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SYSTEMATIC REVIEW

High-Intensity Interval Training for Cancer Patients: A Review of Key Considerations for Exercise Prescription

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Abstract

Background High-intensity interval training (HIIT) performed before, during, and after cancer treatment can attenuate the adverse effects induced by anti-cancer drugs. A clear presentation and rationale of characteristics of HIIT variables is vital to produce the expected HIIT adaptations in cancer patients. However, there are concerns regarding the HIIT protocols used in the cancer literature.

Objectives The aims were to (1) identify the characteristics of HIIT and the formats that have been prescribed, (2) analyze which anchors have been utilized to prescribe effort and pause intensity, (3) examine characteristics of the physical tests used for HIIT prescription, and (4) identify potential adverse events related to HIIT intervention.

Methods This scoping review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) guidelines, including PubMed, Scopus, and Web of Science databases.

Results A total of 51 studies were retrieved, and the following results were found: (1) Only 25 studies reported all four essential variables for HIIT prescription [effort intensity (effort duration): pause intensity (pause duration)]. Of these studies, 23 used active pause and employed the following prescription (on average): [84% (116 s): 39% (118 s)] when percentage of maximal aerobic power (MAP) [maximal/peak oxygen uptake ($VO_{2max/peak}$)/MAP] was used; [124% (161 s): 55% (142 s)] when percentage of anaerobic threshold (AT) was used; [83% (230 s): 62% (165 s)] when maximal heart rate percentage (%HR_{max}) was used. From these 23 studies, 12 used $VO_{2max/peak}$/MAP (one of the most recommended variables for HIIT prescription). Seven studies adopted the HIIT-long format, and in the remaining five studies, the format was unclear. (2) Twenty-four studies used fractions of $VO_{2max/peak}$ or mechanical variables like MAP as anchors for prescribing effort intensity, two studies used AT, 20 studies used fractions of HR_{max}/heart rate reserve, two studies used rate of perceived exertion (RPE), while one used RPE and %VO_{2peak} concomitantly, and two studies utilized RPE/%HR_{max} concomitantly. Two studies utilized passive resting, 12 studies used %VO_{2peak}/%MAP for prescribing pause intensity, four studies used AT, seven studies used %HR_{max}, one study used %HR_{max}/%VO_{2peak}, and two studies used absolute loads. (3) Ten studies did not report the characteristics of the physical tests employed, two studies used submaximal tests, and 39 studies utilized graded exercise tests. (4) Ten studies did not report if there were adverse events associated with the exercise program, while 34 studies did not report any adverse events.

Conclusions Only 50% of the studies provided all the necessary variables for accurate HIIT prescription, raising concerns about the replicability, comprehension, and effective application of HIIT in cancer patients. Most of the studies that reported all variables appeared to have employed the HIIT-long format. Only a few studies used more individualized anchors (e.g., AT) to prescribe HIIT-long format for cancer patients, which is considered a very heterogeneous population.

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Key Points

There is a concerning trend of misreported variables related to high-intensity interval training (HIIT) prescription for cancer patients, with only 50% of the studies providing all variables necessary to understand and replicate HIIT. The most misreported variable was pause intensity (49%), followed by effort duration (18%), pause duration (17%), and effort intensity (4%). These variables are essential for precisely organizing and prescribing HIIT to optimize results.

Although the characteristics of the employed HIIT protocols appear to be similar to the HIIT-long format, it was not possible to precisely identify the specific format of HIIT applied in several studies.

Few studies (4%) used anchors to prescribe HIIT specifically in the HIIT-long format (the most commonly used format) utilizing threshold-based methods. This could improve individualization and precision, thereby enhancing the effectiveness of training, considering the significant heterogeneity in training status and physical characteristics among cancer patients.

Effort intensity was prescribed using fractions of maximal heart rate or heart rate reserve in 40% of the studies, while 4% used rate of perceived exertion. Caution is warranted when using these variables to prescribe HIIT, as they may not accurately reflect the actual exercise intensity for cancer patients, considering the prevalence of autonomic dysfunction and fatigue in this population.

The likely discrepancy in the superiority of HIIT compared to moderate-intensity continuous training in improving cardiorespiratory fitness between the general population and cancer patients may be related to the lack of precision in training prescriptions, possibly due to misreporting of HIIT-related variables in the literature.

1 Introduction

Cancer remains a significant global health concern, ranking as the second leading cause of mortality worldwide [1, 2]. Over the past 2 decades, the United States has observed a 27% increase in cancer survivors, with projections anticipating a further 24% rise in the next decade due to advancements in anti-cancer treatments [3, 4]. Despite these advancements, anti-cancer treatments, such as hormone therapy, radiotherapy, and chemotherapy, are notorious for their debilitating side effects [5], including cancer-related fatigue [6–8] and cardiotoxicity [9–11]. Consequently, managing the adverse effects of anti-cancer treatments remains a global health concern.

The adverse effects of anti-cancer treatments are strongly associated with low levels of cardiorespiratory fitness [12], a term commonly used in the clinical literature and measured by maximal or peak oxygen consumption (i.e., $\dot{V}O_{2max/peak}$). For instance, Gong et al. [13] showed that prostate cancer patients exposed to androgen deprivation therapy experienced reduced cardiorespiratory fitness and a higher risk of mortality. Finally, a 31% impairment in cardiorespiratory fitness has been observed in women with breast cancer undergoing adjuvant chemotherapy [12]. Altogether, reduced cardiorespiratory fitness can be a significant prognostic marker for cancer patients, with emerging evidence suggesting that poor $\dot{V}O_{2max/peak}$ is associated with lower quality of life, increased treatment-induced cardiotoxicity, and an increased risk of cancer-related mortality [13–15]. Fortunately, physical exercise plays an important role in mitigating these side effects and improving $\dot{V}O_{2max/peak}$ [16, 17]. Therefore, it is crucial to discuss the effects of different exercise training types on cardiorespiratory fitness in cancer patients.

Endurance exercises (e.g., running, cycling, and swimming) are widely recommended for enhancing $\dot{V}O_{2max/peak}$, especially when performed at high intensities [18–22]. Recently, high-intensity interval training (HIIT) has been increasingly prescribed to cancer patients [23–26], emphasizing its potential advantages in optimizing improvements in cardiorespiratory fitness when compared to moderate-intensity continuous training (MICT). The advantage of HIIT for improving cardiorespiratory fitness is attributed to the prolonged time periods spent with oxygen uptake near $\dot{V}O_{2max/peak}$ during HIIT sessions. Time spent above 90% of $\dot{V}O_{2max/peak}$ has been a criterion widely recognized for assessing the effectiveness of exercise sessions targeting $\dot{V}O_{2max/peak}$ enhancement [19–21, 27–30]. Indeed, several meta-analyses have shown the superiority of HIIT over MICT in increasing $\dot{V}O_{2max/peak}$ in healthy populations [18–22]. However, this superiority is not fully observed in meta-analyses specifically focused on cancer patients [24, 31, 32], including a recent umbrella review [33]. Thus, it is essential to identify the potential factors that may influence these discordant outcomes.

HIIT may be defined as periods of intense effort interspersed with recovery periods [29, 34] and encompasses manipulation of several variables, with at least four being crucial to attain specific aims within a training session: effort intensity, effort duration, pause intensity, and pause and duration. A well accepted model [29, 34] that organizes

HIIT formats relies on effort intensity and duration as central variables categorizing HIIT into four types: HIIT-long, HIIT-short, and sprint interval and repeated sprint training. HIIT-long involves efforts performed between a marker of maximal aerobic capacity (such as ventilatory and metabolic thresholds or critical power) but below the marker of maximum aerobic power (i.e., intensity associated with $\dot{V}O_{2max/peak}$) with effort duration longer than 1 min. HIIT-short, in contrast, involves effort at 100–120% of a marker of maximal aerobic power (MAP), with effort duration of up to 1 min. Sprint interval training and repeated sprint training usually typically involve maximal (all-out) efforts with durations of up to 30 s. The overarching goal of both HIIT-long and HIIT-short formats is to maintain oxygen consumption above 90% of $\dot{V}O_{2max/peak}$ for as long as possible, thereby improving cardiorespiratory fitness. On the other hand, sprint interval training and repeated sprint training require pronounced neuromuscular and anaerobic contributions [29, 34]. This HIIT classification was intentionally designed aiming to achieve specific objectives during acute sessions, which cumulatively contribute to long-term adaptations.

HIIT intensity is ideally prescribed based on specific physiological anchors [e.g., intensities associated with $\dot{V}O_{2max/peak}$, anaerobic threshold (AT), and/or maximal heart rate (HR_{max})]. These anchors may be identified through a graded exercise test conducted until exhaustion, which is considered the gold standard test for acquiring these anchors. However, the identification of these anchors may be influenced by noteworthy variables such as initial load, load increment, stage duration, and cadence (in the case of cycling) [35]. A graded exercise test structured to a given population enables a highly individualized exercise prescription, reducing variability among individuals in performance responses, even for substantially heterogeneous groups such as cancer patients [35, 36].

Despite the growing interest in prescribing HIIT to cancer patients [23, 32, 33, 37, 38], we have identified some challenges in reproducing and applying HIIT for this population, such as insufficient descriptions of HIIT protocol characteristics, the use of inaccurate variables for prescribing HIIT, and insufficient information regarding the graded exercise tests employed for HIIT prescription. Although exercise guidelines for cancer patients have endorsed HIIT for this population, to the best of our knowledge, none of them specified the key HIIT characteristics, such as effort and pause intensity/duration, which are imperative for accurate HIIT prescription [16, 17, 39]. Thus, a clear presentation and rationale of HIIT variable characteristics, as well as its precise application, are crucial for producing the expected adaptations in cardiorespiratory fitness [18–22]. Moreover, especially in cancer patients, precise HIIT prescription is also important to avoid exercise-induced adverse effects, guaranteeing and ensuring patients safety.

Therefore, this scoping review aimed in the cancer literature to (1) identify characteristics of HIIT, and consequently the type of HIIT format (short, long, repeated sprint training, or sprint interval training) that has been prescribed; (2) analyze which anchors/variables have been utilized to prescribe effort and pause intensity in HIIT; (3) examine characteristics of the physical tests utilized for HIIT prescription; (4) identify potential adverse events related to HIIT intervention; and (5) propose strategies for enhancing the precision of HIIT prescription for cancer patients in future studies. This scoping review may provide a more comprehensive understanding of the current landscape regarding the selection of HIIT protocols for cancer patients. Consequently, it may enhance the practical application of these protocols by health professionals and guide the design of future studies focused on HIIT protocols, with a primary emphasis on improving cardiorespiratory fitness outcomes in this population.

2 Methods

This scoping review followed the guidelines outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) checklist, which consists of 22 items, and is complemented by a three-stage process flow diagram [40, 41]. This review exclusively focused on original research articles, encompassing randomized controlled trials, controlled clinical trials, cohort studies, and case studies. Our inclusion criteria followed the Population-Outcome-Treatment (POT) strategy [41] recommended for scoping reviews:

- *Population:* Cancer patients with various types of cancer who were submitted to HIIT either before, during, or after their cancer treatment, including chemotherapy, radiotherapy, hormone therapy, and/or surgery
- *Outcome:* Evaluation of cardiorespiratory fitness ($\dot{V}O_{2max/peak}$ or intensity/mechanical load associated with $\dot{V}O_{2max/peak}$, or only mechanical load as MAP)
- *Treatment:* High intensity interval training (HIIT)

The intervention was defined as HIIT based on the authors' description, as long as they explicitly mentioned in the text that the protocol involved high-intensity and interval training. Both intervention (HIIT + standard treatment) and comparison groups (standard treatment alone or with other exercise) were included. Studies that were not written in English and abstracts were excluded.

A comprehensive search was conducted on August 7, 2023, using MEDLINE (PubMed), Scopus, and Web of Science databases. The search strategy involved a combination of Medical Subject Headings (MeSH) terms, such as "High-intensity interval training," and non-MeSH terms, such as "cancer," "neoplasm," "carcinoma," "adenocarcinoma," "tumor," "high intensity intermittent training," "high intensity interval exercise," "high intensity intermittent exercise," "high intensity exercise," "high intensity training," "sprint interval training," "maximal oxygen uptake," "maximal oxygen consumption," "oxygen consumption," "peak oxygen uptake," "maximal aerobic power," "maximal aerobic capacity," "aerobic capacity," "aerobic power," "aerobic fitness," "peak power output," "maximal aerobic velocity," and "VO2." Boolean operators (AND and/or OR) were used and adapted for each respective database. Two independent reviewers (G.D.S.J. and R.B.A.) performed the search using identical methodologies.

Two independent reviewers screened titles, abstracts, and keywords, followed by full-text review for eligibility. Disagreements between researchers were resolved through discussion or by involving a third reviewer. Data extraction was focused on key variables for HIIT prescription, such as effort/pause intensity and duration, the characteristics of physical tests used for HIIT prescription, and reported adverse events. When studies employed progressive workloads, the range of intensities was used. If studies included additional interventions, such as moderate-intensity exercise or strength training alongside HIIT, only data related to HIIT were extracted, but the presence of other interventions was noted. Findings regarding the effects of HIIT on cardiorespiratory fitness are presented in the electronic supplementary materials (S1). Data were extracted and verified independently by different team members.

3 Results

According to the inclusion and exclusion criteria of this present review, 51 manuscripts were retrieved (Fig. 1). Table 1 presents characteristics of protocols used in HIIT prescription.

3.1 HIIT Format

Effort intensity was not clearly specified in two studies [85, 90], while pause intensity was not clearly specified in 25

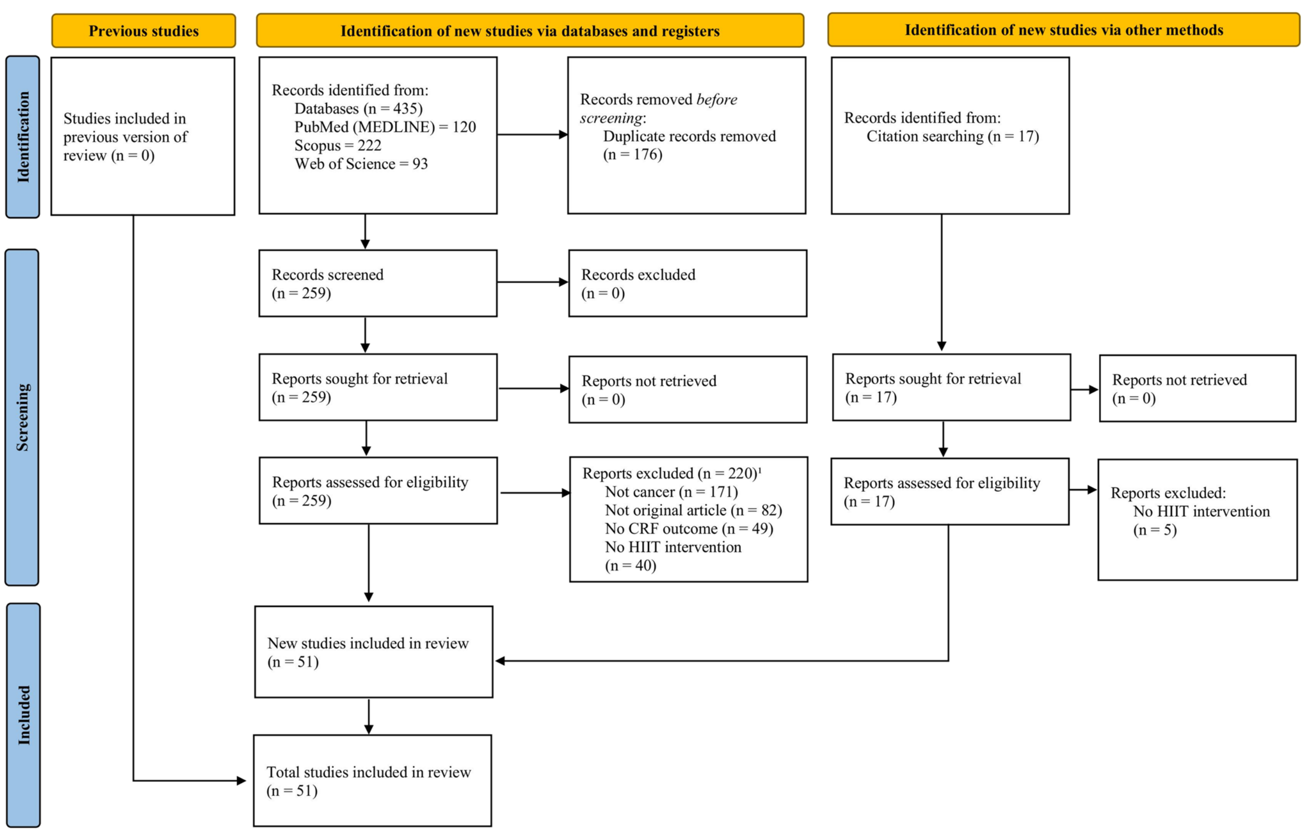


Fig. 1 Flowchart of the study screening process. *CRF* cardiorespiratory fitness, *HIIT* high-intensity interval training. [1]Reports have been excluded for more than one reason

Table 1 Study protocols for HIIT prescription

Study	Type of cancer / Participants	Moment of intervention	Frequency and duration of intervention	Characteristics of aerobic fitness test protocol	High-intensity interval training protocol characteristics				
					Effort intensity	Effort Duration	Pause Intensity	Pause duration	Total volume of HIIT and progression
Stefanelli et al. [42]	Lung N = 40 HIIT	Pre-surgery + Follow up	3 weeks 3x/w	Initial load: 0W - 2 min Conducted until predicted maximal heart rate Increment: not reported Cadence: not reported	70% of load maximum attained in GXT increments of 10W when the patient was able to tolerate 30 min	Not reported	Not reported	Not reported	70% of maximum with increments of 10W until reach 30 min session
West et al. [43]	Rectal N = 35 HIIT	Post neoadjuvant chemoradiotherapy and pre surgery	6 weeks 3x/w	Initial load: freewheel pedaling (3min) Increment: 10 to 25W each min according predicted VO_{2peak} until exhaustion Cadence: not reported	delta 50% of lactate threshold and $i\dot{V}O_{2peak}$ Cadence: not reported	4 - 6 efforts of 2min	80% lactate threshold Cadence: not reported	4 - 6 efforts of 3 min	20-30 min
Dunne et al. [44]	Colorectal liver metastasis N = 20 HIIT N = 17 control (standard care)	Post neoadjuvant or adjuvant treatment and pre surgery	4 weeks 3x/w	Initial load: freewheel pedaling Increment: 10 to 25W each min according predicted VO_{2peak} until exhaustion Cadence: not reported	> 90% of $i\dot{V}O_{2peak}$ Cadence: not reported	Not reported	< 60% of iVO_{2peak} Cadence: not reported	Not reported	30 min
Licker et al. [45]	Lung N = 74 HIIT N = 77 control	Post neoadjuvant chemotherapy and pre surgery	3-4 weeks 2x/w	Not reported	80-90% of W_{peak} Cadence: not reported	15 s	Not reported	15s	2 sets of 10 min with 4 min recovery between sets
Salvi et al. [46]	Lung N = 14 HIIT	Pre-surgery + Follow up	3 weeks	Not reported	70% MAP increased 10W according patient condition	Not reported	Not reported	Not reported	Not reported
Wood et al. [47]	Leukemia N = 40 home-based HIIT	Pre-surgery	6 weeks	Initial load: 25 watts Increment: 10-25 watts until exhaustion Cadence: 50-70 rpm	60-70% (weeks 1 and 2) and 65-95% (weeks 3, 4, 5 and 6) of HR_{max}	3 min	< 65% HR_{max}	2 min	5 -25 min
Banerjee et al. [48]	Bladder N = 30 HIIT N = 30 control	Post neoadjuvant chemotherapy and pre surgery + Follow up	6 weeks 2x/w	Initial load: 0 W - 2 min Increment: 10-20W each min until exhaustion Cadence: not reported	RPE 13-15 equivalent to 70-85% of predicted HR_{max} (220-age) Cadence: 50-60 rpm	5 min	50 W RPM: 50-60	2.5 min	6 sets
Karenovics et al. [49]	Lung N = 74 HIIT N = 77 control	Post neoadjuvant chemotherapy and pre surgery + Follow up	8 sessions	Not reported	all out at MAP	15s	Not reported	15s	2 sets of 10 min: 4 min recovery between sets
Bhatia et al. [50]	Lung N = 74 HIIT N = 77 control	Pre-surgery	3 weeks 2-3x/w	Not reported Until exhaustion	100% of W_{peak} Cadence: 60 -70 rpm	15s	Passive resting	15 s	2 sets of 10 min with 4 min recovery between sets

studies [42, 45, 46, 49, 51, 53, 56, 58, 60, 62, 64–66, 68–70, 72–74, 77, 80, 84–86, 90]. Effort duration was unclear in eight studies [42, 44, 46, 56, 62, 64, 65, 77], while pause duration was unclear in nine studies [42, 44, 46, 56, 62, 64, 65, 74, 77]. Only 25 out of 51 studies reported all key variables for HIIT prescription: effort and pause intensity, and effort and pause duration (Fig. 2).

Among these 25 studies that reported all variables, 23 used active pause [26, 43, 47, 48, 52, 54, 55, 57, 59, 61, 67, 71, 75, 76, 78, 79, 81–83, 87–89, 91], while the remaining two studies used passive pause [50, 51]. Considering studies that used active pause and prescribed HIIT using peak oxygen uptake percentage (%VO_{2peak}) or MAP percentage (%MAP) anchors (12 studies) [26, 52, 54, 55, 59, 61, 67, 71, 79, 81, 82, 91], the average values for effort and pause intensities were 84 ± 12% and 39 ± 15% of VO_{2peak}/MAP, respectively. Moreover, the average values for effort and pause duration were 116 ± 77 s and 118 ± 50 s, respectively, resulting in an effort-to-pause ratio of 1:1. When the AT was the anchor used for HIIT prescription (two studies) [43, 57], the average values for effort and pause intensities were 124 ± 6% and 55 ± 35% of AT, respectively, with the average values for effort and pause duration being 161 ± 81 s and 142 ± 46 s, respectively, resulting in an effort-to-pause

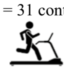
Table 1 (continued)

Boereboom et al. [51]	Colon N = 18 HIIT	Pre-surgery	4 weeks 3-4x/w	Initial: 2 min 0w Increment: 15-30W/min ramp protocol until >85%HRR or RER >1 Cadence: 50-60 rpm Until exhaustion	Intensity: between 100-120% of the maximum wattage achieved during baseline CPET. Cadence: not reported	1 min	Unloaded (passive resting)	90s	5 x 1 min HIIT, interspersed with 90 second
Minnella et al. [52]	Colorectal N = 21 HIIT+RT N = 21 MICT+RT	Post neoadjuvant chemotherapy and pre surgery	4 weeks 3x/w	Not reported Until exhaustion	85-90% W_{peak} Cadence: not reported	2 min	80-85 % AT	3 min	30 min
Wood et al. [53]	Myeloid leukemia N = 6 home-based HIIT N = 10 control	Pre-surgery	Median: 8,5 weeks (range 3-20 weeks).	Not reported	80% HR_{max}	2 min	Not reported	3 min	25 min
Argudo et al. [54]	Esophagogastric N = HIIT 33	Post neoadjuvant chemoradiotherapy or chemotherapy and pre surgery	5 weeks 5x/w	Cycle Ergometer until exhaustion	80% of MAP	1 min	40% of MAP Cadence: 55-65 rpm	2 min	40 min Progression utilizing RPE
Kang et al. [55]	Prostate N = 26 HIIT N = 26 control	Pretreatment (active surveillance)	12 weeks 3x/w	Bruce protocol Until exhaustion	85-95%$\dot{V}O_{2peak}$	2 min	40% VO_{2peak}	2 min	20-32 min
Minnella et al. [56]	Lung N = 39 HIIT or MICT+RT N = 26 control	Pre-surgery	4 weeks 2-3x/w	Not reported	85-95% MAP	Not reported	Not reported	Not reported	Not reported
Berkel et al. [57]	Colorectal N = 28 HIIT+RT N = 29 control	Post neoadjuvant chemoradiotherapy or chemotherapy and pre surgery	3 weeks 3x/w	Initial load: unloaded for 3 minutes Increment: 5 to 15W per minute Cadence: 60-80 rpm	120% AT Cadence: 60-80 rpm	1st week: 120s 2nd week: 140s 3rd week: 160s	50% AT	1st week: 180s 2nd week: 160s 3rd week: 140s	30 min
Bojesen et al. [58]	Colon N = 8 HIIT+RT	Pre-surgery	4 weeks 3x/w	Not reported Until exhaustion	90% HR_{max} Cadence: not reported RPE > 16	2 min	Not reported	4 min	24 min
Djurhuus et al. [59]	Prostate N = 20 HIIT N = 10 control	Pre-surgery	2 to 8 weeks 4x/w	Initial load: 70 watts Increment: 20 W each min until exhaustion Cadence: not reported	100-120% MAP	1 min	30% MAP	3 min	20-25 min
Foulkes et al. [60]	Breast N = 49 HIIT+MICT+RT N = 38 control	Post different treatments (chemo, radio, immune, HER2-targeted therapies) and pre surgery	12 months 1x/w (HIIT)	Initial load: 70 watts Increment: 20 W each min until exhaustion Cadence: not reported	>85% HR_{max}	2-4 min	Not reported	3 min	20-28 min

ratio of 1:0.9. It is noteworthy that one of those two studies [43] used the delta concept for HIIT prescription in which specifically a fraction of 25% of the difference between AT and MAP was used.

Alternatively, when HIIT was prescribed based on maximal or reserve heart rate ($HR_{max/reserve}$) (ten studies) [47, 48, 75, 76, 78, 83, 87–89, 91], the average values for effort and pause intensities were 83 ± 7% and 62 ± 7% of

Table 1 (continued)

Van Wijk et al. [61]	Liver and pancreatic N = 26 HIIT+MICT 	Pre-surgery	4 weeks 3x/w	Initial load: 0 Increment: 5, 10 or 15W each min until exhaustion Cadence: 60 to 80 rpm	60% of MAP 60-100 rpm	30s	20W 40-60 rpm	60s	30 min
Adamsen et al. [62]	Various (breast, bowel, hematological and other oncological malignancies) N = 135 HIIT N =134 control 	During chemotherapy	6 weeks 3x/w	Initial load: 67 W during 8 minutes Increment: 20 W each min until exhaustion Cadence: not reported	85-95% of HR_{max} Workload of 70-250W Cadence: not reported	Not reported	Not reported	Not reported	15 min
Hwang et al. [63]	Lung N = 13 HIIT N = 11 control 	During targeted therapy and post chemo or radiotherapy or lobectomy	8 weeks 3x/w	Initial load: 20W 1 min Increment: 5-20 W each min (depending on the participant's comorbidities, treatment history, or exercise response in the first minute)	80% of $\dot{V}O_{2peak}$, or RPE of 15–17 Cadence: not reported Cycle ergometer or treadmill	2–5-min	60% of VO_{2peak}, or a RPE of 11–13	2–5-min	15-25 min
Edvardsen et al. [64]	Lung N = 30 HIIT+RT N = 31 control 	After surgery	20 weeks 3x/w	Not reported Until exhaustion	80–95% of HR_{max}	Not reported	Not reported	Not reported	Not reported
Møller et al. [65]	Colon N = 15 HIIT N = 16 control	During chemotherapy	12 weeks 3x/w	Initial load: 4-10 min at 30-80W)	70-250 W equivalent to 85-95% HR_{max} Cadence: not reported	Not reported	Not reported	Not reported	60-90 min
	N = 14 home-based LI 			Increment: 5-20W each min until exhaustion Cadence: not reported					
Schulz et al. [66]	Breast N = 15 HIIT N = 11 control 	During chemo, radio and hormone therapies and post chemo, radio hormone therapies and surgery	6 weeks 2x/w	Initial load: 25W Increment: 25W every 3 min Cadence: not reported	85–100% of $\dot{V}O_{2peak}$ Cadence: not reported	10x 1 min	Not reported	1 min	Not reported
Freitag et al. [67]	Colon N =1 HIIT + hyperoxia 	During chemotherapy	4 weeks 8 training sessions	Initial load: 25 watts Increment: 25 W each minute until exhaustion Cadence: 65rpm	90%MAP	3 min	45% MAP	2 min	25 min
Mijwel et al. [68]	Breast N = 74 HIIT + RT N = 72 HIIT + AT N = 60 control 	During chemotherapy	16 weeks 2x/w	Not reported *Åstrand-Rhyming submaximal test	RPE of 16–18 Cadence: not reported	3 min	Not reported	1 min	12 min
Egegaard et al. [69]	Non-small cell lung N = 8 HIIT+MICT N = 7 control	During chemoradiotherapy	7 weeks Daily (Mon-Fri)	Initial load: 4-min at 20–80 W Increment: 5–15 W/min until exhaustion Cadence: not reported	80–95% MAP Cadence: not reported	30 sec	Not reported	30 sec	10 min

$HR_{max/reserve}$, respectively, and the effort and pause durations were 230 ± 37 s and 165 ± 50 s, respectively, resulting in an effort-to-pause ratio of 1:0.7.

For studies employing passive pause [50, 51], the effort intensity was reported as 105 ± 7% of VO_{2peak}/MAP, with effort and pause durations of 38 ± 32 s and 53 ± 53 s, respectively, resulting in an approximate 1:1.4 effort-to-pause ratio. It is important to note that four studies did not utilize the same type of anchor to prescribe effort and pause intensities [48, 52, 76, 81], and one study used two variables (%HR_{max} and %VO_{2peak}) to prescribe effort intensity [91].

Table 1 (continued)

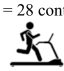
Lee et al. [26]	Breast N = 15 HIIT N =15 control	During chemotherapy	8 weeks 3x/w	Initial load: 40w Increment: 10w each min Cadence: 60 RPM Until exhaustion	90% of MAP	7 x 1min	10% of MAP	2 min	20 min
Ansund et al. [70]	Breast N = 29 RT-HIIT N = 32 do AT-HIIT N = 27 control	During chemotherapy	16 weeks 2x/w	Not reported *Åstrand-Rhyming submaximal test	RPE of 16–18 Cadence: not reported	3 min	Not reported	3 min	Not reported
MacDonald et al. [71]	Lymphocytic Leukemia N = 10 HIIT + RT N = 6 control	During treatment	12 weeks 3x/w	2 mph/0% grade with increasing speed and/or grade such that the metabolic demand increased at approximately 3.5 mL/kg/min until volitional exhaustion.	80-90%$VO_{2reserve}$	60-90s	50-60%VO_{2} reserve	60-90s	30 min
Bjørke et al. [72]	Breast N = 128 RT+HIIT N = 127 RT +LMI	During chemo or non-chemo therapies	6 months 2x/week	Initial load: 4km/h (2% inclination) Increment: not reported *Modified Balke protocol: 2% inclination	80-90 % of HRR Home based running, cycling, walking uphill, or any other endurance-based activity Cadence: not reported	2 min	Not reported	1 min	Progression over the course of the program: 5 to 10 sets (15 to 30 min).
				increase/min until 12%, from which the speed increased 0.5 km/h per min until exhaustion					
Reljic et al. [73]	Various (not specified) N = 13 HIIT N = 14 control	During treatment	12 weeks 2x/w	Initial load: 50 W Increment: 1 W each 5s for females and 1 W each 4s for males until volitional exhaustion Cadence: not reported	80% to 85% HR_{peak} weeks 1 to 4 85% to 90% HR_{peak} weeks 5 to 8, 90% to 95% $HR_{peak.}$ weeks 9 to 12	1 min	Not reported	1 min	14 min
Bloomquist et al. [74]	Testicular N = 40 HIIT + RT	During chemotherapy	6 weeks 2 x/week	Initial load: 47-87 Increment: 10-watts each minute until exhaustion Cadence: not reported	85-95% HR_{max}	30s-2 min	Not reported	Not reported	15-30 min
Kerrigan et al. [75]	Not specified N = 11 HIIT N = 11 control	During chemotherapy	10 weeks 2 or 3x/w (30 visits)	Haskell treadmill protocol (two metabolic equivalents of task increase each 3min) until exhaustion	71-90%HRR Treadmill, stationary cycle, and elliptical trainer)	4 min	60-70%HRR	3 min	40-50 min
Kampshoff et al. [76]	Various (breast, colon, ovarian, lymphoma, cervix, testicular) N=91 RT+HI N=95 RT+LMI N=91 control	Post surgery, chemo, radio, immune or hormone therapies	12 weeks 2x/w	Initial load: 25W Increment: 25 W each 10s Cadence: 70 to 80 rpm Until exhaustion	1st to 4th week 65% of the maximum short exercise capacity (Maximum short exercise capacity - estimated by the steep ramp test). Cadence: not reported	1st to 4th week 30s	1st to 4th week 30% maximum short exercise capacity	1st to 4th week 60s	1st to 4th week 2 blocks of 8 min = 16 min
					5th to 12th week 80% of HRR treadmill or cycling Cadence: not reported	5th to 12th week 5 min	5th to 12th week Not reported	5th to 12th week 1 min	5th to 12th week 3 blocks of 6 min = 18 min

3.2 Anchors Used to Prescribe Effort and Pause Intensity

Regarding the effort intensity, 24 studies used fractions of $\dot{V}O_{2max/peak}$ or mechanical variables like MAP [26, 42, 44–46, 49–52, 54–56, 59, 61, 66, 67, 69, 71, 76, 79, 81, 82, 86, 91] as anchors to prescribe HIIT. One study prescribed effort intensity using AT [57], and one used delta 50% of the lactate threshold and intensity associated with $\dot{V}O_{2max/peak}$ [43].

Twenty studies prescribed effort intensity based on fractions of HR_{max} or heart rate reserve (HRR) [47, 53, 60, 62, 64, 65, 72–76, 78, 80, 83, 84, 87–89]. Specifically, nine studies directly measured HR_{max} during the graded exercise test [47, 53, 60, 65, 73, 75, 80, 87, 88], while one employed an

Table 1 (continued)

Martin et al. [77]	Breast N=13 HIIT N=19 LI N=40 control Prostate N=27 HIIT N=25 LI N=35 control 	Post surgery or radiotherapy	8 weeks 3x/w	Initial load: 30W Increment: 30 W each 60s Cadence: 60 rpm	HR corresponding to 75% and 80% of $\dot{V}O_{2peak}$ multiple pieces of equipment (walked or jogged outside)	Not reported	Not reported	Not reported	25 min
Devin et al. [78]	Colon N=21 HIIT N=14 MICT Rectal N=9 HIIT N=3 MICT 	Post surgery, chemo or radiotherapy	4 weeks 3x/w	Initial load: 50W Increment: 20-30 W each 60s Cadence: 60 to 70 rpm Until exhaustion	85–95 % HR_{peak} Cadence: not reported	4 min	50–70 % HRpeak	3 min	4 sets (4:3) = 28 min
Dolan et al. [79]	Breast N=12 HIIT N=11 MICT N=10 control 	Post surgery, chemo or radiotherapy	6 weeks 3x/w	Initial load (fixed): 3.5 ± 0.5 mph Increment (gradient): 2% each 2 min Until exhaustion	65 to 95% $\dot{V}O_{2peak}$ depending on day and week	2 to 4 min depending on day and week	50 to <60% VO2peak depending on day and week	2 to 4 min depending on day and week	Volume calculated by distance: 3.22 km and progressing to 4.02 km by week 5
Schmitt et al. [80]	Various (breast, ovarian, colon, vaginal, non-invasive urothelial, non-Hodgkin's lymphoma) N=15 HIIT N=14 LMI 	During hormone therapy and post-surgery, chemo, radio and hormone therapies	3 weeks 2x/w	Initial load: 2.7 km/h Increment: increases in velocity or inclination or both each 3 min - load and gradient of inclination not reported	>95% HR_{peak}	1 min	Not reported	2 min	8 sets (1:2) = 24 min
Adams et al. [81]	Testicular N = 35 HIIT N = 28 control 	Post surgery, chemo or radio therapies	12 weeks 3x/w	Initial load: not reported Increment: 2% incline increasing each 2 minutes until exhaustion	75-95% $\dot{V}O_{2peak}$	4 min	5-10% below VT	3 min	25 min
Persoon et al. [82]	Multiple myeloma N=29 HIIT N=29 control Non-Hodgkin's lymphoma N=25 HIIT N=26 control 	Post cell transplantation	18 weeks 2x/w on 12 first weeks 1x/w from 13 week onward	Initial load: not reported Increment: not reported Cadence: 60 rpm	1-8 week 65% MAP Cadence: not reported	1-8 week 30s	1-8 week 30% MAP	1-8 week 60s	1-8 week 2 x 8 min.
					9-18 week 65% MAP Cadence: not reported	8-18 week 30s	8-18 week 30% MAP	8-18 week 30s	8-18 week 2 x 8 min.

equation to predict HR_{max} [76]. Notably, in eight of these studies, detailed information on how heart rate (HR) was used to determine effort intensity was not clear. Specifically, they do not report whether the HR_{max} was measured or estimated, if an actual test was performed, or if an age-based equation was used to estimate it [62, 64, 72, 74, 78, 83, 84, 89].

Two studies used rate of perceived exertion (RPE) to prescribe effort intensity [68, 70], while one used RPE and $\%\dot{V}O_{2peak}$ concomitantly [63], and two studies utilized RPE and $\%HR_{max}$ [48, 58], of which Bojesen et al. [58] directly measured HR_{max} during the graded exercise test, and Banerjee et al. [48] used an equation to predict HR_{max}.

Regarding the pause intensity, two studies utilized passive resting [50, 51], 12 studies utilized $\%\dot{V}O_{2peak}$/%MAP [26, 48, 54, 55, 59, 61, 67, 71, 76, 79, 82, 91], four studies used AT [43, 52, 57, 81], and seven studies used $\%HR_{max}$ to prescribe pause intensity [47, 75, 78, 83, 87–89], of which four studies measured directly HR_{max} in graded exercise tests [47, 75, 87, 88], while two studies did not describe how HR_{max} was identified to prescribe pause intensity [78, 89]. One study used both $\%HR_{max}$ and $\%\dot{V}O_{2peak}$ [91]. Two studies prescribed the pause intensity using absolute loads [48, 61]. Figure 3 presents the variables/anchors used to prescribe effort and pause intensity.

Table 1 (continued)

Devin et al. [83]	Colon N=12 HIIT N=14 HIIT-tapered N=15 MICT Rectal N=6 HIIT N=6 HIIT-tapered N=4 MICT	Post surgery, chemo or radiotherapy	8 weeks HIIT and MICT: 3x/w HIIT-T: 3x/w on 4 first weeks and 1x/w from week 5 onward	Initial load: 50W Increment: 20-30 W each 60s Cadence: 60 to 70 rpm Until exhaustion	85–95 % HR_{peak} Cadence: not reported	4 min	50–70 % HR_{peak}.	3 min	4 sets (4:3) = 28 min
Northey et al. [84]	Breast N=6 HIIT N=5 MICT N=6 control	Post surgery, chemo, radio or hormone therapies	12 weeks 3x/w	Initial load: 20W Increment: 20W each 60s Cadence: self-selected cadence >60 rpm Until exhaustion	> 90% HR_{max} Cadence: 95-115 rpm	30s	Not reported	2 min	1 to 7 sets (30s:2min) = 2.5 min to 17.5 min
Toohey et al. [85]	Breast N = 6 HIIT N = 5 MICT N = 6 control	Post surgery, chemo or radio therapies	12 weeks 3x/w	Initial load: 20W Increment: ≤ 20 W each minute until exhaustion Cadence: > 60 rpm	Not reported Cadence: 95-115 rpm	30s	Not reported	2 min	7x30sec - 3.5 min 6x2min - 12min
Bartelt et al. [86]	Breast N = 16 HIIT + RT semi supervised N = 11 control	Post surgery, chemo, radio or hormone therapies	16 weeks 3x/w	Initial load: 20 W Increment: 15 W each minute until volitional exhaustion	60% MAP Cadence: not reported	3 min	Not reported	1.5 min	42 min: - 1 min warm up 0%; - 1 min at 30% peak power; - 10 x 3 min interval at 60%; - 10 x 1,5 active recovery.
Bell et al. [87]	Breast N = 10 HIIT N = 10 MICT	Post chemo or radio therapies	12 weeks 2x/w	Initial load: 25-30 W Increment: 10-30 W each 2 minutes until exhaustion	70-75% HRR	4 sessions 2 min 20 sessions: 5 min	< 60% HRR	2 min	4x 2: 2 = 16 min 4 x 5:2 = 28 min
Samhan et al. [88]	Breast N = 30 HIIT N = 30 control	Post surgery, chemo or radio therapies	8 weeks 3x/w	Bruce protocol Until exhaustion	70-90%HR_{max}	4 minutes	50-60%HR_{max}	3min	28 minutes
Choi et al. [89]	Breast N = 2 (case report) HIIT	Post chemotherap y	8 weeks 3x/w	Not reported	85% HRR	4 min	50-60%HRR	3 min	4x 4:3 = ~25 minutes
Koevoets et al. [90]	Breast N = 91 HIIT + MICT + RT N = 60 control	Post chemotherap y	6 months 2x/w	Initial load: no load Increment: 10, 15 or 20 W Cadence: not reported Until exhaustion	Not reported	Week 10-17 10 x 30s Week 18-26 8 x 30s	Not reported	Week 10-17 1min Week 18-26 1min	Week 10-17 10x 30s: 1 min = 10.5 min Week 18-26 8 x 30s: 1 min = 12 min
Isanejad et al. [91]	Breast N = 10 HIIT N = 10 MICT N = 10 control	During hormone therapy and post chemo and/or radiotherapy	12 weeks 3x/w	Min 1: 3.2 km/h Min 2: 4.3 km/h Min 3: 5.9km/h 1% increment each min until $VO2_{peak}$ was reached Until exhaustion	90%$\dot{V}O_{2peak}$ and 95%HR_{peak}	4 min	60%VO_{2peak} and 75% HR_{peak}	3min	4x 4:3 = 28 min

AT aerobic training, *AT* anaerobic threshold, *CPET* cardiorespiratory exercise test, *GXT* graded exercise test, *HIIT* high-intensity interval training, *HR* heart rate, HR_{max} maximal heart rate, HR_{peak} peak heart rate, *HRR* heart rate reserve, *LI* low intensity, *LMI* low-to-moderate intensity, *MAP* maximal aerobic power, *MICT* moderate-intensity continuous training, *RPE* rate of perceived exertion, *RPM* rotations per minute, *RT* resistance training, VO_{2peak} peak oxygen uptake, $VO_{2reserve}$ oxygen uptake reserve, W_{peak} peak power output

3.3 Characteristics of Physical Tests Employed to Prescribe Exercise Intensity

The characteristics of the tests used were not reported in ten studies [45, 46, 49, 50, 52, 53, 56, 58, 64, 89]. Two studies used submaximal tests [68, 70], and the remaining 39 studies employed graded exercise tests [26, 42–44, 47, 48, 51, 54, 55, 57, 59–63, 65–67, 69, 71–88, 90, 91]. Among these, 22 studies insufficiently reported one or more important variables to determine intensity of HIIT prescription, such as initial load, load increment, stage duration, in the case of cycling cadence, and whether the test was conducted until exhaustion [42–44, 48–50, 54, 57, 59, 62, 63, 65, 66, 69, 72–74, 77, 80–82, 90]. Five studies employed and referenced

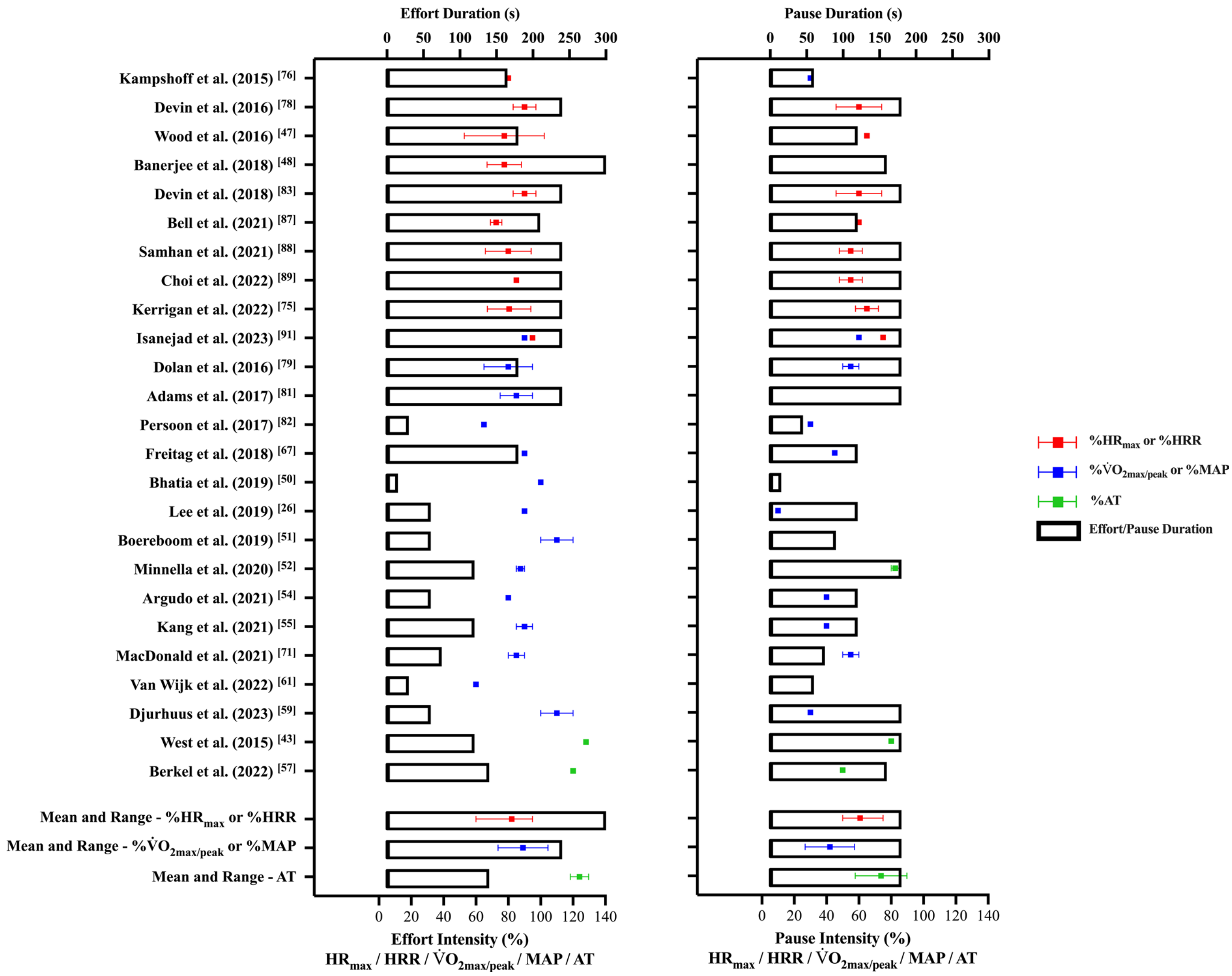


Fig. 2 Effort and pause intensity of studies that reported all four key variables (effort and pause intensity and effort and pause duration) in HIIT prescription. Average and range were reported for effort and pause intensity, while for effort and pause duration, only the range of all protocols is reported in the figure. *AT* anaerobic threshold, *HIIT* high-intensity interval training, HR_{max} maximal heart rate, *HRR* heart rate reserve, *MAP* maximal aerobic power, $\dot{V}O_{2max/peak}$ maximal or peak oxygen uptake

standardized protocols such as Bruce, Haskell, or Astrand and Rhythm protocols [55, 68, 70, 75, 88].

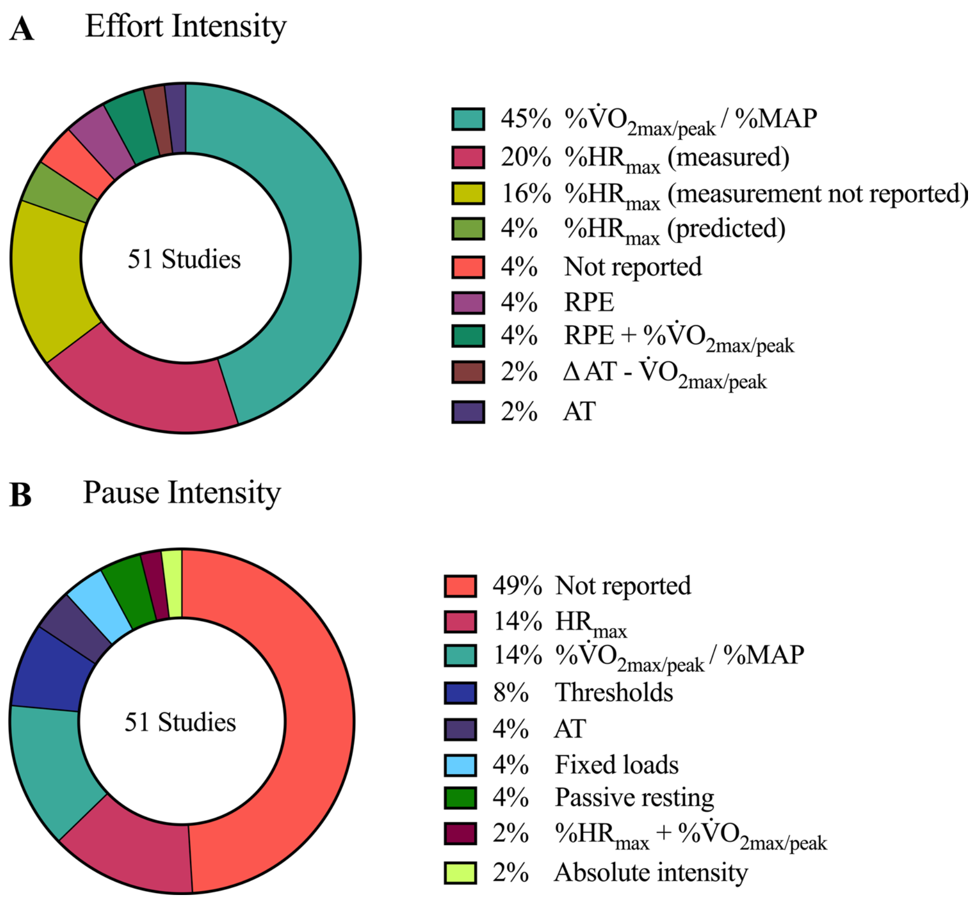
3.4 Adverse Events

Ten studies did not provide information about potential adverse events associated with the exercise program [42, 45, 46, 53, 55, 70, 72, 86, 89, 90], while 34 studies reported no adverse events at all [26, 43, 44, 47–52, 54, 56–61, 63–69, 71, 73–77, 79–81, 83–85, 87, 88]. Conversely, six studies documented adverse events [54, 62, 65, 75, 78, 91], including strained calf muscles, pre-existing sciatica, knee pain, nausea, muscle soreness, joint pain, intermittent increases in HR and/or blood pressure discomfort, pain, neuropathies, nausea/vomiting, fatigue, neutropenia, fever, diarrhea, neuropathy pain, leukopenia, high blood pressure, excessive fatigue, lower limb pain, and exercise-associated hypotension.

4 Discussion

Our search identified 51 studies employing HIIT in cancer patients that aimed to improve cardiorespiratory fitness. These studies were published between 2009 and 2023, with a significant percentage (40%) published between January 2021 and August 2023 (according to our search), demonstrating recent interest in HIIT prescription for cancer patients. However, the precise prescription of HIIT remains a challenge in oncology literature. Importantly, if HIIT is not precisely prescribed, cancer patients may experience minimal or no improvement in cardiorespiratory fitness. Given

Fig. 3 Variables used to prescribe effort intensity (**A**) and pause intensity (**B**), specifying which variable/anchor was utilized and when this information was unclearly reported. *ΔAT* anaerobic threshold delta, *AT* anaerobic threshold, HR_{max} maximal heart rate, *MAP* maximal aerobic power, *RPE* rate of perceived exertion, $\dot{V}O_{2max/peak}$ maximal or peak oxygen uptake



the critical importance of cardiorespiratory fitness for these patients, especially those undergoing or having undergone treatment, optimizing HIIT prescription and improvements in cardiorespiratory fitness can enhance their chances of survival.

4.1 HIIT Format

Based on the widely accepted model in the literature for organizing HIIT formats adopted for this review [29, 34], studies that used active pause and prescribed HIIT using $\%VO_{2peak}$/%MAP [26, 52, 54, 55, 59, 61, 67, 71, 79, 81, 82, 91] appeared to be similar to the HIIT-long format in terms of average effort and pause intensity, as well as effort and pause duration calculated for these studies. However, upon closer examination (scrutinizing each study separately), only seven studies [52, 55, 67, 71, 79, 81, 91] seemed to have actually used the HIIT-long format. In the remaining five studies [26, 54, 59, 61, 82], we were unable to identify the specific format of HIIT applied. Examining studies that utilized the AT as an anchor [43, 57], HIIT-long was also the employed format. Similarly, when HIIT was prescribed based on $HR_{max/reserve}$ (ten studies) [47, 48, 75, 76, 78, 83, 87–89, 91], these protocols also appeared to resemble the HIIT-long format. Alternatively, studies that applied passive pause seemed to have used the HIIT-short format [50, 51], and these protocols were prescribed utilizing $\%\dot{V}O_{2peak}$/MAP as anchors.

Taking those data together, the HIIT-long format appears to be the most commonly used format. However, it is important to highlight the lack of clear descriptions of variables among the studies, with only 25 of them reporting all the variables necessary to classify the HIIT format. Eighteen percent of all the studies (nine studies) did not provide clear descriptions of effort duration; similarly, in 18% of the studies (nine studies) pause duration was not disclosed. Notably, in 49% of the studies, information about pause intensity was unclearly reported. Only 4% of studies did not report effort intensity. As mentioned previously, HIIT classification is not arbitrary; rather, it is grounded in studies demonstrating that such configurations enable participants to maintain $\dot{V}O_{2max/peak}$ for as long as possible above 90% of $\dot{V}O_{2max/peak}$. Furthermore, recent meta-analyses dedicated to identifying optimal HIIT formats for improving $\dot{V}O_{2max/peak}$ or MAP have demonstrated that longer efforts exhibit superiority in enhancing these variables [19, 21]. This suggests that HIIT-long models are more effective in eliciting favorable outcomes. However, in several studies involving cancer, the challenge of understanding the most effective protocol persists due to the scarcity of detailed information regarding effort and pause characteristics, encompassing both intensity and duration.

Superior effects of HIIT on cardiorespiratory fitness compared to MICT have been found in several studies involving healthy populations; however, this has not been consistently observed in cancer studies [15, 20, 23, 24, 27, 28, 38, 92, 93]. The disagreement in the results produced by HIIT in cancer patients compared to other populations might be explained by the fact that HIIT has not been precisely prescribed in the oncology context. For example, Devin et al. [83] investigated a well-prescribed standard HIIT-long format, reporting all key variables in a randomized controlled trial involving colon and rectal cancer survivors. In this study, the HIIT-long produced superior results compared to MICT (Table S1 in the electronic supplementary material and Neuendorf et al. [93]). In contrast, studies in which HIIT appeared to be unstructured (e.g., Northey et al. and Schmitt et al. [80, 84]) found that HIIT and MICT yielded similar results in cardiovascular fitness. In the latter studies, HIIT was prescribed with pause duration two (Schmitt et al. [80]) or four times (Northey et al. [84]) longer than effort duration, which is not typical in HIIT formats designed for improving cardiorespiratory fitness, such as HIIT-long and HIIT-short, and pause intensity was not reported. Additionally, the study by Northey et al. [84] used a pause duration of 30 s, which is recommended more for HIIT-short formats. However, the effort intensity employed in this study (95% of HR_{max}) is typically recommended for HIIT-long formats, with effort duration longer than 1 min. These findings highlight the importance of well-structured HIIT protocols in achieving optimal outcomes.

HIIT prescription may also lack precision, likely due to the variety of cancer types and subtypes, their severity, and the differing treatment consequences (e.g., loss of muscle mass and strength, reduced cardiorespiratory fitness, and chronic fatigue), which complicate the training prescription process. This lack of specificity limits the ability to precisely identify the protocols employed and poses difficulties in comprehending the nuanced effects of different protocols, especially those that might be more beneficial for individuals undergoing cancer treatment.

4.2 Anchors Used to Prescribe Effort and Pause Intensity

Effort intensity characteristics emerged as the most consistently reported variable. Despite this consistency, limitations in how effort intensity was determined and utilized were identified. Various variables can be employed to define intensity zones for endurance exercises, including $\%\dot{V}O_{2max/peak}$, $\%HR_{max}$, metabolic and ventilatory thresholds, critical power, and RPE [92, 94–98]. Considering that $\dot{V}O_{2max/peak}$ is a crucial determinant of aerobic fitness (MAP), it logically follows that $\%\dot{V}O_{2max/peak}$ or its mechanical equivalents (intensity associated with $\dot{V}O_{2max/peak}$) assume a pivotal role in exercise intensity prescription. Consequently, it is unsurprising that fractions of $\dot{V}O_{2max/peak}$ are frequently endorsed in endurance exercise prescriptions by major guidelines [94, 95, 97, 98]. Remarkably, approximately 45% of cancer-related studies have adopted the use of $\%\dot{V}O_{2max/peak}$ or its mechanical counterparts in their investigations. Although this method is valid and very useful, it is important to acknowledge the limitations associated with the utilization of $\%\dot{V}O_{2max/peak}$ or its mechanical counterparts' metric in certain formats of HIIT. The $\%\dot{V}O_{2max/peak}$ or its mechanical counterparts' method may not accurately reflect the rate of metabolic energy demand for a given intensity [98–100] particularly in HIIT-long format, where high-intensity efforts entail exercising above a marker of maximal aerobic capacity [29] (e.g., ventilatory or lactate thresholds and/or critical power [101–103]). This marker represents the upper limit of intensity where metabolic stability is maintained; beyond this point, the disruption of physiological homeostasis accelerates disproportionately [104] and, consequently, exercise above this threshold must be conducted intermittently.

Therefore, considering physiological thresholds to determine endurance exercise intensity is a valuable approach, particularly for individuals with different training status and/or backgrounds. Importantly, the position of the physiological threshold relative to $\dot{V}O_{2max/peak}$ can differ among individuals [105], and this could be considered for prescribing exercise intensity, which is notably limited in cancer studies. Only two studies [43, 57] used thresholds to prescribe effort intensity, and four studies used them to prescribe pause intensity [43, 52, 57, 81]. Specifically, the use of the delta concept employed by West et al. [43] in exercise prescription is noteworthy. This approach involves utilizing two intensity anchors, such as the AT and MAP, and a fraction of the difference between them is employed. In the West et al. [43] study, the intensity was prescribed at delta 25%. This highly individualized method holds significant potential in cancer studies due to the substantial heterogeneity among participants. Indeed, this approach has been shown to reduce variability in some responses, such as time to exhaustion and physiological markers as blood lactate [35, 36].

Conversely, 39% of the studies (20 studies) opted to prescribe exercise intensity based on fractions of HR_{max} or HRR. Within this subset, 20% of studies precisely measured HR_{max} during graded exercise tests, while 4% employed equations to predict HR_{max}. Intriguingly, 16% of the studies lacked clarity on how HR was used to prescribe effort intensity, without specifying whether HR_{max} was measured, estimated, or derived from an age-based equation [62, 64, 72, 74, 78, 83, 84, 89]. The practical accessibility of HR contributes to its prevalent use as a tool for prescribing exercise intensity; however, it is important to recognize the utilization of this variable in HIIT prescription. $\dot{V}O_{2max/peak}$ is determined as the product of cardiac output (HR multiplied by systolic volume) and the arterial-venous difference (a-vO_2 diff) [106]. Consequently, there is linear correlation between $\%\dot{V}O_{2max/peak}$ and $\%HR_{max}$, rendering these variables interchangeable in specific conditions, particularly during moderate-intensity exercises [94]. However, when prescribing HIIT, a noteworthy issue with the use of $\%HR_{max}$ lies in its lack of correspondence with $\%\dot{V}O_{2max/peak}$. As exercise intensity increases, the linear relationship between $\%\dot{V}O_{2max/peak}$ and $\%HR_{max}$ undergoes considerable changes due to dependencies on other aerobic-related physiological components, such as a-vO_2 diff [107], and anaerobic demands for energy production, in which HR may not reflect the overall physiological demands of the exercise [108]. Moreover, some cancer studies (4% of the total; Fig. 3) employed predicted HR_{max} equations, introducing one more potential bias in the reflection of metabolic demand of exercise in HIIT. These equations may exhibit poor agreement with HR_{max}, leading to under- or overestimation compared to measured values [109].

It is important to mention that cancer patients undergoing treatment can present autonomic dysfunction, characterized by a loss of autonomic control, with sympathetic nervous system overdrive and reduced parasympathetic nervous system activity, affecting HR regulation and further complicating exercise prescription with $\%HR_{max}$ [110]. Generic prescriptions that overlook the individual's baseline physiological status can lead to underdosing or overdosing of exercise therapy, a concern particularly relevant in cancer contexts. Meanwhile, the practicality of $\%HR_{max}$ is understandable, especially in studies involving home-based exercise [47, 65, 72] and in different ergometers [72, 75]. Thus, this method is potentially failing to accurately reflect the actual level of effort exerted by participants and may introduce bias in the outcomes.

Approximately 8% of the studies (Fig. 3) used the RPE scale for HIIT prescription [68, 70]. The RPE scale represents overall exertion perceptions and correlates with HR during exercise. Notably, RPE values of 10–11 can indicate the first lactate threshold, while values of 13–15 signify the second lactate threshold [95]. Despite the appeal and versatility of RPE, it is important to highlight that relying exclusively on RPE for training prescription has the following limitations in HIIT protocols: (1) Its time-dependent nature leads to increasing RPE throughout an acute HIIT session [111], requiring load adjustments after each effort, which introduces imprecision in achieving the intended intensity; (2) External and internal factors can have an influence, since RPE can be influenced by several factors that may be altered in cancer patients, such as stress, sleep, nutrition, pain, fatigue, and emotional state, which may not be directly related to the patient's current physical capacity [112]. These factors can result in a prescription that does not accurately reflect the patient's actual physical condition at the time; (3) There can be under- or overestimation of intensity, as cancer patients may underestimate or overestimate their level of effort. Underestimation can lead to less effective training, while overestimation can increase the risk of injury or excessive fatigue [39]; (4) Without objective measures such as HR, oxygen uptake, or workload (i.e., watts/velocity), it becomes challenging to monitor and progressively adjust training intensity accurately and based on concrete data. Considering these limitations, while recognizing the utility of RPE in clinical settings, training prescription should be based on RPE in conjunction with other objective exercise monitoring metrics, such as HR, power output, or specific performance measures. This combined approach ensures the efficiency and safety of exercise sessions, particularly for cancer patients, for whom accurately assessing their current physical capacity is crucial to conducting exercise safely and effectively [16].

Finally, in contrast to effort intensity, which was the most reported variable, pause intensity was the least reported variable. Excluding studies that utilized passive resting [50, 51], similar issues to those reported in effort intensity regarding the precision of the anchors utilized for HIIT prescription were observed. Moreover, the use of absolute loads was observed. Variables with low precision and utilization of absolute loads are problematic because participants may be exercising in different intensity zones/domains. For example, it is known that if pause intensity is not performed below the second threshold, session duration may be shortened due to exacerbated fatigue [113], a concern that becomes even more significant for cancer patients, due to the heterogeneity of individual characteristics.

4.3 Characteristics of Physical Tests Employed to Prescribe Exercise Intensity

In 22% of the studies, the characteristics of the graded exercise test were unclear [45, 46, 49, 50, 52, 53, 56, 58, 64, 70, 89]. Two studies used submaximal tests [68, 70], while out of the 39 studies that employed graded exercise tests, only 17 reported all relevant test characteristics to reproduce the test. A number of studies mentioned adjustments in the initial load or load increment during the tests based on participant characteristics [43, 44, 47, 48, 51, 57, 61, 63, 65, 69, 73, 74, 78, 83, 87, 90]; however, only one study [73] explained in detail how increment load was adjusted according to participants' characteristics.

Notably, mechanical variables such as MAP and load associated with $\dot{V}O_{2max/peak}$ are particularly sensitive to manipulations of graded exercise test variables. For example, the use of shorter stages or larger increments has been associated with higher performance, and variations in cadence, such as very low (40 rpm) or very high cadences (120 rpm), have been observed to underestimate MAP or the load associated with $\dot{V}O_{2max/peak}$ [35]. Considering that these mechanical anchors are widely used for a safe and efficient HIIT prescription, inaccurate estimates resulting from an inappropriate exercise performance test can impair both HIIT-induced adaptations and safety. Thus, precise reporting of exercise performance test characteristics and any adjustments made for participants with different training status is essential to ensure replicability and application of HIIT, and consequently to advance knowledge in the context of exercise oncology research.

4.4 Adverse Events

While most studies did not report adverse events specifically related to HIIT, ten studies failed to mention whether any adverse events occurred, and six studies reported specific symptoms during the exercise program. It is noteworthy that, across the studies that reported adverse events, no severe adverse events were observed, reinforcing the safety of HIIT for this population. However, minor adverse events, although rare, have been documented. Commonly reported minor events include excessive fatigue, lower limb pain, nausea, and post-exercise hypotension [54, 62, 65, 75, 82]. These effects were often related to the underlying conditions of the patients, such as pre-existing osteoarthritis [91] or sciatica [78], and are similar to the experiences of healthy sedentary individuals engaging in high-intensity exercise. Importantly, these adverse events are generally manageable, and their frequency of occurrence is observed not to be significantly higher than that observed in moderate-intensity exercise groups, indicating that HIIT does not pose a greater risk when appropriately managed. Indeed, current exercise and oncology guidelines [16, 94] support the view that exercise, including HIIT, is generally safe for cancer patients.

The need for pre-exercise screening and individualized adjustments is reinforced by the diverse side effects of cancer treatments, highlighting the importance of ensuring that HIIT prescription accounts for biological individuality and enhancing healthcare professionals' understanding of its application in clinical practice. In alignment with existing guidelines, clinical practice should encompass a comprehensive assessment of the patient's condition, identification of health problems, and prioritization of factors contributing to the risk of morbidity and/or mortality. As highlighted by Hayes et al. [16], the exercise prescription should focus on addressing issues with the greatest impact on health and survival. It is crucial to identify patient capacity and determine the appropriateness of interventions by considering economic, psychosocial, and physiological constraints (including contraindications), as well as accessibility, limitations, self-efficacy, barriers and facilitators to exercise, and potential benefits.

4.5 Limitations and Strengths

The limitations of this review include its focus on the characteristics of HIIT protocols without a detailed discussion of the effects of these formats on cardiorespiratory fitness. Moreover, the HIIT formats and potential issues raised in this review regarding variables used for HIIT prescription were discussed based on healthy individuals' literature, which may not fully reflect the context of cancer patients. Furthermore, we only included studies that explicitly labelled their training intervention as HIIT, which may have excluded studies that used HIIT but did not use this terminology. On the other hand, the strength of our scoping review lies in its rigorous methodology, which entailed a systematic search aimed at retrieving every study involving HIIT in cancer patients, and meticulously reporting details of each protocol utilized across all included studies, enhancing the transparency and reliability of our findings.

5 Conclusion and Future Perspectives

Our review identified that HIIT protocols used in the literature were generally aligned with characteristics of the HIIT-long format (i.e., effort and pause intensity and effort and pause duration), although it was not possible to precisely identify the specific format of HIIT applied in several studies. The lack of detailed information regarding HIIT variables in a considerable percentage of studies—only 50% reported all variables necessary for HIIT prescriptions—along with uncertainties surrounding pause intensity (49%) and effort duration (18%) raise concerns regarding replicability, comprehension, and effective application of HIIT protocols in cancer research. Given the multifaceted nature of HIIT, involving several variables, meticulous reporting is imperative to ensure accurate interpretation and implementation.

An analysis of the anchors used to prescribe effort and pause intensity revealed a wide array of approaches, with a notable reliance on $\%\dot{V}O_{2max/peak}$ and $\%HR_{max}$. However, there are important drawbacks to using these metrics due to the heterogeneity of the physical condition of cancer patients. Moreover, autonomic dysfunction in cancer patients is a critical issue which can disrupt HR dynamics, further complicating HIIT prescription based on HR parameters. Only a few studies opted to use metabolic

Table 2 Relevant research priorities that should be considered in future studies prescribing HIIT for cancer patients and how to address these questions

Relevant research priorities	How to address them
Format of HIIT	
Considering the diverse metabolic demands associated with different HIIT protocols, researchers should explicitly justify their format selections. This justification should include detailed descriptions of the protocol's characteristics. Providing such information will contribute to a more informed and nuanced interpretation of study outcomes	Report effort and pause intensity Report effort and pause duration Report total volume of HIIT Report cycling cadence (if applicable) Prioritize to use formats that have been proven to be effective to improve cardiorespiratory fitness, as HIIT-long and HIIT-short formats
Precision of HIIT prescription	
Recognizing the high heterogeneity among cancer patients in terms of cardiorespiratory fitness, maximal strength, body mass, age, and sex, future studies may explore the utilization of threshold-based exercise prescriptions. Embracing highly individualized methods, such as incorporating one or two anchors in delta-based exercise prescriptions, holds the potential to offer more personalized and effective exercise interventions in this specific population, particularly in HIIT-long format prescription	Prioritize utilization of HIIT-long prescription based on metabolic threshold or equivalent variables such as critical power/velocity. While identification of thresholds seems to be complex these days, there is validated and free software that enables thresholds identification easily https://exercisethresholds.com/ [114]
Comprehensive graded exercise tests	
Conducting graded exercise tests until exhaustion is important for future studies. These tests should offer detailed insights into variables such as initial load, increment, cadence, criteria for interruption, and variations tailored to individual participant characteristics. This comprehensive approach would significantly enhance our understanding of individual responses to exercise and improve the applicability, reproducibility, and precision of exercise prescriptions	Report initial load, increment load, and cadence (if applicable) Clearly report adaptations of initial load and load increment for patients with distinct training status or backgrounds Clearly report the criteria to interrupt the test
Adverse events	
Information about adverse events is essential for patient safety, ethical considerations, and application of protocols and may serve as a base for future studies	Specify if any adverse events occurred and clarify if they were directly related to the exercise Indicate whether participants were able to complete the prescribed dose/volume of training as planned

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thresholds to prescribe HIIT, a method that is considered more individualized.

Furthermore, the examination of graded exercise tests revealed potential issues related to the manipulation of variables such as initial load, load increment, and cycling cadence. The impact of these variables on outcomes, particularly in anchors used to prescribe HIIT intensity (e.g., MAP or load associated with $\dot{V}O_{2max/peak}$), underscores the need for standardized reporting to enhance the reliability and comparability of graded exercise test results in cancer studies.

Lastly, while some studies omitted reports on adverse events, among those that reported, no severe adverse events were observed. Although minor adverse events can occur during HIIT in cancer patients, these are typically manageable and comparable to those seen in the general population, reinforcing the safety of HIIT for this population. Enhancing the reporting HIIT characteristics and utilizing more precise variables could improve our understanding of the adverse effects of HIIT. Safely incorporating HIIT into cancer care requires careful patient selection, individualized programming, and vigilant monitoring, ensuring that the potential benefits of this exercise modality are fully realized while respecting the complexities of each patient's unique condition.

It is crucial to emphasize that the primary objective in conducting this review was not to criticize studies or highlight errors. We fully recognize the significant challenges associated with designing training protocols for cancer patients and the importance of initiatives promoting physical activity in this population. Any effort dedicated to encouraging physical activity in cancer patients is not only commendable but also invaluable. Our overarching aim in addressing the identified issues related to HIIT prescription is to contribute to the scientific advancement of the exercise oncology field. By spotlighting these considerations, we aimed to provide valuable insights that can guide the development of the most effective and safe exercise protocols for cancer patients. Ultimately, our goal was to enhance the quality and precision of interventions in this critical area of healthcare, ensuring that individuals undergoing cancer treatment can receive optimal and tailored exercise regimens. Based on our conclusions, Table 2 presents ideas for future studies.

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Declarations

Competing interests The authors declare no competing interests.

Author contributions GDSJ*: Conceptualization; methodology; formal analysis; data curation; writing—original draft; writing—review and editing. VLGP*: Conceptualization; methodology; formal analysis; data curation; writing—original draft; writing—review and editing. SD: Writing—review and editing. MF: writing—review; formal analysis; data curation; editing. GT: Writing—review; formal analysis; data curation; editing. GB: Writing—review. RB: Writing—review; formal analysis; data curation. FV: Writing—review; formal analysis; data curation; editing. MC: Conceptualization; writing—review and editing; supervision and guarantor. All authors contributed to the planning, conduct, and reporting of the work described in this article. All authors read and approved the final version. * Equal contribution.

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