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RESEARCH PAPER

Peak oxygen uptake after the 80s as a survival predictor

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Key summary points

Aim Is direct measurement of peak oxygen uptake (VO2peak) a predictor of survival in octogenarians?

Findings The mortality rate was nearly three times higher in individuals with VO2peak below 80% of the predicted values. The data emphasize the prognostic value of VO2peak in older adults, comparable to its significance in younger individuals.

Message Oxygen uptake below 80% of age-specific reference values serves as a predictor of mortality in octogenarians.

Abstract

Purpose Peak oxygen uptake (VO2peak) is a crucial health marker, extensively studied in adults for its prognostic value. However, its significance in the older persons, especially octogenarians, remains underexplored due to limited representation in research. This study aims to assess the predictive power of VO2peak for survival in individuals aged 80 and above.

Methods We included individuals aged 80 or older who underwent cardiopulmonary exercise tests at a single center. Mortality rates were compared based on VO2peak relative to 80% of predicted values (%VO2peak). We employed three multivariate Cox regression models: Model 1 (unadjusted), Model 2 (adjusted for age) and Model 3 (adjusted for age and stroke).

Results Among 188 participants (mean age 83.3 ± 3 years, 68.9% male), 22 (11.7%) passed away during a median follow-up of 494 days. Non-survivors tended to be older with lower VO2peak and %VO2peak. All models demonstrated associations between %VO2peak $\leq$ 80% and mortality: HR = 3.19 (95% CI: 1.30–7.86, $p = 0.011$) for M1; HR = 3.12 (95% CI: 1.26–7.74, $p = 0.013$) for M2 and HR = 2.80 (95% CI: 1.11–7.06, $p = 0.028$) for M3.

Conclusion In the context of an aging population, this study underscores the enduring significance of VO2peak as a survival predictor among the older person, including octogenarians. These findings carry profound implications for tailoring healthcare strategies to address the evolving demographic landscape.

Keywords Cardiorespiratory fitness · Exercise test · Cardiopulmonary exercise test · Octogenarians · Survival analysis

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Introduction

The direct measurement of peak oxygen uptake (VO2peak) through cardiopulmonary exercise testing (CPET) serves as the gold standard for assessing cardiorespiratory fitness (CRF). This measurement is a firmly established indicator of health and holds substantial prognostic value concerning all-cause mortality in both populations with and without cardiovascular diseases [1]. A recent meta-analysis revealed that every incremental unit of metabolic equivalent (MET) was linked to a 19% reduction in all-cause mortality [2]. Furthermore, over the last four decades, multiple studies have consistently underscored the pivotal role of CRF in the prevention of high-risk cardiovascular diseases [2–4]. Moreover, it has been demonstrated to attenuate the onset of conditions such as dementia [5], cardiovascular risk factors [4], certain types of cancer [6], and various other relevant clinical endpoints [1].

The underrepresentation of individuals aged 80 and older in prognostic studies related to VO2peak is a significant concern in the field of health research. The predominant focus of most studies on younger age groups has resulted in a notable knowledge gap concerning the impact of CRF on older adults, particularly those aged over 80. The existing data on octogenarians primarily rely on indirect measurement of VO2peak through the estimation of peak MET achieved [3]. It is worth noting that indirect estimation is generally less precise compared to direct measurement through CPET [7]. This gap raises questions about the enduring validity of VO2peak as a robust predictor of mortality and morbidity in this specific demographic, akin to its predictive efficacy among younger individuals [1, 4, 8].

In addition, recent decades have witnessed a remarkable increase in life expectancy on a global scale [9]. This increase can be attributed to advancements in scientific knowledge and improvements in the quality of life [10]. Notably, countries that have surpassed the 80-year life expectancy mark also tend to experience higher healthcare expenses per capita [11], highlighting the socioeconomic implications associated with this aging population cohort.

While data on VO2peak in older individuals, particularly octogenarians, remain limited, relevant studies help emphasize its significance. For instance, [12] conducted a comprehensive investigation into age-related declines in VO2peak, encompassing both men and women over an 8-year period. Their findings revealed a significant acceleration in VO2peak decline in individuals aged 70 years and older, highlighting the importance of studying this age group. Notably, gender differences in the 'aging' of VO2peak may also play a crucial role. DeLorey et al. [13] investigated the effects of prior heavy-intensity exercise on pulmonary oxygen uptake and muscle deoxygenation kinetics in both young and older adult populations, providing valuable insights into potential gender-specific differences in VO2peak responses.

Given the upward trend in life expectancy in various regions and the increasing significance of older adults' health, it is imperative for future research to encompass a more diverse sample, including octogenarians individuals. This approach will enable a more comprehensive understanding of how CRF influences health prognosis in older adults, ultimately contributing to the development of enhanced interventions and clinical guidelines for this growing and relevant population. Therefore, the primary objective of this study was to determine whether direct measurement of VO2peak remains a robust predictor of mortality in individuals aged 80 and above.

Methods

Study design and population

A cohort of patients underwent cardiopulmonary exercise testing (CPET) at a single private center between May 2018 and June 2023. Participants were included when aged 80 + at the time of their CPET assessment. Patients visited the center for fitness level assessment or cardiopulmonary risk screening. Only patients who met the criteria of understanding the test instructions and information, as specified by the CPET protocol, were included in the analyzed database. These individuals were also community-dwelling residents. Since all patients resided in Rio de Janeiro, we ascertained whether they were alive or deceased by consulting the General Justice Ombudsman website (http://www4.tjrj.jus.br/Portal-Extrajudicial/CNO/). We also confirmed the individuals' life status by conducting phone interviews with the patients themselves or their families. All cases were successfully contacted. The date of death was recorded for survival analysis, and individuals not located were presumed to be alive during the search. Confirmation of their living or deceased status was obtained between September 10th and 15th, 2023.

This study obtained approval from the Human Research Ethics Committee with the registration CAAE: 35,706,720.4.0000.8093. All procedures conducted in this study were in accordance with the principles outlined in the 1975 Helsinki Declaration, as updated in 2013. All patients provide informed consent.

Cardiopulmonary exercise test (CPET)

All participants underwent CPET using a cycle ergometer, and an individualized ramp protocol was employed. The participants underwent an exhaustive exercise test using a magnetic-braked cycle ergometer (Lode Corival$_{®}$, Groningen, Netherlands) following an individualized ramp protocol based on the Wasserman algorithm (Wasserman, Hansen, Sue, & Stringer, 2012). Following a 2-min rest period, patients were instructed to pedal without resistance for 3 min before entering the incremental phase. They were also instructed to maintain a consistent cadence between 50 and 60 revolutions per minute (rpm). The test was terminated when participants were unable to sustain a minimum cadence of 50 rpm for more than 5 s, despite verbal encouragement.

During the exercise, a computerized metabolic cart (Metalyzer 3B$^{®}$, Cortex$^{®}$, Leipzig, Germany) recorded breath-by-breath measurements, including tidal volume (VT), breathing frequency (Bf), oxygen uptake (VO2), and carbon dioxide output (VCO2). All data were smoothed using a 15-point moving average method and calculated automatically using analytical software (Meta-Soft Studio$^{®}$, Cortex$^{®}$, Leipzig, Germany). More detailed information on CPET procedures can be found in a previous publication. [14]. All procedures followed international recommendations [15, 16]. Additionally, participants were assessed for their ability to maintain a cadence between 50 and 60 revolutions per minute (rpm) for one minute, as part of the comprehension evaluation. Only tests in which the examiner determined that patients were capable of fulfilling this task were conducted.

Prior to undergoing CPET, a comprehensive medical history assessment was conducted, which included an evaluation of comorbidities such as hypertension, both insulin-dependent and non-insulin-dependent diabetes mellitus, a history of cancer (excluding non-melanoma skin cancer), acute myocardial infarction, heart failure, chronic obstructive pulmonary disease, stroke, and chronic renal disease.

Furthermore, participants were requested to self-report their weekly physical activity levels over the preceding 12 months, categorizing it as sedentary, irregular physical activity (equivalent to ‘Some light physical activity’ in the Saltin–Grimby Scale), or regular physical activity [17].

The variable VO2peak was determined as the highest 30-s average sample obtained during the final minute of the effort. The measured value was subsequently compared to predicted values by the Wasserman algorithm [18], which incorporated factors such as sex, age, and anthropometric measurements. The result was reported as the percent-predicted VO2peak achieved (%VO2peak). The Brazilian reference value for VO2peak was not employed in this study, primarily because it is not considered suitable for individuals aged over 80 years [19].

Statistical analysis

Due to the exploratory nature of this study, a predetermined sample size calculation was not conducted. Instead, we adopted an all-inclusive design, enrolling all eligible participants who met the inclusion criteria (age over 80 years). Categorical variables were presented as frequencies and percentages and compared using either the $\chi 2$ test or Fisher's exact test. Continuous variables were expressed as means and standard deviations and compared using the t-student test.

To determine the optimal cutoff point for the %VO2peak, we conducted receiver operating characteristic (ROC) curve analysis, a widely accepted method for assessing diagnostic accuracy and identifying the most appropriate threshold values. The Youden statistic was employed in this analysis to identify the optimal cutoff point.

For the multivariate Cox regression models, we followed a stepwise approach [20] to investigate the associations between various covariates and survival outcomes, employing threedistinct models.

Model 1: This model made no adjustments, allowing us to assess the unadjusted relationships between the covariates and survival outcomes.

Model 2: In this model, age was introduced as a covariate to evaluate its impact on survival outcomes while accounting for age-related effects.

Model 3: This model incorporated adjustments for age and stroke, enabling an examination of their respective contributions to survival outcomes.

We employed the Cox proportional hazards regression method to compute hazard ratios (HR) along with their corresponding 95% confidence intervals (CI) for each covariate incorporated into the models. The performance of each Cox model was assessed using Harrell's C-index. The selection of variables for the multivariate Cox regression models followed a two-step process. Initially, candidate variables were chosen based on univariate analysis with a significance threshold set at $p < 0.1$, thereby identifying covariates demonstrating some association with survival outcomes, albeit at a less stringent significance level.

The statistical significance level was set at $p < 0.05$ for all analyses. All statistical computations were conducted using the Statistical Package for the Social Sciences software (IBM SPSS Statistics for Windows, version 22.0, IBM

Corp., Armonk, NY) and MedCalc (MedCalc® Statistical Software version 22.013, Ostend, Belgium; 2023).

Results

The patient inclusion schematic is presented in Fig. 1. Between May 2018 and September 2023, a total of 4,458 patients underwent CPET. Among this cohort, 188 individuals (4.22%) were aged 80 years or older, with a mean age of 83.3 ± 3 years, and comprising 68.9% males. Over the study period, 22 (11.7%) of the patients died and the median follow-up duration was 494 days (interquartile range: 556 days).

Table 1 provides a summary of patient characteristics. Non-survivors were notably older (84.6 ± 3.0 vs. 83.0 ± 3.0 years, $p = 0.023$) and exhibited a lower VO2peak (13.4 ± 3.9 vs. 15.6 ± 4.4 ml/kg/min, $p = 0.026$) in comparison to survivors. Additionally, a significant distinction in %VO2peak was observed, with non-survivors having a markedly lower value compared to survivors (74.5 ± 16.1% vs. 88.1 ± 20.6%, $p = 0.003$).

Figure 2 illustrates the ROC curve for mortality prediction by %VO2peak. The area under the ROC curve was 0.699 (95% CI: 0.627–0.764; $p < 0.001$). The optimal cutoff point was determined to be %pVO2 ≤ 80%. Among patients with %pVO2 > 80% ($n = 109$), the mortality rate was 6.4%, whereas it was notably higher at 20.3% ($p = 0.005$) for those with %pVO2 ≤ 80% ($n = 74$). The mean VO2peak was 12.0 ± 2.2 and 17.5 ± 4.0 ml/kg/min for the %pVO2 ≤ 80% and %pVO2 > 80% groups, respectively ($p < 0.001$).

In our multivariable Cox regression models (Table 2), we examined the associations between various covariates and survival outcomes. In Model 1, the unadjusted analysis, patients with %VO2peak ≤ 80% exhibited a hazard ratio (HR) of 3.19 (95% CI: 1.29–7.87, $p = 0.011$). In Model 2, which adjusted for age, the HR for %VO2peak ≤ 80% was 3.12 (95% CI: 1.21–7.74, $p = 0.013$). Model 3, further adjusted for age and stroke, revealed significant HRs for stroke (HR 5.01, 95% CI: 1.06 to 23.72, $p = 0.042$) and %VO2peak ≤ 80% (HR 2.80, 95% CI: 1.11–7.06, $p = 0.028$). Figure 3 illustrates the survival curves for the three models.

While the level of physical activity did not demonstrate a significant association with mortality, it is worth noting that the prevalence of %VO2peak ≤ 80% significantly varied among activity groups. Specifically, rates of %VO2peak ≤ 80% were 52.2% for sedentary individuals, 33.3% for those engaging in irregular exercise, and 18.8% for those participating in regular exercise ($p = 0.002$). Hence, a low CRF level was nearly three times more common among sedentary individuals in comparison to those who participated in regular physical activity.

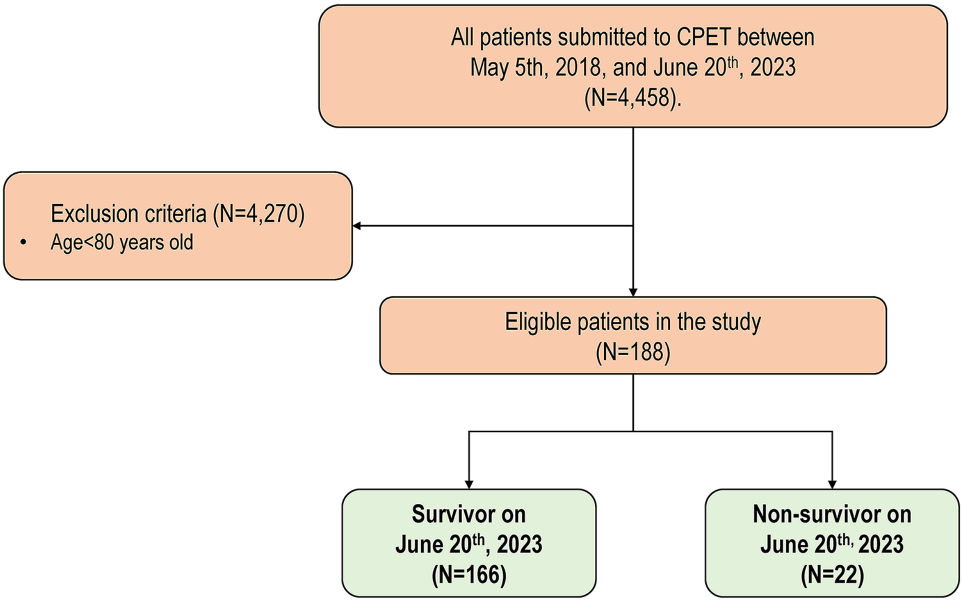

Fig. 1 Flowchart of the study sample

Table 1 Characteristics of the study sample according to survival status

Variables	All ($n = 188$)	Survivors ($n = 166$)	Non-survivors ($n = 22$)	p value
Age (years)	83.3 ± 3.0	83.0 ± 2.9	84.6 ± 3.0	0.023
Male sex (%)	123(68.9)	109(67.7)	17(77.3)	0.363
Weigth (kg)	73.9 ± 13.9	73.8 ± 14.3	74.1 ± 11.2	0.847
Heigth (cm)	166.4 ± 9.3	166.3 ± 9.0	167.2 ± 10.8	0.7
pVO2 (ml/kg/min)	15.2 ± 4.3	15.5 ± 4.4	13.4 ± 3.9	0.026
% pVO2	86.5 ± 20.5	88.1 ± 20.6	74.5 ± 16.1	0.003
Hypertension (%)	106(59.2)	95(59.4)	11(50)	0.403
Diabetes (%)	45(24.6)	38(23.6)	7(31.8)	0.401
Cancer (%)	52(28.4)	43(26.7)	9(40.9)	0.207
AMI (%)	29(15.8)	26(16.1)	3(13.6)	0.762
HF (%)	38(20.8)	35(21.7)	3(13.6)	0.379
COPD (%)	33(18)	28(17.4)	5(22.7)	0.541
Stroke (%)	4(2.2)	2(1.2)	2(9.1)	0.071
Renal failure (%)	6(3.4)	5(3.2)	1(4.8)	0.707
Physical activity				
Sedentary	94(51.4)	79(49.1)	15(68.2)	0.228
Irregular Exercise	57(31.1)	52(32.2)	5(22.7)	
Regular Exercise	32(17.5)	30(18.7)	2(9.1)	

Data expressed as mean and standard deviation or absolute and relative frequency

AMI acute myocardial infarction, *COPD* chronic obstructive pulmonary disease, *HF* heart failure, *VO2peak* peak oxygen uptake, *%VO2peak* percent-predicted peak oxygen uptake achieved

Fig. 2 Receiver operating characteristic curve for mortality prediction by percent-predicted peak oxygen uptake achieved

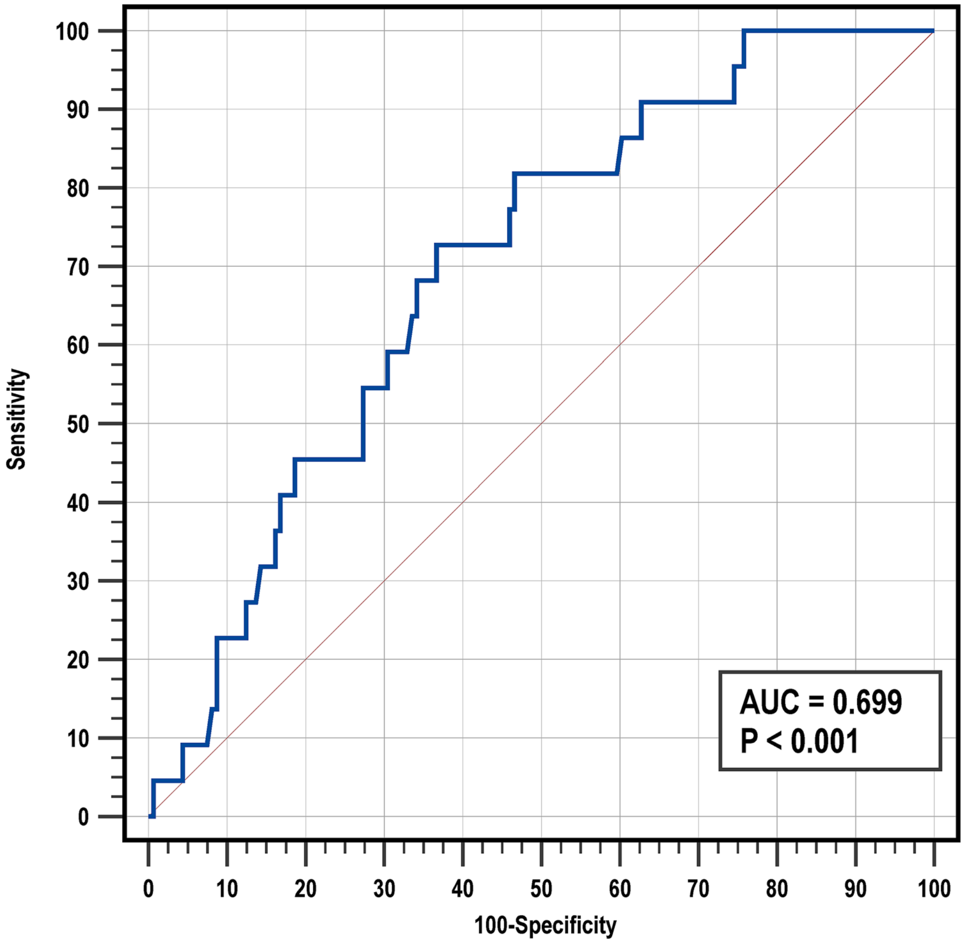

Table 2 Cox regression analysis of different models with cardiorespiratory fitness as a predictor of mortality with and without other variables

Covariates	*β*	SE	*p* value	HR (95% CI)
Model 1 (unadjusted)				
%VO2peak ≤ 80%	1.159	0.46	0.011	3.19 (1.29 to 7.87)
Model 2 (age adjusted)				
Age	0.119	0.061	0.052	1.13 (1.00 to 1.27)
%VO2peak ≤ 80%	11.393	0.462	0.013	3.12 (1.26 to 7.74)
Model 3 (Multivariable adjusted: age and stroke)				
Age	0.109	0.062	0.079	1.12 (0.99 to 1.26)
Stroke	1.611	0.793	0.042	5.01 (1.06 to 23.72)
%VO2peak ≤ 80%	1.03	0.471	0.028	2.80 (1.11 to 7.06)

SE Standard error, *HR* Hazard ratio, *%VO2peak* percent-predicted peak oxygen uptake achieved

Discussion

Our study underscores the prognostic significance of CRF in predicting mortality among octogenarians. In all our Cox regression models, the presence of a VO2peak lower than 80% of the predicted values consistently correlated with mortality. An additional noteworthy aspect of our study is the direct measurement of VO2peak through CPET, which departs from the common practice of estimating peak MET in studies involving older adults' populations during exercise testing. This direct measurement approach enhances the accuracy and reliability of our findings, further emphasizing the robustness of our results.

In a study conducted by Kokkinos et al.[3], which assessed CRF using exercise tests in a substantial sample of over 26,000 patients aged 80 and older, the findings revealed a remarkable 73% reduction in mortality for individuals at the highest fitness level when compared to the least fit individuals. Their study demonstrated that achieving a CRF of 7 MET, equivalent to a VO2peak of approximately 24.5 ml/kg/min, was associated with a remarkable 50% improvement in survival among octogenarians. Similar results have been reported in another study [21]. Notably, these values significantly surpassed the average VO2peak of 15.5 ml/kg/min observed within our cohort by more than 50%.

Setting such a high threshold for halving mortality, as exemplified by the 7 METs of CRF demonstrated by Kokkinos et al.[3], implies a requirement of achieving a level of CRF that may be nearly unattainable. This, in large part, can be attributed to the overestimation of VO2peak by standard exercise tests when compared to the more precise measurements obtained through CPET. In a prior study conducted by the same authors in 2017, it was demonstrated that the equation used to estimate VO2peak had a mean error of 21.4% when compared to the measured VO2peak obtained through CPET [7].

To the best of our knowledge, our study represents the largest cohort of patients aged 80 and older who have undergone CPET. Beyond the advantage of obtaining accurate measurements of VO2peak for CRF assessment, it offers valuable insights into the underlying factors contributing to exercise limitations[22] and aids in identifying optimal thresholds for exercise intensity, ultimately enabling more precise exercise prescriptions[23, 24].

Identifying patients with diminished CRF represents the primary and pivotal step in addressing this reversible risk factor, with profound implications for social, clinical, and economic outcomes [25]. Despite their relatively lower representation in epidemiological studies, the older adults' population bears the brunt of healthcare costs in many countries. Alemayehu et al. [26] have demonstrated that individuals who reach the age of 85 will incur 35.9% of their lifetime healthcare costs during their remaining years.

To date, 44 countries worldwide have achieved the significant life expectancy milestone of 80 years or more [10], with the majority of these countries being in the developed world. Notably, despite persistent social inequalities, global life expectancy increased by a decade from 1980 to 2015, with the most substantial improvements occurring in sub-Saharan Africa [9]. In Brazil, life expectancy at 80 years old has risen from 4.3 years in 1940 to 9.7 years in 2019 [27]. This increase in life expectancy has been accompanied by a rising burden of non-communicable diseases, which account for the majority of global deaths, disabilities, and hospitalizations, leading to an expanding healthspan [28]. Physical inactivity and its physiological consequence, low CRF, are among their principal risk factors [29].

As we confront the interconnected challenges of an aging population and the increasing burden of non-communicable diseases, it becomes increasingly evident that prioritizing the assessment of CRF and promoting physical activity among the older adults is not solely a matter of personal well-being but a vital societal imperative. Ensuring that individuals in their advanced years maintain and enhance their CRF can lead to not only extended survival but also an improved healthspan, granting them a higher quality of life [30]. Additionally, the economic implications of this approach are substantial, as investing in the health and fitness of the older adults population has the potential to alleviate the strain on healthcare systems [30] and reduce the substantial costs associated with age-related illnesses [31]. Therefore, our research underscores the urgency of implementing strategies that accurately measure and enhance CRF while tailoring physical activity recommendations.

Our study has several notable limitations that warrant consideration. First, the study's relatively small number of

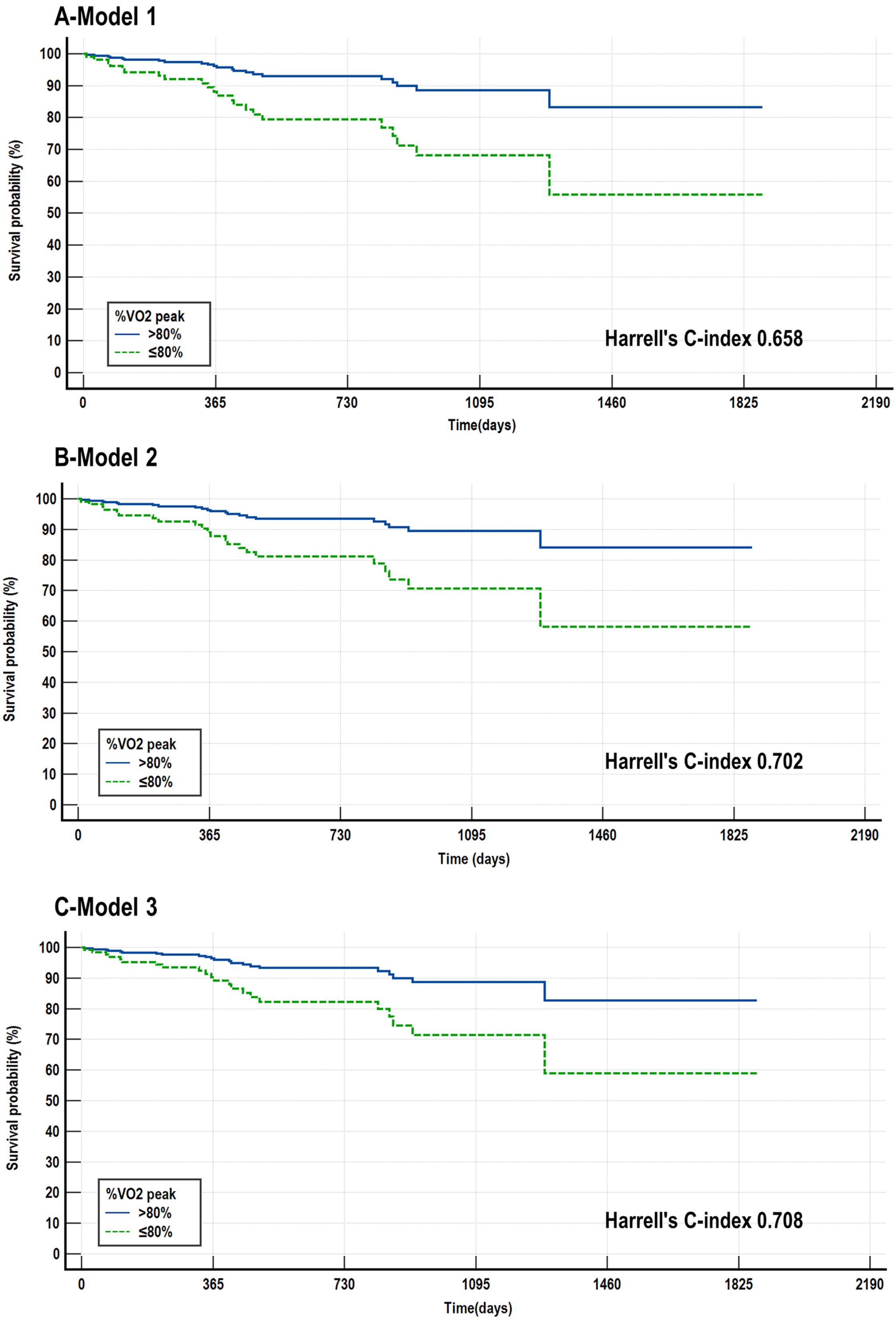

Fig. 3 Survival analysis according to three different multivariate Cox regression models. Model 1: Unadjusted; Model 2: Age-Adjusted and Model 3: Multivariable Adjusted—Age and Stroke;

outcomes could potentially raise concerns about overfitting in multivariable analysis. Nevertheless, it is essential to note that HR and confidence intervals for %VO2peak ≤ 80% remained consistent across all models, reinforcing their validity as robust predictors of mortality. Second, the study relied on death confirmation through the issuance of death certificates in the state of Rio de Janeiro, which may potentially omit deaths occurring outside this region. However, it is worth emphasizing that the vast majority of patients in the study had established healthcare relationships within the state.

Third, despite our models incorporating several key variables, it is acknowledged that additional unmeasured factors may influence the relationship between %VO2peak ≤ 80% and mortality. Future research can explore potential confounding factors more in-depth, enabling a comprehensive understanding of their impact. Fourth, this study involved a single-center analysis with patients from a specific geographic region and private care, which may limit the generalizability of our findings to broader populations.

Fifth, we will expand our discussion to address the potential practical implications of our research in clinical practice, considering the limitations and challenges associated with CPET accessibility, which can vary widely across different regions. Sixth, our study primarily included individuals who were community-dwelling residents, as our inclusion criteria were based on the capability of patients to understand the test instructions and information required for the CPET protocol. While this approach effectively screened out individuals with significant cognitive decline, it may limit the generalizability of our findings to a broader population of older adults. Seventh, the study population is predominantly male, which may pose challenges in extrapolating the findings to female populations. Moreover, sample deviates from the typical gender distribution in the elderly, where females predominate. However, recent trends show a narrowing gender gap in older populations, potentially making your findings more applicable in the future [32, 33].

Last, a significant limitation of our study is the exclusion of established predictors of mortality in the elderly, such as frailty, cognitive function, and nutritional status. While our research focused on VO2peak as a survival predictor, the absence of these critical factors may have impacted our findings. It is well-documented in geriatric medicine that frailty, often characterized by decreased strength and endurance, increased vulnerability to stressors, and diminished physiologic reserve, is a strong predictor of mortality. Similarly, cognitive impairment, ranging from mild cognitive deficits to severe dementia, has been shown to significantly affect survival outcomes in older adults. Additionally, nutritional status, particularly malnutrition, which is prevalent in the elderly, has a profound impact on morbidity and mortality. Future studies should aim to incorporate these variables to provide a more comprehensive analysis of survival predictors in this age group. The inclusion of these factors would not only enhance the validity of the findings but also offer a holistic view of the multifactorial nature of mortality risk in the elderly.

Conclusion

Our findings, derived from a cohort that underwent cardiopulmonary exercise testing, establish that a peak oxygen uptake lower than 80% of predicted values is an independent predictor of mortality in octogenarians. These results, consistent across various multivariate models, underscore the critical importance of evaluating and enhancing cardiorespiratory fitness in the older adults.

Our research delves into the enduring significance of VO2peak as a life extender, even for those aged 80 and beyond. In an era characterized by a rapidly aging population, our findings offer profound insights into tailoring healthcare strategies to address the evolving demographic landscape.

Author contributions Each of the authors listed met all four specified criteria for authorship. FB take responsibility as guarantors of the paper. We affirm that the study results are transparently presented, free from fabrication, falsification, or data manipulation of any kind.

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Declarations

Conflict of interest None.

Ethical approval This study obtained approval from the Human Research Ethics Committee with the registration CAAE: 35,706,720.4.0000.8093. All procedures conducted in this study were by the principles outlined in the 1975 Helsinki Declaration, as updated in 2013.

Informed consent All patients provided Informed consent for publication.

References

1. Ross R, Blair SN, Arena R et al (2016) Importance of assessing cardiorespiratory fitness in clinical practice: a case for fitness as a clinical vital sign: a scientific statement from the american heart association. Circulation 134(24):e653–e699. https://doi.org/10.1161/CIR.0000000000000461

2. Ezzatvar Y, Izquierdo M, Nunez J, Calatayud J, Ramirez-Velez R, Garcia-Hermoso A (2021) Cardiorespiratory fitness measured with cardiopulmonary exercise testing and mortality in patients with cardiovascular disease: a systematic review and meta-analysis. J Sport Health Sci 10(6):609–619. https://doi.org/10.1016/j.jshs.2021.06.004
3. Kokkinos P, Faselis C, Samuel IBH et al (2022) Cardiorespiratory fitness and mortality risk across the spectra of age, race, and sex. J Am Coll Cardiol 80(6):598–609. https://doi.org/10.1016/j.jacc.2022.05.031
4. Laukkanen JA, Kurl S, Salonen R, Rauramaa R, Salonen JT (2004) The predictive value of cardiorespiratory fitness for cardiovascular events in men with various risk profiles: a prospective population-based cohort study. Eur Heart J 25(16):1428–1437. https://doi.org/10.1016/j.ehj.2004.06.013
5. Defina LF, Willis BL, Radford NB et al (2013) The association between midlife cardiorespiratory fitness levels and later-life dementia: a cohort study. Ann Intern Med 158(3):162–168. https://doi.org/10.7326/0003-4819-158-3-201302050-00005
6. Ekblom-Bak E, Bojsen-Moller E, Wallin P et al (2023) Association between cardiorespiratory fitness and cancer incidence and cancer-specific mortality of colon, lung, and prostate cancer among swedish men. JAMA Netw Open 6(6):e2321102. https://doi.org/10.1001/jamanetworkopen.2023.21102
7. Kokkinos P, Kaminsky LA, Arena R, Zhang J, Myers J (2018) A new generalized cycle ergometry equation for predicting maximal oxygen uptake: the fitness registry and the importance of exercise national database (FRIEND). Eur J Prev Cardiol 25(10):1077–1082. https://doi.org/10.1177/2047487318772667
8. Laukkanen JA, Zaccardi F, Khan H, Kurl S, Jae SY, Rauramaa R (2016) Long-term change in cardiorespiratory fitness and all-cause mortality: a population-based follow-up study. Mayo Clin Proc 91(9):1183–1188. https://doi.org/10.1016/j.mayocp.2016.05.014
9. Uthman OA (2016) Global, regional, and national life expectancy, all-cause mortality, and cause-specific mortality for 249 causes of death,: a systematic analysis for the global burden of disease study. Lancet 388(10053):1459–1544. https://doi.org/10.1016/S0140-6736(16)31012-1
10. Life Expectancy by Country and in the World (2023)—Worldometer. Accessed 03 Oct 2023. https://www.worldometers.info/demographics/life-expectancy
11. Life expectancy vs. health expenditure per capita (2019). Accessed 28 Sep 2023. https://ourworldindata.org/grapher/life-expectancy-vs-health-expenditure-per-capita
12. Fleg JL, Morrell CH, Bos AG et al (2005) Accelerated longitudinal decline of aerobic capacity in healthy older adults. Circulation. 112(5):674–682
13. DeLorey DS, Kowalchuk JM, Paterson DH (2004) Effects of prior heavy-intensity exercise on pulmonary O_2 uptake and muscle deoxygenation kinetics in young and older adult humans. J Appl Physiol 97(3):998–1005
14. Braga F, Domecg F, Kalichsztein M et al (2023) Abnormal exercise adaptation after varying severities of COVID-19: a controlled cross-sectional analysis of 392 survivors. Eur J Sport Sci 23(5):829–839. https://doi.org/10.1080/17461391.2022.2054363
15. American Thoracic S, American College of Chest P. (2003) ATS/ACCP statement on cardiopulmonary exercise testing. Am J Respir Crit Care Med 167(2):211–277. https://doi.org/10.1164/rccm.167.2.211
16. Herdy AH, Ritt LE, Stein R et al (2016) Cardiopulmonary exercise test: background, applicability and interpretation. Arq Bras Cardiol 107(5):467–481. https://doi.org/10.5935/abc.20160171
17. Grimby G, Borjesson M, Jonsdottir IH, Schnohr P, Thelle DS, Saltin B (2015) The, "Saltin-Grimby physical activity level scale" and its application to health research. Scand J Med Sci Sports 25(Suppl 4):119–125. https://doi.org/10.1111/sms.12611
18. Wasserman KHJE, Sue DY, Stringer WW, Whipp BJ (2012) Principles exercise testing and interpretation, 5th edn. Lippincollt Williams & Wilkins
19. Milani M, Milani J, Cipriano GFB, de Castro I, Cipriano JG (2022) Reference standards for cardiorespiratory fitness in brazil: a pooled analysis and overview of heterogeneity in national and international studies. J Cardiopulm Rehabil Prev 42(5):366–372. https://doi.org/10.1097/HCR.0000000000000690
20. Cox DR, Oakes D (1984) Analysis of survival data. Chapman and Hall
21. Faselis C, Doumas M, Pittaras A et al (2014) Exercise capacity and all-cause mortality in male veterans with hypertension aged >/=70 years. Hypertension 64(1):30–35. https://doi.org/10.1161/HYPERTENSIONAHA.114.03510
22. Adachi H (2017) Cardiopulmonary exercise test. Int Heart J 58(5):654–665. https://doi.org/10.1536/ihj.17-264
23. Anselmi F, Cavigli L, Pagliaro A et al (2021) The importance of ventilatory thresholds to define aerobic exercise intensity in cardiac patients and healthy subjects. Scand J Med Sci Sports 31(9):1796–1808. https://doi.org/10.1111/sms.14007
24. Milani J, Milani M, Cipriano GFB, Hansen D, Cipriano JG (2023) Exercise intensity domains determined by heart rate at the ventilatory thresholds in patients with cardiovascular disease: new insights and comparisons to cardiovascular rehabilitation prescription recommendations. BMJ Open Sport Exerc Med 9(3):e001601. https://doi.org/10.1136/bmjsem-2023-001601
25. Bachmann JM, DeFina LF, Franzini L et al (2015) Cardiorespiratory fitness in middle age and health care costs in later life. J Am Coll Cardiol 66(17):1876–1885. https://doi.org/10.1016/j.jacc.2015.08.030
26. Alemayehu B, Warner KE (2004) The lifetime distribution of health care costs. Health Serv Res 39(3):627–642. https://doi.org/10.1111/j.1475-6773.2004.00248.x
27. IBGE. Life Expectancy in 2019. https://www.ibge.gov.br/en/statistics/full-list-statistics/17117-complete-life-tables.html?edicao=29511. Accessed 05 Sep 2023
28. Kramer A (2020) An overview of the beneficial effects of exercise on health and performance. Adv Exp Med Biol 1228:3–22. https://doi.org/10.1007/978-981-15-1792-1_1
29. Lee IM, Shiroma EJ, Lobelo F et al (2012) Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of burden of disease and life expectancy. Lancet 380(9838):219–229. https://doi.org/10.1016/S0140-6736(12)61031-9
30. Martin MY, Powell MP, Peel C, Zhu S, Allman R (2006) Leisure-time physical activity and health-care utilization in older adults. J Aging Phys Act 14(4):392–410. https://doi.org/10.1123/japa.14.4.392
31. Baras Shreibati J, Hlatky MA (2015) Fiscal fitness? Exercise capacity and health care costs. J Am Coll Cardiol 66(17):1886–1887. https://doi.org/10.1016/j.jacc.2015.08.861
32. Carmel S (2019) Health and well-being in late life: gender differences worldwide. Front Med 6:218
33. Pinho-Gomes A-C, Vassallo A, Carcel C, Peters S, Woodward M (2022) Gender equality and the gender gap in life expectancy in the European Union. BMJ Glob Heal 7(2):e008278