

CLINICAL INVESTIGATION

A simplified (modified) Duke Activity Status Index (M-DASI) to characterise functional capacity: a secondary analysis of the Measurement of Exercise Tolerance before Surgery (METS) study

Bernhard Riedel^{1,2,3,4,*}, Michael H-G. Li¹, C. H. Angus Lee², Hilmy Ismail^{1,2,3}, Brian H. Cuthbertson^{5,6,7}, Duminda N. Wijeyesundera^{6,7,8}, Kwok M. Ho^{9,10,11}, and for the METS Study Investigators¹²

¹Department of Anaesthesia, Perioperative and Pain Medicine, Peter MacCallum Cancer Centre, Melbourne, Australia, ²Division of Cancer Surgery, Peter MacCallum Cancer Centre, Melbourne, Australia, ³Centre for Integrated Critical Care Medicine, University of Melbourne, Melbourne, Australia, ⁴Sir Peter MacCallum Department of Oncology, University of Melbourne, Melbourne, Australia, ⁵Department of Critical Care Medicine, Sunnybrook Health Sciences Centre, Toronto, ON, Canada, ⁶Department of Anesthesiology and Pain Medicine, University of Toronto, Toronto, ON, Canada, ⁷Institute of Health, Policy, Management and Evaluation, University of Toronto, Toronto, ON, Canada, ⁸Department of Anesthesia, St Michael's Hospital, Toronto, ON, Canada, ⁹Department of Intensive Care Medicine, Royal Perth Hospital, Perth, Australia, ¹⁰Medical School, University of Western Australia, Perth, Australia and ¹¹School of Veterinary and Life Sciences, Murdoch University, Perth, Australia

*Corresponding author. E-mail: bernhard.riedel@petermac.org

¹²The members of METS Study are listed in [Appendix](#) section

Abstract

Background: Accurate assessment of functional capacity, a predictor of postoperative morbidity and mortality, is essential to improving surgical planning and outcomes. We assessed if all 12 items of the Duke Activity Status Index (DASI) were equally important in reflecting exercise capacity.

Methods: In this secondary cross-sectional analysis of the international, multicentre Measurement of Exercise Tolerance before Surgery (METS) study, we assessed cardiopulmonary exercise testing and DASI data from 1455 participants. Multivariable regression analyses were used to revise the DASI model in predicting an anaerobic threshold (AT) >11 ml kg⁻¹ min⁻¹ and peak oxygen consumption (VO₂ peak) >16 ml kg⁻¹ min⁻¹, cut-points that represent a reduced risk of postoperative complications.

Results: Five questions were identified to have dominance in predicting AT >11 ml kg⁻¹ min⁻¹ and VO₂ peak >16 ml.kg⁻¹.min⁻¹. These items were included in the M-DASI-5Q and retained utility in predicting AT >11 ml.kg⁻¹.min⁻¹ (area under the receiver-operating-characteristic [AUROC]-AT: M-DASI-5Q=0.67 vs original 12-question DASI=0.66) and VO₂ peak (AUROC-VO₂ peak: M-DASI-5Q 0.73 vs original 12-question DASI 0.71). Conversely, in a sensitivity analysis we removed one potentially sensitive question related to the ability to have sexual relations, and the ability of the remaining four questions (M-DASI-4Q) to predict an adequate functional threshold remained no worse than the original 12-question DASI model. Adding a dynamic component to the M-DASI-4Q by assessing the chronotropic response to exercise improved its ability to discriminate between those with VO₂ peak >16 ml.kg⁻¹.min⁻¹ and VO₂ peak <16 ml.kg⁻¹.min⁻¹.

Conclusions: The M-DASI provides a simple screening tool for further preoperative evaluation, including with cardiopulmonary exercise testing, to guide perioperative management.

Keywords: anaerobic threshold; cardiopulmonary exercise test; Duke Activity Status Index; functional capacity; maximal oxygen uptake; preoperative risk assessment; questionnaire

Accepted: 5 June 2020

© 2020 Published by Elsevier Ltd on behalf of British Journal of Anaesthesia.
For Permissions, please email: permissions@elsevier.com

Editor's key points

- Assessment of functional capacity as a predictor of postoperative morbidity and mortality is essential for improving surgical planning, preparation, and outcomes.
- The Duke Activity Status Index (DASI) is a 12-question tool to determine exercise capacity.
- The authors assessed cardiopulmonary exercise testing (CPET) and DASI data from 1455 participants from the Measurement of Exercise Tolerance before Surgery (METS) study.
- A simplified, recalibrated (modified 5 question or 4 question) version of the DASI (M-DASI) was accurate as a screening tool to distinguish patients who have adequate functional capacity from those who might benefit from further testing and prehabilitation.

The global population is characterised by advancing age and an increasing burden of comorbid disease (including deconditioning from sedentary lifestyles) with increasing healthcare utilisation.¹ These factors contribute to increased incidence of postoperative complications and prolonged length of hospital stay.^{2–4} Assessment of functional capacity is central to the current American College of Cardiology/American Heart Association guidelines on perioperative cardiovascular evaluation and management of patients undergoing noncardiac surgery.⁵ Given that impaired functional capacity is a well-established predictor of postoperative morbidity and mortality,^{6,7} then accurate preoperative risk assessment of functional capacity is pivotal to improving surgical outcomes by allowing preoperative optimisation of modifiable risks such as deconditioning (prehabilitation) and facilitating perioperative management, including postoperative level of dependence planning.^{8,9}

Cardiopulmonary exercise testing (CPET), using gas exchange-derived parameters such as oxygen consumption at anaerobic threshold (AT, ml kg⁻¹ min⁻¹) and at peak exercise (VO₂ peak, ml kg⁻¹ min⁻¹), provides the gold standard for objective assessment of functional capacity.¹⁰ However, CPET is resource intensive and not accessible to all perioperative clinicians. The Duke Activity Status Index (DASI), using 12 questions to assess a person's ability to perform activities of daily living, was developed as a simple and inexpensive surrogate measure of VO₂ peak.¹¹ The DASI considers the total sum of responses to these 12 questions to estimate VO₂ peak (VO₂ peak = total DASI score × 0.43 + 9.6). In patients with chronic obstructive pulmonary disease, the DASI has criterion validity for predicting functional capacity, with $r=0.34$ when correlated with measured VO₂ peak. In the perioperative setting, a limited number of small studies report that the DASI has moderate correlation with the VO₂ peak ($R^2=0.2–0.45$) as measured by CPET in patients undergoing intra-abdominal surgery.^{12,13}

The Measurement of Exercise Tolerance before Surgery (METS) study,¹⁴ a large international multicentre study, compared the prognostic accuracy of subjective preoperative assessment, various tools measuring fitness (DASI and CPET) and pro-B-type natriuretic peptide to assess the composite primary endpoint of myocardial infarction or death within 30

days after major noncardiac surgery. The DASI score was associated with improved ability to predict the primary outcome of the composite of myocardial infarction or death within 30 days after surgery, whereas the other assessed tools, including CPET, had limited ability to do so. Importantly, CPET-derived VO₂ peak did have reasonable ability to discriminate the probability of moderate or severe in-hospital postoperative complications (odds ratio 0.86 per 3.5 ml kg⁻¹ min⁻¹ [1 metabolic equivalent] increased VO₂ peak, 95% confidence interval [95% CI] 0.78–0.97, $P=0.007$). Although DASI did not statistically improve the ability to predict postoperative morbidity, it may be a useful triage tool for referral to CPET services. This is especially important given that subjective clinician assessment only had 19.2% sensitivity (95% CI 14.2–25.0) for identifying patients with the inability to attain four metabolic equivalents (METS) (VO₂ peak < 14 ml kg⁻¹ min⁻¹) during CPET. However, the validity of the DASI, both in whole and in part, has not been thoroughly investigated against a robust dataset of patients who have completed CPET in the perioperative setting.

We hypothesised that not all activity domains assessed by the 12 questions of daily living within the original DASI questionnaire are necessary to estimate exercise capacity (predicting VO₂ peak). Using data from the recent METS study,¹⁴ we aimed to assess whether some of the activity domains assessed by the DASI questionnaire are more discriminating than others, and, if so, whether a simplified, recalibrated (modified) version of the DASI (M-DASI) would be sufficiently accurate to be used as a screening tool to identify patients who have adequate functional threshold from those who would benefit from a more formal referral for objective CPET testing and possible prehabilitation of deconditioned patients before major elective noncardiac surgery. We then sought to ascertain if the M-DASI would be able to predict the secondary outcomes of the METS study.

Methods

This is a secondary cross-sectional analysis of the METS study;¹⁴ the METS study protocol has been published.¹⁵ In brief, the main goal of the METS study was to compare the prognostic accuracy of subjective preoperative assessment tools measuring fitness (DASI, CPET) or pro-B-type natriuretic peptide to predict the composite primary endpoint of myocardial infarction or death within 30 days after major noncardiac surgery. Patients enrolled in this international multicentre prospective cohort study were aged 40 yr or above and deemed to have one or more risk factors for cardiac complications (e.g. a history of heart failure, stroke, or diabetes mellitus) or coronary artery disease and presenting for major elective noncardiac surgery. For this sub-study, we only included patients from the METS dataset who had both preoperative DASI and preoperative CPET data available. Unlike the initial METS study, patients were not ultimately required to undergo surgery. Patients with more than six DASI questions unanswered were excluded. In addition, those who did not achieve AT (3% of the participants) were excluded.

In the METS study, symptom-limited CPET was performed on a cycle ergometer under clinician supervision and based on institutional guidelines for participating centres.⁶ CPET used a ramp protocol with a 3-min resting phase, 3 min of unloaded cycling, and then a ramp phase with increasing pedal resistance until exercise was terminated at the patient's volition (peak exercise capacity). Oxygen consumption and carbon

dioxide production were monitored using breath-by-breath gas exchange analysis. For each patient, oxygen consumption at ($\text{ml kg}^{-1} \text{min}^{-1}$) and peak exercise ($\text{VO}_2 \text{ peak}$, $\text{ml kg}^{-1} \text{min}^{-1}$) were determined according to current consensus guidelines.¹⁰ AT provides an index of submaximal, sustainable exercise capacity, and is independent of patient volition, and this was identified using a three-point discrimination technique,¹⁶ including, the modified V-slope method to identify the inflection point in the carbon dioxide output, the change in the ventilatory equivalents, and the end-tidal partial pressures of oxygen and carbon dioxide to confirm hyperventilation with respect to oxygen but not to carbon dioxide. Peak VO_2 was defined as the average oxygen consumption during the last 20 s of the ramp phase before achieving the peak limit of exercise tolerance.¹⁰

Statistical analysis

The cut-points of $\text{AT} > 11 \text{ ml kg}^{-1} \text{min}^{-1}$ and $\text{VO}_2 \text{ peak} > 16 \text{ ml kg}^{-1} \text{min}^{-1}$ were considered as satisfactory functional capacity. These cut-points were based on literature suggesting that patients not achieving these levels of exercise capacity have an increased risk of postoperative morbidity.^{6,17–20} Cut-points were adjusted to ensure that, as a screening tool, the M-DASI would capture most patients with a truly unsatisfactory AT or $\text{VO}_2 \text{ peak}$, and this clarifies the deviation from the METS study where $\text{VO}_2 \text{ peak} > 14 \text{ ml kg}^{-1} \text{min}^{-1}$ (4 metabolic equivalents) and $\text{AT} > 11 \text{ ml kg}^{-1} \text{min}^{-1}$ were used to define patients with satisfactory functional capacity.

The differences in patient characteristics between those patients with and those without satisfactory CPET capacity were assessed using the χ^2 or Mann–Whitney *U* test. Multivariable linear regression was used to recalibrate the weights of the original DASI questions to assess whether a positive response to each question was associated with an improvement in the measured exercise capacity. We assigned a missing response to any DASI question as a negative response, which would reduce the risk of inflating the predictive value of the DASI questions. Multivariable logistic regression was used to identify the significance of each DASI question in predicting $\text{AT} > 11 \text{ ml kg}^{-1} \text{min}^{-1}$ and $\text{VO}_2 \text{ peak} > 16 \text{ ml kg}^{-1} \text{min}^{-1}$ (Table 1). A simplified modified DASI model (M-DASI) was then developed using only those DASI questions that were statistically significantly associated with both $\text{AT} > 11 \text{ ml kg}^{-1} \text{min}^{-1}$ and $\text{VO}_2 \text{ peak} > 16 \text{ ml kg}^{-1} \text{min}^{-1}$. Weighting of each question was not used in the M-DASI if the strength of associations (i.e. beta coefficients in regression model) between the DASI questions and outcome were similar. The discriminative ability of the M-DASI and the original DASI to predict a satisfactory CPET capacity was assessed using the area under the receiver-operating-characteristic (AUROC). AUROCs between 0.70 and 0.80 and > 0.80 were considered as having reasonable and good discrimination, respectively.²¹ The same method was then applied to investigate our secondary outcomes, which included the composite 30-day outcome of myocardial infarction or death, 30-day complications, 30-day mortality, or 1-yr mortality. We used the method suggested by Hanley and McNeil²² to compare the AUROC derived from the same cases. Calibration of the M-DASI model was illustrated by the probability of achieving $\text{AT} > 11 \text{ ml kg}^{-1} \text{min}^{-1}$ and $\text{VO}_2 \text{ peak} > 16 \text{ ml kg}^{-1} \text{min}^{-1}$ with the number of positive responses to the M-DASI model.

A series of sensitivity analyses were conducted to assess whether the predictive ability of the M-DASI would change

Table 1 Anaerobic threshold: multivariable logistic regression assessing the relative importance of each Duke Activity Status Index (DASI) question in predicting $\text{AT} > 11 \text{ ml kg}^{-1} \text{min}^{-1}$

Questions	Odds ratio (95% confidence interval)	P-value
1. Are you able to take care of yourself?	0.82 (0.25–2.68)	0.74
2. Are you able to walk indoors?	0.62 (0.14–2.67)	0.52
3. Are you able to walk a block or two on level ground?	1.42 (0.69–2.91)	0.34
4. Are you able to climb a flight of stairs or walk up a hill?	1.91 (1.07–3.41)	0.03
5. Are you able to run a short distance?	0.91 (0.69–1.21)	0.53
6. Are you able to do light work around the house?	0.96 (0.35–2.67)	0.94
7. Are you able to do moderate work around the house?	1.08 (0.63–1.85)	0.78
8. Are you able to do heavy work around the house?	1.73 (1.29–2.33)	<0.01
9. Are you able to do yard work?	1.62 (1.17–2.25)	0.04
10. Are you able to have sexual relations?	1.72 (1.34–2.21)	<0.01
11. Are you able to participate in moderate recreational activities?	0.95 (0.71–1.27)	0.729
12. Are you able to participate in strenuous sports?	1.38 (1.06–1.79)	0.02

Peak VO_2 : multivariable logistic regression assessing the relative importance of each DASI question in predicting $\text{pVO}_2 > 16 \text{ ml kg}^{-1} \text{min}^{-1}$. The four questions that are significantly associated with peak $\text{VO}_2 \text{ peak} > 16 \text{ ml kg}^{-1} \text{min}^{-1}$ are shown in bold and italics.

after: (a) combining gender (given that males may have a higher average exercise capacity); (b) removing the question on the ability to have sexual relations (given the potential sensitivity of the question to patients); (c) analysing for a satisfactory peak HR response to exercise (given the importance of chronotropic response to predicting perioperative complications²³ and longevity²⁴); or (d) adding ASA physical status (allowing comorbid disease to be factored into the score). All statistical analyses were conducted using MedCalc Statistical Software (version 18.11.3, Ostend, Belgium) and SPSS for Windows (version 23, IBM, Chicago, IL, USA), taking a two-sided alpha-error < 0.05 as statistically significant.

Results

Of 1455 patients in the METS study who had completed a CPET assessment, fewer than 5% had missing data (Fig. 1). The cohort had a median participant age of 65 (inter-quartile range=57–72) years, two-thirds were ASA physical status 1 or 2, and level of functional capacity characterised by mean AT of 12.6 (standard deviation 4.1) $\text{ml kg}^{-1} \text{min}^{-1}$ and mean $\text{VO}_2 \text{ peak}$ of 19.2 (standard deviation 6.5) $\text{ml kg}^{-1} \text{min}^{-1}$, with 63.7% of patients achieving $\text{VO}_2 \text{ peak} > 16 \text{ ml kg}^{-1} \text{min}^{-1}$ during CPET. Patients who did not achieve a satisfactory AT (47%) or $\text{VO}_2 \text{ peak}$ (36.3%) were more likely to be older males, with higher BMI and higher ASA physical status, and correspondingly lower DASI scores ($P=0.001$; Supplementary Tables S1 and S2).

With the exception of the question ‘Are you able to walk indoors?’ in relation to measured AT, the responses to all other 11 questions in the DASI questionnaire were significantly

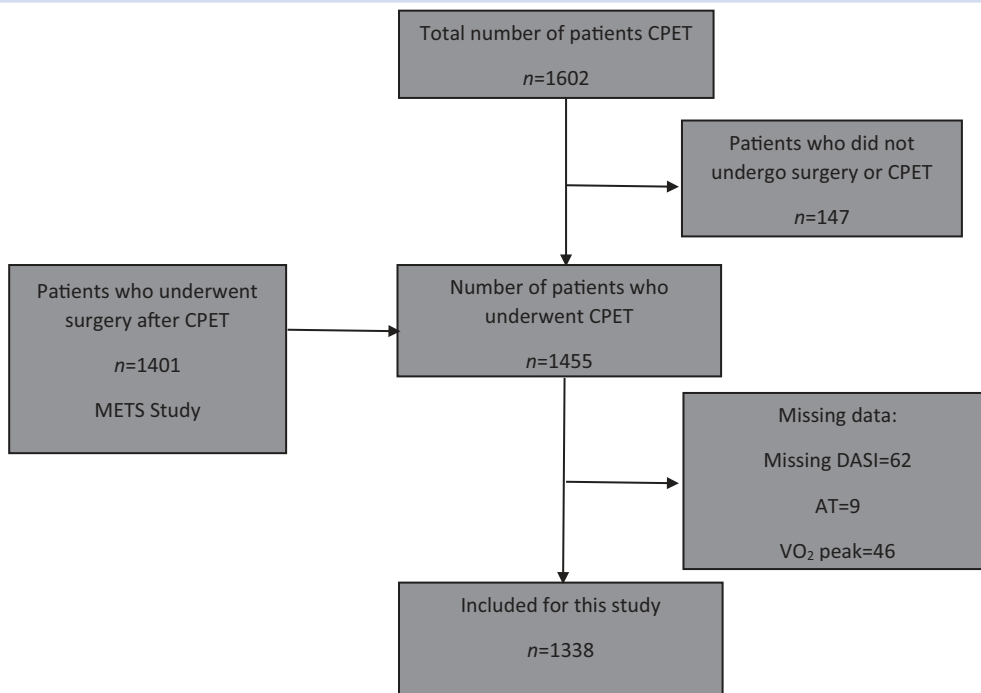


Fig 1. CONSORT diagram. AT, anaerobic threshold; CPET, cardiopulmonary exercise testing; DASI, Duke Activity Status Index; METS, Measurement of Exercise Tolerance before Surgery; VO₂, oxygen consumption.

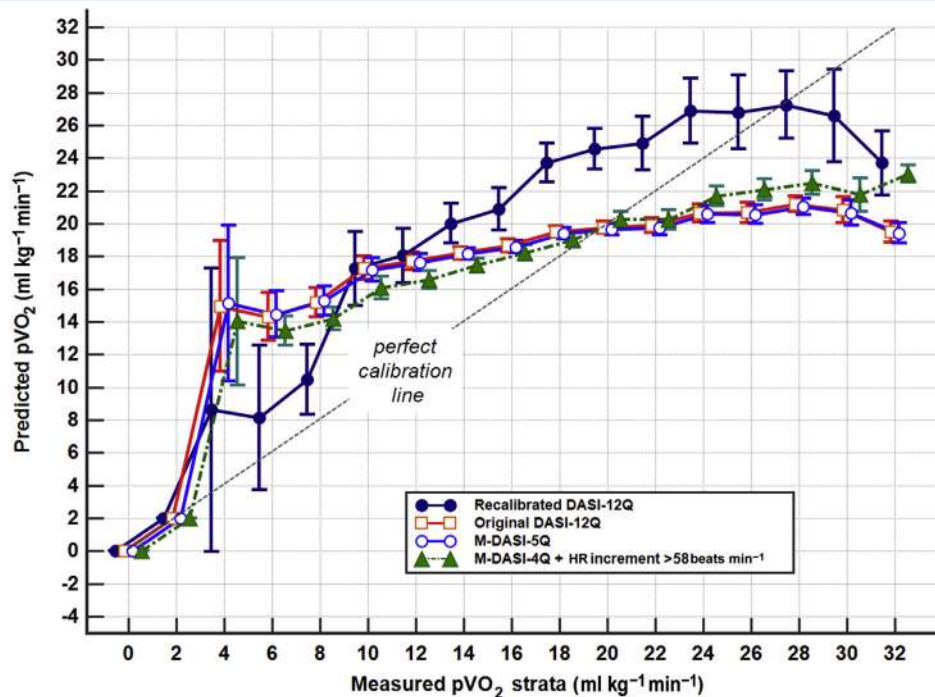


Fig 2. Relationships between pVO₂ (ml kg⁻¹ min⁻¹) predicted by the original DASI, recalibrated DASI-12Q, M-DASI-5Q, or M-DASI-4Q with HR increment >58 beats min⁻¹ models and the measured pVO₂ (ml kg⁻¹ min⁻¹). DASI, Duke Activity Status Index; pVO₂, peak oxygen consumption.

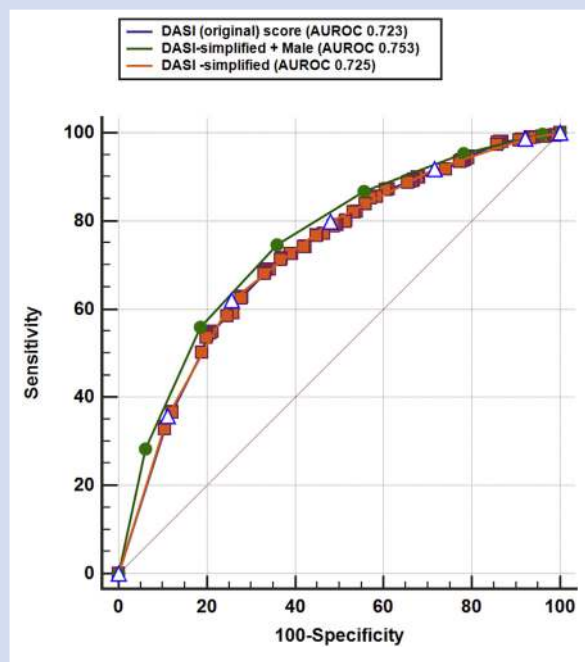


Fig 3. Peak VO_2 : area under the receiver-operating-characteristic (AUROC) of original DASI model, modified DASI (M-DASI-5Q) (one point for each of the most important five questions only), or M-DASI-5Qsex (with male adding one extra point) to predict peak oxygen consumption (pVO_2) $>16 \text{ ml kg}^{-1} \text{ min}^{-1}$ on cardiopulmonary exercise testing. DASI, Duke Activity Status Index.

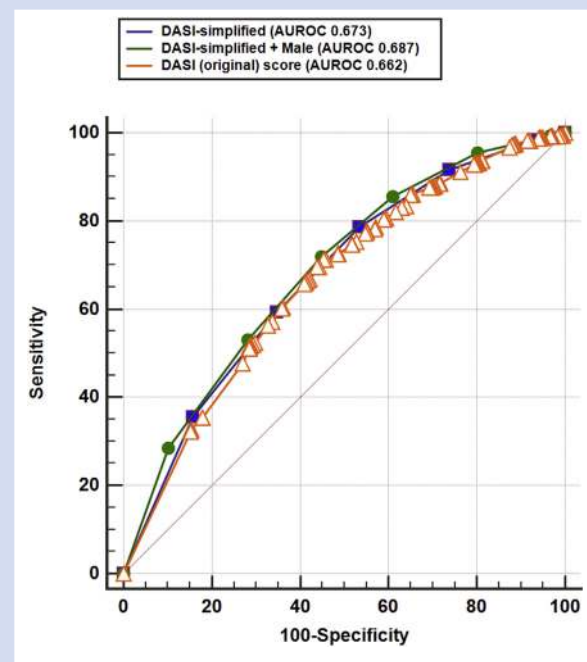


Fig 4. Anaerobic threshold: area under the receiver-operating-characteristic (AUROC) of DASI original model, simplified or modified DASI (M-DASI) (one point for each of the most important five questions only), or M-DASI-5Q-sex (with male adding one extra point) to predict anaerobic threshold (AT) $>11 \text{ ml kg}^{-1} \text{ min}^{-1}$ on cardiopulmonary exercise testing. DASI, Duke Activity Status Index.

different between those with and without satisfactory functional capacity as measured by CPET. The calibration curve showed that the DASI predicted VO_2 peak significantly overestimated the measured VO_2 peak for those with VO_2 peak $<20 \text{ ml kg}^{-1} \text{ min}^{-1}$, but significantly underestimated the measured VO_2 peak for those with VO_2 peak $>20 \text{ ml kg}^{-1} \text{ min}^{-1}$ (Fig. 2). Recalibrating the weights of the 12 DASI questions improved the calibration of the prediction (predicted VO_2 peak = $13.1 + 2.1 \times \text{stairs} + 1.3 \times \text{heavy housework} + 1.9 \times \text{yardwork} + 1.8 \times \text{sexual relations} + 2.3 \times \text{strenuous exercise} - 0.1 \times \text{take care of self} - 0.9 \times \text{walk indoors} + 1 \times \text{walk 200 yards} + 0.8 \times \text{run short distance} - 0.2 \times \text{light housework} - 0.1 \times \text{moderate housework} - 0.3 \times \text{moderate recreational activities}$). The recalibrated equation showed that the ability to take care of self, walk indoors, do light or moderate housework, and moderate recreational activities were negatively associated with the measured VO_2 peak, suggesting that any positive responses to these five questions were not useful and, indeed, could lead to overestimation of the measured VO_2 peak (Appendix 1).

Five (out of the 12) DASI questions were identified to have dominance in predicting a satisfactory exercise capacity (AT $>11 \text{ ml kg}^{-1} \text{ min}^{-1}$ and VO_2 peak $>16 \text{ ml kg}^{-1} \text{ min}^{-1}$; Table 1), with similar adjusted odds ratios in association with a satisfactory AT or VO_2 peak value. A modified DASI (M-DASI) model was thus constructed by assigning equal weights to these five dominant questions (M-DASI-5Q; with one point assigned per positive response to each of the five questions: maximum score is 5 and minimum score is 0).

The bar charts in Figs. 2 and 3 represent the probability of achieving an AT $>11 \text{ ml kg}^{-1} \text{ min}^{-1}$ and VO_2 peak $>16 \text{ ml kg}^{-1} \text{ min}^{-1}$ during CPET in relation to the number of positive responses to the five dominant DASI questions. For example, if a patient reported the ability to perform four out of five M-DASI tasks, the probability to achieve an AT $>11 \text{ ml kg}^{-1} \text{ min}^{-1}$ and VO_2 peak $>16 \text{ ml kg}^{-1} \text{ min}^{-1}$ during CPET would be 58.7% (95% CI 53.1–64.0) and 76.1% (95% CI 71.0–80.5), respectively. Conversely, if a patient could not perform any of the five M-DASI tasks, the probability of achieving an AT $>11 \text{ ml kg}^{-1} \text{ min}^{-1}$ and VO_2 peak $>16 \text{ ml kg}^{-1} \text{ min}^{-1}$ during CPET would only be 20% (95% CI 11.8–31.8) and 23% (95% CI 13.7–36.1), respectively.

By removing DASI questions that were not positively associated with the measured VO_2 peak, the M-DASI-5Q had a similar discriminative power as the original 12-question DASI model in predicting (1) VO_2 peak (AUROC- VO_2 peak: M-DASI-5Q 0.73 vs original 12 question DASI 0.71; Fig. 3), and (2) AT $>11 \text{ ml kg}^{-1} \text{ min}^{-1}$ (AUROC-AT: M-DASI-5Q = 0.67 vs original 12-question DASI = 0.66; Fig. 4).

The M-DASI could be further improved by incorporating gender (M-DASI-5Q-sex; assigning males one additional point), but the increment in its discrimination ability was relatively small and will unlikely improve clinical utility. Conversely, removing the question related to ability to have sexual relations (i.e. M-DASI-4Q) did not substantially affect its ability to predict AT $>11 \text{ ml kg}^{-1} \text{ min}^{-1}$ (AUROC 0.66, 95% CI 0.63–0.69) and VO_2 peak $>16 \text{ ml kg}^{-1} \text{ min}^{-1}$ (AUROC 0.71, 95%

CI 0.69–0.74) compared with the original 12-question DASI model (Table 2).

The optimal HR increment from baseline to discriminate between those with a satisfactory and unsatisfactory VO₂ peak was 58 (95% CI 56–62) beats min⁻¹, with a sensitivity of 59.3% and specificity of 81.5%. Combining four DASI questions (M-DASI-4Q) with the ability to mount a peak HR response of >58 beats min⁻¹ compared with baseline further improved its ability to discriminate between patients who achieved a VO₂ peak >16 ml kg⁻¹ min⁻¹ and those with a VO₂ peak <16 ml kg⁻¹ min⁻¹ (AUROC 0.78, 95% CI 0.76–0.80). Combining ASA physical status score with M-DASI-4Q did not improve the performance of the model compared with the original DASI (difference in AUROC-VO₂ peak: 0.01, 95% CI -0.01 to 0.02) (Table 2). Only the recalibrated 12-question DASI (AUROC 0.59, 95% CI 0.51–0.69) and the M-DASI-4Q with HR response >58 beats min⁻¹ (AUROC 0.60, 95% CI 0.51–0.69) were significantly predictive of 1-yr mortality.

Discussion

The modified four-question DASI (M-DASI-4Q) provides an equivalent ability to predict VO₂ peak compared with the original DASI, although this does not translate to predicting postoperative outcomes. Gender and peak HR response of >58 beats min⁻¹ all marginally improved the ability to discriminate VO₂ peak >16 ml kg⁻¹ min⁻¹ and AT >11 ml kg⁻¹ min⁻¹.

Strengths and limitations

Our study is the largest, heterogenous, sample size study to date to assess and recalibrate the relationship between the DASI and VO₂ peak. Prior uses of the DASI have been based on small population studies and have had limited validation for use in surgical cohorts, therefore this study is likely to provide invaluable information to clinicians. However, there are a number of limitations. First, although the M-DASI is easy to use, as with all surveys or questionnaires, all the M-

DASI questions can still be subjected to misinterpretation. Further study is thus needed to validate the accuracy of M-DASI externally and to confirm the utility of combining M-DASI with HR responses to exercise. Second, we did not assess whether M-DASI would be as good as the original DASI or CPET findings in predicting postoperative complications. Third, factors affecting the internal validity of the measured AT and VO₂ peak in the original METS study may introduce error into our study. Such factors include: (1) the AT calculation lends itself to substantial interobserver variation, and in the METS study this value was not centrally adjudicated; and (2) VO₂ peak is highly dependent on patient volition. Fourth, the original METS study included patients who were relatively young (median age 65 yr), healthy (two-thirds had ASA physical status <3), fit (two-thirds had VO₂ peak >16 ml kg⁻¹ min⁻¹, with a mean VO₂ peak of 19 ml kg⁻¹ min⁻¹), and an inherent potential bias toward recruiting patients with a willingness to exercise (with only one-third of eligible patients consenting to recruitment). As such, studies are needed to validate the utility of the M-DASI as a screening tool in older patients or those with significant multiple comorbidities scheduled for major noncardiac surgery.

Differences in prior literature

Our findings are similar to previous results obtained in small cohort studies ($n=50$, abdominal surgery¹²; $n=43$, intracavity cancer surgery¹³), in which the DASI was a reasonably sensitive and specific predictor of AT (≥ 11 ml kg⁻¹ min⁻¹: AUROC 0.767, 95% CI 0.630–0.994; $P=0.0002$) and VO₂ peak (>15 ml kg⁻¹ min⁻¹: AUROC 0.765, 95% CI 0.620–0.900; $P=0.002$).¹² Owing to our larger sample size using the METS study dataset¹⁴ our results have increased precision as reflected by the narrower CIs.

Discriminatory ability of individual DASI questions

We noted that there were some discrepancies in patient interpretation of the DASI questions, with positive responses

Table 2 Comparison of the area under the receiver-operating-characteristic (AUROC) curves for the original Duke Activity Score Index (DASI) model and the modified versions of the DASI (M-DASI) to predict preoperative functional capacity as measured by cardiopulmonary exercise testing in the Measurement of Exercise Tolerance before Surgery (METS) study

	AUROC-AT: for predicting AT >11 ml kg ⁻¹ min ⁻¹	Difference in AUROC-AT compared with the original DASI	AUROC-pVO ₂ : for predicting pVO ₂ >16 ml kg ⁻¹ min ⁻¹	Difference in AUROC-pVO ₂ compared with the original DASI
Original DASI (12 questions weighted)	0.66	Reference	0.71	Reference
Modified DASI-5Q (5 questions only unweighted)	0.67	0.01 (95% CI 0.006–0.022)	0.73	0.04 (95% CI 0.03–0.05)
Modified DASI-5Q-sex (5 questions unweighted+male sex)	0.69	0.03 (95% CI 0.01–0.04)	0.76	0.05 (95% CI 0.04–0.07)
Modified DASI-4Q (removing the question on ability to have sexual relations from the modified DASI-5Q)	0.66	0.001 (95% CI -0.01 to 0.01)	0.71	0.01 (95% CI -0.01 to 0.02)
Modified DASI-4Q-sex (Modified DASI-4Q+male sex)	0.68	0.02 (95% CI 0.002–0.037)	0.75	0.03 (95% CI 0.01–0.05)
Modified DASI-4Q + ASA physical status	0.66	0.02 (95% CI 0.001–0.03)	0.71	0.01 (95% CI -0.01 to 0.02)
Modified DASI-4Q + HR increment (Modified DASI-4Q+ability to achieve peak HR >58 beats min ⁻¹ from baseline)	0.69	0.04 (95% CI 0.02–0.07)	0.78	0.06 (95% CI 0.04–0.08)

AT, anaerobic threshold; CI, confidence interval; pVO₂, peak oxygen consumption. The four questions that are significantly associated with peak VO₂ peak >16 ml kg⁻¹ min⁻¹ are shown in bold and italics.

to some more demanding exercise tasks while giving negative responses to some less demanding tasks. This explained why positive responses to five questions on least demanding exercise tasks were associated with a reduction in measured VO_2 peak. This may, at least in part, explain why a simplified version of the DASI was as good as the original DASI model. A simplified DASI would improve ease of administration, compliance, and possibly validity by focusing on the most discriminative questions related to moderate and intense activities, which are less likely to be misinterpreted. A single question (ability to climb one flight of stairs), often used during preoperative assessment of patients, had low predictive ability (AUROC=0.55 for VO_2 peak > 16 ml kg^{-1} min^{-1}), which emphasises the need to qualify functional status using multiple questions (e.g. four or five questions) for validity.

Rationale for the M-DASI-4Q

Although the accuracy of M-DASI was improved by incorporating patient gender into the model, the improvement was only marginal and unlikely to add clinically important value. Taking into consideration that the cut-points of AT and VO_2 peak may be applicable equally to females and males,¹⁹ we suggest that the M-DASI without patient gender is the preferred version of the simplified DASI and potentially may have good clinical utility. Our results also showed that eliminating the potentially sensitive question on sexual relations did not substantially weaken the discriminative ability of the M-DASI. However, combining a satisfactory HR response with the four-question M-DASI (M-DASI-4Q) did improve the discriminative ability, suggesting that there is potential in combining HR responses to exercise, which could be elicited without formal CPET testing, with a simple four-questionnaire DASI in assessing exercise capacity before surgery.

Utility of the DASI questionnaire in predicting postoperative outcomes

Poor preoperative functional capacity is associated with adverse postoperative outcomes after various types of noncardiac surgery, including in the recent METS study.^{14,23,25–28} Accurate assessment of functional capacity for risk stratification is crucial in preoperative work-up, patient optimisation (e.g. prehabilitation), and level of dependence planning postoperatively (e.g. postoperative high dependency unit/ICU vs surgical ward destination). Although DASI has been validated to be a reliable functional assessment tool in patients with cardiac, chronic respiratory, and renal diseases,^{28–30} evidence supporting its role in surgical patients before the METS study is limited. A secondary analysis of the same METS data set suggests that a cutpoint at a score of 34 may represent a threshold for identifying patients at risk for myocardial injury, myocardial infarction, moderate-to-severe complications, and new disability (ref BJA 2020 - PMID; 31864719). Our sub-study suggests that a modified DASI could be linked to 1-yr mortality. This improved discriminatory ability of the DASI is likely attributable to known surgical morbidity associated with impaired HR response²³ and general cardiovascular mortality.²⁹ Similarly, a recalibrated DASI score was also associated with 1-yr mortality, suggesting that the DASI has an intrinsic ability to discriminate between potential survivors and non-survivors.

Utility of the M-DASI-4Q in prehabilitation

Prehabilitation before major surgery uses a multimodal approach, including a structured exercise program, and nutritional, haematonic, and psychological support, to optimise modifiable risk, including preoperative deconditioning, to mitigate physiological stress perioperatively to achieve better outcome and earlier recovery.^{30–33} The evidence of prehabilitation on functional capacity and postoperative outcome is conflicting.^{32,34,35} Despite improvement in preoperative functional capacity, older studies failed to show a statistically significant difference in postoperative complications.^{33,36,37} Conversely, recent published RCTs report halving of postoperative complications in the prehabilitation arms.^{34,38} Studies of prehabilitation also report improved patient well-being,³⁴ ability to sustain functional capacity during neoadjuvant chemoradiotherapy, improved fitness before surgery,^{30,33} reduced postoperative complications,³⁰ and recently intriguing findings of augmented pathological tumour regression.³⁹ Identifying higher risk groups through formal CPET testing is resource intensive. Because discrepancies between patients' own assessment and their real exercise capacity often exist,⁴⁰ using the M-DASI as a screening tool supplemented by field walk tests, such as the six-minute walk test or the incremental shuttle walk test, may further improve the accuracy of the assessment of functional capacity and outcomes.^{41–43} The M-DASI and standardised field walking tests are easy to perform/administer, cost-effective, and may provide high clinical utility as screening tools before CPET.

M-DASI-4Q in screening for CPET

CPET remains the gold standard in evaluating overall exercise capacity.^{10,44} Results obtained from CPET are highly reproducible^{45–47} and predictive of postoperative complications across different surgical subspecialties.^{6,7} Although the METS study failed to show good utility of CPET as a predictor of the composite of myocardial infarction and death within 30 days postoperatively, it was a reasonable predictor of all-cause postoperative morbidity.¹⁴ A recent survey from the UK highlighted that a substantial proportion of centres without CPET had tried and failed to set up such services because of insufficient funding,³⁸ notwithstanding the evidence that hospitals with CPET services appeared to have improved postoperative outcomes including 18% reduction (relative risk 0.82, 95% CI 0.70–0.96, $P=0.0157$) in 90-day mortality associated with centres that had onsite CPET facilities.⁴⁸ The M-DASI should not be considered as a replacement for CPET (unless such resources are not available) but rather as a triage tool for those patients who would benefit from a more formal assessment using field walking tests or CPET. Importantly, CPET has the added benefit of a diagnostic component to discriminate the underlying cause of exercise limitation.

Conclusions

Accurate assessment of preoperative functional capacity is crucial in risk stratification and determining the level of perioperative support required for patients undergoing major surgery. Both the original and modified DASI (M-DASI) have a reasonable ability to discriminate between patients with and without satisfactory functional capacity as defined by AT > 11 ml kg^{-1} min^{-1} and VO_2 peak > 16 ml kg^{-1} min^{-1} (AUROC > 0.70). In centres where resources to provide CPET are limited, the M-

DASI-4Q with and without peak HR response may serve as a screening tool to select the most appropriate patients for referral for CPET for objective assessment of functional capacity. Further research is needed to confirm whether M-DASI with and without HR responses to exercise is as accurate as CPET parameters in predicting postoperative outcomes, especially in older deconditioned individuals.

Authors' contributions

Study design: BR, HI, KMH, BHC, DW
 Manuscript writing: BR, HI, MHGL, CHAL, KMH, BHC, DW
 Data management: MHGL
 Data interpretation: CHAL, BHC, DW
 Data analysis: KMH
 Data collection: BHC, DW

Declarations of interest

The authors declare that they have no conflicts of interest.

Funding

KMH is funded by WA Health and Raine Medical Research Foundation through the Raine Clinical Research Fellowship. DW is supported in part by a New Investigator Award from the Canadian Institutes of Health Research, an Excellence in Research Award from the Department of Anesthesia at the University of Toronto, and the Endowed Chair in Translational Anesthesiology Research at St. Michael's Hospital and University of Toronto. The funding agencies have no influence on the choice of the subject matter, design of the study, data analyses, the decision to publish the results and the final content of the manuscript. The other authors have not received any funding. The METS study was funded by the Canadian Institutes of Health Research; Heart and Stroke Foundation of Canada; Ontario Ministry of Health and Long-Term Care; Ontario Ministry of Research, Innovation and Science; UK National Institute of Academic Anaesthesia; UK Clinical Research Collaboration; Australian and New Zealand College of Anaesthetists; Monash University.

Appendix. METS study collaborators listing

Wallace S, Thompson B, Ellis M, Borg B, Kerridge RK, Douglas J, Brannan J, Pretto J, Godsall MG, Beauchamp N, Allen S, Kennedy A, Wright E, Malherbe J, Ismail H, Riedel B, Melville A, Sivakumar H, Murmane A, Kenchington K, Kirabiyik Y, Gurnathan U, Stonell C, Brunello K, Steele K, Tronstad O, Masel P, Dent A, Smith E, Bodger A, Abolfathi M, Sivalingam P, Hall A, Painter TW, Macklin S, Elliott A, Carrera AM, Terblanche NCS, Pitt S, Samuels J, Wilde C, Leslie K, MacCormick A, Bramley D, Southcott AM, Grant J, Taylor H, Bates S, Towns M, Tippett A, Marshall F, Mazer CD, Kunasingam J, Yagnik A, Crescini C, Yagnik S, McCartney CJL, Choi S, Somascanthan P, Flores K, S Au, Beattie WS, Karkouti K, Clarke HA, Jerath A, McCluskey SA, Wasowicz M, Day L, Pazmino-Canizares J, Oh P, Belliard R, Lee L, Dobson K, Chan V, Brull R, Ami N, Stanbrook M, Hagen K, Campbell D, Short T, Van Der Westhuizen J, Higgle JK, Lindsay H, Jang R, Wong C, Mcallister D, Ali M, Kumar J, Waymouth E, Kim C, Dimech J, Lorimer M, Tai J, Miller R, Sara R, Collingwood A, Olliff S, Gabriel S, Houston H, Dalley P, Hurford S, Hunt A, Andrews L, Navarra L, Jason-Smith A, Thompson H, McMillan N, Back G, Lum M, Martin D, S James, Filipe H, Pinto M,

Kynaston S, Phull M, Beilstein C, Bodger P, Everingham K, Hu Y, Niebrzegowska E, Corriea C, Creary T, Januszewska M, Ahmad T, Whalley J, Haslop R, McNeil J, Brown A, MacDonald N, Pakats M, Greaves K, Jhanji S, Raobaikady R, Black E, Rooms M, Lawrence H, Koutra M, Pirie K, Gertsman M, Jack S, Celinski M, Levett D, Edwards M, Salmon K, Bolger C, Loughney L, Seaward L, Collins H, Tyrell B, Tantony N, Golder K, Ackland GL, Stephens RCM, Gallego-Paredes L, Reyes A, Gutierrez del Arroyo A, Raj A, R Lifford, Melo M, Mamdani M, Hillis G, Wijeyesundera HC.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.bja.2020.06.016>.

References

- Palladino R, Tayu Lee J, Ashworth M, Triassi M, Millett C. Associations between multimorbidity, healthcare utilisation and health status: evidence from 16 European countries. *Age Ageing* 2016; **45**: 431–5
- Sukharamwala P, Thoens J, Szuchmacher M, Smith J, DeVito P. Advanced age is a risk factor for post-operative complications and mortality after a pancreaticoduodenectomy: a meta-analysis and systematic review. *HPB (Oxford)* 2012; **14**: 649–57
- Kim S, Marsh AP, Rustowicz L, et al. Self-reported mobility in older patients predicts early postoperative outcomes after elective noncardiac surgery. *Anesthesiology* 2016; **124**: 815–25
- Park HA, Park SH, Cho SI, et al. Impact of age and comorbidity on the short-term surgical outcome after laparoscopy-assisted distal gastrectomy for adenocarcinoma. *Am Surg* 2013; **79**: 40–8
- Fleisher LA, Fleischmann KE, Auerbach AD, et al. ACC/AHA guideline on perioperative cardiovascular evaluation and management of patients undergoing noncardiac surgery: a report of the American College of Cardiology/American Heart Association Task Force on practice guidelines. *J Am Coll Cardiol* 2014; **64**: 77–137
- Lee CHA, Kong JC, Ismail H, Riedel B, Heriot A. Systematic review and meta-analysis of objective assessment of physical fitness in patients undergoing colorectal cancer surgery. *Dis Colon Rectum* 2018; **61**: 400–9
- 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**: 177–91
- Schilling PL, Dimick JB, Birkmeyer JD. Prioritizing quality improvement in general surgery. *J Am Coll Surg* 2008; **207**: 698–704
- Khuri SF, Daley J, Henderson W, et al. The Department of Veterans Affairs' NSQIP: the first national, validated, outcome-based, risk-adjusted, and peer-controlled program for the measurement and enhancement of the quality of surgical care. National VA Surgical Quality Improvement Program. *Ann Surg* 1998; **228**: 491–507
- Levett DZH, Jack S, Swart M, et al. Perioperative cardiopulmonary exercise testing (CPET): consensus clinical guidelines on indications, organization, conduct, and

- physiological interpretation. *Br J Anaesth* 2018; **120**: 484–500
11. Hlatky MA, Boineau RE, Higginbotham MB, et al. A brief self-administered questionnaire to determine functional capacity (the Duke Activity Status Index). *Am J Cardiol* 1989; **64**: 651–4
 12. Struthers R, Erasmus P, Holmes K, Warman P, Collingwood A, Sneyd JR. Assessing fitness for surgery: a comparison of questionnaire, incremental shuttle walk, and cardiopulmonary exercise testing in general surgical patients. *Br J Anaesth* 2008; **101**: 774–80
 13. Li MH, Bolshinsky V, Ismail H, Ho KM, Heriot A, Riedel B. Comparison of Duke Activity Status Index with cardiopulmonary exercise testing in cancer patients. *J Anesth* 2018; **32**: 576–84
 14. Wijeyesundera DN, Pearse RM, Shulman MA, et al. Assessment of functional capacity before major non-cardiac surgery: an international, prospective cohort study. *Lancet* 2018; **391**: 2631–40
 15. Wijeyesundera DN, Pearse RM, Shulman MA, et al. Measurement of Exercise Tolerance before Surgery (METS) study: a protocol for an international multicentre prospective cohort study of cardiopulmonary exercise testing prior to major non-cardiac surgery. *BMJ Open* 2016; **6**, e010359
 16. Gaskill SE, Ruby BC, Walker AJ, Sanchez OA, Serfass RC, Leon AS. Validity and reliability of combining three methods to determine ventilatory threshold. *Med Sci Sports Exerc* 2001; **33**: 1841–8
 17. Forshaw MJ, Strauss DC, Davies AR, et al. Is cardiopulmonary exercise testing a useful test before esophagectomy? *Ann Thorac Surg* 2008; **85**: 294–9
 18. West MA, Asher R, Browning M, et al. Validation of preoperative cardiopulmonary exercise testing-derived variables to predict in-hospital morbidity after major colorectal surgery. *Br J Surg* 2016; **103**: 744–52
 19. Wilson RJ, Davies S, Yates D, Redman J, Stone M. Impaired functional capacity is associated with all-cause mortality after major elective intra-abdominal surgery. *Br J Anaesth* 2010; **105**: 297–303
 20. Lai CW, Minto G, Challand CP, et al. Patients' inability to perform a preoperative cardiopulmonary exercise test or demonstrate an anaerobic threshold is associated with inferior outcomes after major colorectal surgery. *Br J Anaesth* 2013; **111**: 607–11
 21. Mandrekar JN. Receiver operating characteristic curve in diagnostic test assessment. *J Thorac Oncol* 2010; **5**: 1315–6
 22. Hanley JA, McNeil BJ. A method of comparing the areas under receiver operating characteristic curves derived from the same cases. *Radiology* 1983; **148**: 839–43
 23. Hightower CE, Riedel BJ, Feig BW, et al. A pilot study evaluating predictors of postoperative outcomes after major abdominal surgery: physiological capacity compared with the ASA physical status classification system. *Br J Anaesth* 2010; **104**: 465–71
 24. Duarte CV, Myers J, de Araujo CG. Exercise heart rate gradient: a novel index to predict all-cause mortality. *Eur J Prev Cardiol* 2015; **22**: 629–35
 25. Moyes LH, McCaffer CJ, Carter RC, Fullarton GM, Mackay CK, Forshaw MJ. Cardiopulmonary exercise testing as a predictor of complications in oesophagogastric cancer surgery. *Ann R Coll Surg Engl* 2013; **95**: 125–30
 26. Snowden CP, Prentis JM, Anderson HL, et al. Submaximal cardiopulmonary exercise testing predicts complications and hospital length of stay in patients undergoing major elective surgery. *Ann Surg* 2010; **251**: 535–41
 27. West MA, Lythgoe D, Barben CP, et al. Cardiopulmonary exercise variables are associated with postoperative morbidity after major colonic surgery: a prospective blinded observational study. *Br J Anaesth* 2014; **112**: 665–71
 28. West MA, Parry MG, Lythgoe D, et al. Cardiopulmonary exercise testing for the prediction of morbidity risk after rectal cancer surgery. *Br J Surg* 2014; **101**: 1166–72
 29. Savonen KP, Lakka TA, Laukkanen JA, et al. Heart rate response during exercise test and cardiovascular mortality in middle-aged men. *Eur Heart J* 2006; **27**: 582–8
 30. Barberan-Garcia A, Ubre M, Roca J, et al. Personalised prehabilitation in high-risk patients undergoing elective major abdominal surgery: a randomized blinded controlled trial. *Ann Surg* 2018; **267**: 50–6
 31. Bolshinsky V, Li MH, 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**: 124–38
 32. Li C, Carli F, Lee L, et al. Impact of a trimodal prehabilitation program on functional recovery after colorectal cancer surgery: a pilot study. *Surg Endosc* 2013; **27**: 1072–82
 33. Minnella EM, Bousquet-Dion G, Awasthi R, Scheede-Bergdahl C, Carli F. Multimodal prehabilitation improves functional capacity before and after colorectal surgery for cancer: a five-year research experience. *Acta Oncol* 2017; **56**: 295–300
 34. Dunne DF, Jack S, Jones RP, et al. Randomized clinical trial of prehabilitation before planned liver resection. *Br J Surg* 2016; **103**: 504–12
 35. West MA, Loughney L, Ambler G, et al. The effect of neoadjuvant chemotherapy and chemoradiotherapy on exercise capacity and outcome following upper gastrointestinal cancer surgery: an observational cohort study. *BMC Cancer* 2016; **16**: 710
 36. Carli F, Charlebois P, Stein B, et al. Randomized clinical trial of prehabilitation in colorectal surgery. *Br J Surg* 2010; **97**: 1187–97
 37. Gillis C, Li C, Lee L, et al. Prehabilitation versus rehabilitation: a randomized control trial in patients undergoing colorectal resection for cancer. *Anesthesiology* 2014; **121**: 937–47
 38. Barakat HM, Shahin Y, Khan JA, McCollum PT, Chetter IC. Preoperative supervised exercise improves outcomes after elective abdominal aortic aneurysm repair: a randomized controlled trial. *Ann Surg* 2016; **264**: 47–53
 39. West MA, Astin R, Moyses HE, et al. Exercise prehabilitation may lead to augmented tumor regression following neoadjuvant chemoradiotherapy in locally advanced rectal cancer. *Acta Oncol* 2019; **58**: 588–95
 40. Stokes JW, Wanderer JP, McEvoy MD. Significant discrepancies exist between clinician assessment and patient self-assessment of functional capacity by validated scoring tools during preoperative evaluation. *Perioper Med (Lond)* 2016; **5**: 18
 41. Moran J, Wilson F, Guinan E, McCormick P, Hussey J, Moriarty J. The preoperative use of field tests of exercise tolerance to predict postoperative outcome in intra-abdominal surgery: a systematic review. *J Clin Anesth* 2016; **35**: 446–55
 42. Sinclair RC, Batterham AM, Davies S, Cawthorn L, Danjoux GR. Validity of the 6 min walk test in prediction

- of the anaerobic threshold before major non-cardiac surgery. *Br J Anaesth* 2012; **108**: 30–5
43. Shulman MA, Cuthbertson BH, Wijeyesundera DN, et al. Using the 6-minute walk test to predict disability-free survival after major surgery. *Br J Anaesth* 2019; **122**: 111–9
 44. Guazzi M, Arena R, Halle M, Piepoli MF, Myers J, Lavie CJ. 2016 focused update: clinical recommendations for cardiopulmonary exercise testing data assessment in specific patient populations. *Eur Heart J* 2018; **39**: 1144–61
 45. Hansen JE, Sun XG, Yasunobu Y, et al. Reproducibility of cardiopulmonary exercise measurements in patients with pulmonary arterial hypertension. *Chest* 2004; **126**: 816–24
 46. Kothmann E, Danjoux G, Owen SJ, Parry A, Turley AJ, Batterham AM. Reliability of the anaerobic threshold in cardiopulmonary exercise testing of patients with abdominal aortic aneurysms. *Anaesthesia* 2009; **64**: 9–13
 47. Saynor ZL, Barker AR, Oades PJ, Williams CA. Reproducibility of maximal cardiopulmonary exercise testing for young cystic fibrosis patients. *J Cyst Fibros* 2013; **12**: 644–50
 48. Davies RG, Tobin S, Moses T, Appadurai IR, Rose G, Bailey DM. Bowel cancer surgery outcomes and pre-operative cardiopulmonary exercise testing: insights from real-world data. *Anaesthesia* 2018; **73**: 1445–6. Utility of DASI questionnaire in predicting postoperative outcomes

Handling editor: Hugh C Hemmings Jr