young adults. *Dig Dis Sci*. 2015;60(3):722–33.

## Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

### Ready to submit your research? Choose BMC and benefit from:

- fast, convenient online submission
- thorough peer review by experienced researchers in your field
- rapid publication on acceptance
- support for research data, including large and complex data types
- gold Open Access which fosters wider collaboration and increased citations
- maximum visibility for your research: over 100M website views per year

At BMC, research is always in progress.

Learn more [biomedcentral.com/submissions](https://biomedcentral.com/submissions)

