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Systematic review

Home-based and remote functional exercise testing in cardiac conditions, during the covid-19 pandemic and beyond: a systematic review

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Abstract

Background With the change in healthcare to one that adopts a greater reliance on remote delivery, guidance regarding functional exercise testing, either in-person in the home or performed remotely, is urgently needed for people with cardiac conditions.

Objectives To identify functional exercise tests that have been conducted in the home or remotely in patients with cardiac conditions.

Data sources A search was undertaken across four electronic databases and grey literature for English language publications without time restrictions.

Study eligibility criteria Studies of any designs were selected if they reported an exercise test conducted at home or remotely in patients with cardiac conditions.

Study appraisal and synthesis Studies were independently screened and graded by two reviewers according to the Downs and Black checklist. A narrative synthesis of the included studies was undertaken.

Results Five studies (six articles) were included, with a total of 438 patients with cardiac conditions. Tests used at home or remotely were the 6-minute walk test (6MWT, five studies) and the timed up and go test (one study). No studies reported the use of step tests in the home or remotely. The 6MWTs were administered via a smartphone application, rope, videoconferencing and accelerometer and proved to be feasible, valid and reliable.

Conclusions Despite a marked demand for home-based exercise programs, the 6MWT remains the most commonly administered functional exercise test for people with cardiac conditions. Surprisingly few studies have explored alternative tests for this patient population that may be more suitable for home or remote performance.

Systematic review registration number PROSPERO: CRD42020219512.

Keywords: Heart disease; Exercise test; Telemedicine; Remote consultation

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Contribution of the Paper

- There is a range of alternative approaches for the administration of the 6-minute walk test in people with cardiac conditions within the home or remote setting. These include smartphone application, fixed-length rope, videoconferencing and accelerometer.
- Evidence on the use of alternative functional exercise tests in the home environment for people with cardiac conditions is limited.

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Background

In response to the coronavirus (COVID-19) pandemic, many outpatient cardiac rehabilitation programs have rapidly adopted alternative delivery models. Traditionally, cardiac rehabilitation programs use baseline exercise tests to ascertain exercise safety and to facilitate appropriate exercise prescription. One of the most commonly used measures for this purpose is the 6-minute walk test (6MWT) [1], which is a sub-maximal measure of exercise capacity that requires the participant to walk along a 30-m track for six minutes [2]. The 6MWT has shown to be a valid, reliable and responsive measure to changes in clinical status following cardiac rehabilitation [3]. Whilst the test is standard practice in centre-based rehabilitation programs, the supervision recommendations and the necessity for an uninterrupted track often makes its application challenging in the home environment.

Cessation of in-person appointments during the peak COVID-19 months led to unplanned changes in the way clinicians deliver care. In many instances, baseline exercise tests were unable to be conducted in health facilities and were therefore moved to the home environment where physical distancing could be maintained. As there was no guidance on the most appropriate measure of functional exercise capacity in the absence of undertaking a traditional 6MWT, some clinicians trialled alternative tests such as the sit-to-stand, timed up and go (TUG) and step tests [4].

With the change in healthcare to one that adopts a greater reliance on remote delivery, guidance regarding functional exercise testing, either in-person in the home or performed remotely, is urgently needed for people with cardiac conditions. To date, there has been no synthesis of the research evidence relating to this topic for people with cardiac conditions, and hence our systematic review aimed to address this gap. Specifically, our research questions were:

- 1 Which functional exercise tests have been conducted in the home or remotely in patients with cardiac conditions?
- 2 What are the clinimetric properties of tests that have been conducted in the home environment or remotely, including feasibility, validity, reliability and responsiveness to cardiac rehabilitation?
- 3 Can these functional exercise tests be used to assess the safety of exercise and prescribe exercise when conducted in the home environment or remotely?

Methods

This systematic review is registered with the international prospective register of systematic reviews (PROSPERO registration number: CRD42020219512) and based on the preferred reporting items for systematic reviews and meta-analysis: the PRISMA statement [5].

Electronic databases were searched for relevant studies without time restrictions, and including EBSCO Medline, Cumulative Index to Nursing and Allied Health Literature (CINAHL), Cochrane Central Register of Controlled Trials (CENTRAL) and Physiotherapy Evidence Database (PEDro). Grey literature and reference lists from relevant articles were also reviewed to identify additional articles. The last search was undertaken on 27 September 2020. Search terms used include a combination of medical subject headings and relevant keywords (Appendix A).

Studies were included if they involved adults with cardiac conditions, including but not limited to, coronary heart disease and chronic heart failure; and a functional exercise test conducted at home or remotely. Studies were excluded on the following criteria: published in non-English language; case studies; reviews; conference abstracts; protocols; and duplications.

Titles and abstracts of potential articles were extracted so that reviewers were blinded to authors and journals. These titles and abstracts were independently screened by two reviewers to identify relevant articles. Conflicts were resolved after consensus meetings or arbitration by a third reviewer. When multiple articles reported the same study, the article describing the longest follow-up and largest sample was included, or the results combined if articles reported different outcomes. Full copies of relevant articles were retrieved and screened by two reviewers according to the inclusion and exclusion criteria. In the event of missing or ambiguous data, authors of relevant articles were contacted to determine eligibility status and to seek missing data.

The methodological quality of the included studies was assessed by two independent reviewers using a validated checklist [6]. Studies were assessed against 27 items, which evaluated reporting, external validity, bias, confounding and power, leading to a maximum score of 28. Consistent with a previous review [7], item 27 relating to power calculation was dichotomised to answer yes or no. This checklist is suitable for both non-randomised and randomised controlled trials, and has been shown to have high internal consistency, reli-

ability and validity [6]. Differences in quality rating were resolved after consensus meetings or arbitration by a third reviewer.

Data from the included studies were extracted for analysis. This pertained to the study design, participants, types of exercise tests, test performance and study outcomes. Data extraction also included details of any physiological monitoring, and whether the test results were used to prescribe exercise. Dependent upon findings, we sought to undertake a meta-analysis of results, however, if deemed not possible, a narrative synthesis of the included studies was planned. The latter refers to a process in which a narrative approach where the findings are summarised and explained in words, is used to synthesise evidence extracted from multiple studies.

The primary outcome was the number of studies on home or remote administration of each exercise test in cardiac patients. Secondary outcomes included clinimetric properties (feasibility, validity, reliability, and responsiveness) of these exercise tests. Feasibility was determined according to test compliance (the proportion of participants who could perform the test). For criterion validity, we considered the comparisons of home or remotely administered exercise tests with traditional tests undertaken at health facilities. For concurrent validity, we considered the comparisons with other functional exercise tests (such as the 6MWT, TUG test, 10-m walk test, incremental shuttle walk test and step test), and other outcomes (such as physical activity levels and quality of life). For reliability, studies of test-retest reliability, inter-rater reliability or measurement error were considered. The responsiveness of the exercise tests was ascertained in the studies that used these measures to establish the effects of exercise-based rehabilitation programs over time and through comparisons with changes in other outcomes. Safety was determined by the number and type of adverse events.

Results

The search yielded 450 potentially relevant articles. An example of the search strategies used and the corresponding results is available in Appendix B. After the removal of duplicate records and the screening of titles and abstracts, 25 full-text articles were retrieved. Of these, five studies (six articles) were retained for the final analysis. The flowchart of study selection is presented in Fig. 1.

Due to the small number and heterogeneity of studies, a meta-analysis was unable to be performed and a narrative synthesis is presented. Characteristics of the included studies are shown in Table 1 and a quality appraisal in Appendix C. The majority of studies scored well on the Downs and Black checklist. Scores ranged from 18 to 22 out of 28. In most studies, it was difficult to achieve subject blinding due to the nature of the exercise test. Randomisation, loss to follow-up and adequate power were also inconsistently reported.

Four of the six articles were reporting on validity, one on prognosis and the remaining on intervention. Of the six arti-

cles, two reported different outcomes on the same group of participants and thereby combined as one study [8,9], and another two articles involved the same investigator group, focusing on different patient populations and thereby considered as two separate studies [10,11]. Four of the five studies recruited patients with chronic heart failure and the other included patients with coronary heart disease. A total of 438 individuals with cardiac conditions participated across these five studies, of whom 71% were males. The mean (SD) age of study participants was 62 (8) years. Of the included studies, only two functional exercise tests were reported, these being the 6MWT and TUG test. Only one study reported both tests [12]. No studies reported the use of step tests in the home or remotely. Four of the included studies had exercise tests that were administered at home and two included tests administered remotely.

6MWT

All five studies investigated the 6MWT and used different approaches to administer the test: a smartphone application [13], a rope [10,11], videoconferencing [12] and an accelerometer [8,9]. Apart from the study that used videoconferencing [12], all the other studies administered the 6MWT within the home setting. It is unclear if any of these home walking tests were undertaken outdoors. The length of the walking track was also inconstant, with some studies using 5-m tracks and others varying dependent upon the participant's home set-up.

Home

Four studies were self-administered at home. Brooks *et al.* [13] used a smartphone application (SA-6MWTapp) to administer the 6MWT. The participants watched an instructional video and then independently undertook multiple 6MWTs in their home, without prior in-person training and supervision. This application enabled Borg's dyspnoea scale and heart rate monitoring (taken using photoplethysmography from the participant's finger placed over the phone's camera), as well as the distance on the 6MWT (estimated based on the participant's height and step count measured by the iPhone's accelerometer). In the study by Du *et al.* [10], the home-heart-walk test was conducted whereby participants performed the 6MWT along a 5-m rope (marked with 1-m increments) in a flat, unobstructed corridor. Unlike the first study, these authors only recruited participants who were familiar with the 6MWT protocol and no physiological monitoring was reported [10]. Participants counted the number of laps walked using a lap counter and recorded this number in a diary. In an extension of this study, the authors employed the same test as an intervention, where the participants undertook weekly home-heart-walks over six months [11]. In the remaining study, an accelerometer-based 6MWT was implemented into participants' home as part of a more comprehensive telemonitoring system in TIM-HF study [8,9]. The telemonitoring system incorporated Bluetooth

Table 1
Characteristics of included studies.

Study	Study design	Subject number	Patient group	Participants	Study location	Functional exercise test	Test performance	Physiological monitoring
Brooks 2015 [13]	Validity	52 for model development, 32 for in-clinic validation and 19 for home validation	CHF or pulmonary hypertension	Mean age = 48 years Male = 32% NYHA II = 45% NYHA III = 27%	United States of America	6MWT	Identified hallways or other spaces that enabled back and forth walking with a smartphone application	Heart rate
Du 2010 [10]	Validity	29	CHD	Mean (SD) age = 64 (8) years Male = 69%	Australia	6MWT	Used counter to record the number of laps achieved along a 5-m rope	None
Du 2018 [11]	Intervention	132	CHF	Mean (SD) age = 60 (15) years NYHA II = 70% NYHA III = 30% Male = 79% Mean ejection (SD) fraction = 33 (13)%	Australia	6MWT	Used counter to record the number of laps achieved along a 5-m rope	None
Hwang 2017 [12]	Validity	17	CHF	Mean (SD) age = 69 (12) years Male = 88% NYHA II = 88% NYHA III = 6% Mean (SD) ejection fraction = 34 (14)%	Australia	6MWT and TUG test	Supervised functional tests using videoconferencing along a 30-m corridor	Heart rate, oxygen saturation and blood pressure
Jehn 2013 [8] and Prescher 2016 [9]	Validity and prognosis (sub-study of interventional trial)	155	CHF	Mean (SD) age = 68 (11) years Male = 84% NYHA II = 57% NYHA III = 43% Mean (SD) ejection fraction = 28 (5)%	Europe	6MWT	Customized 3-dimensional tele-accelerometry with the start button and automatic end of the test. Walk track length individualised to the participant's home circumstances.	Electrocardiogram, blood pressure and weight

6MWT, 6-minute walk test; CHD, coronary heart disease; CHF, chronic heart failure; NYHA, New York Heart Association functional classification; TUG test, timed up and go test.

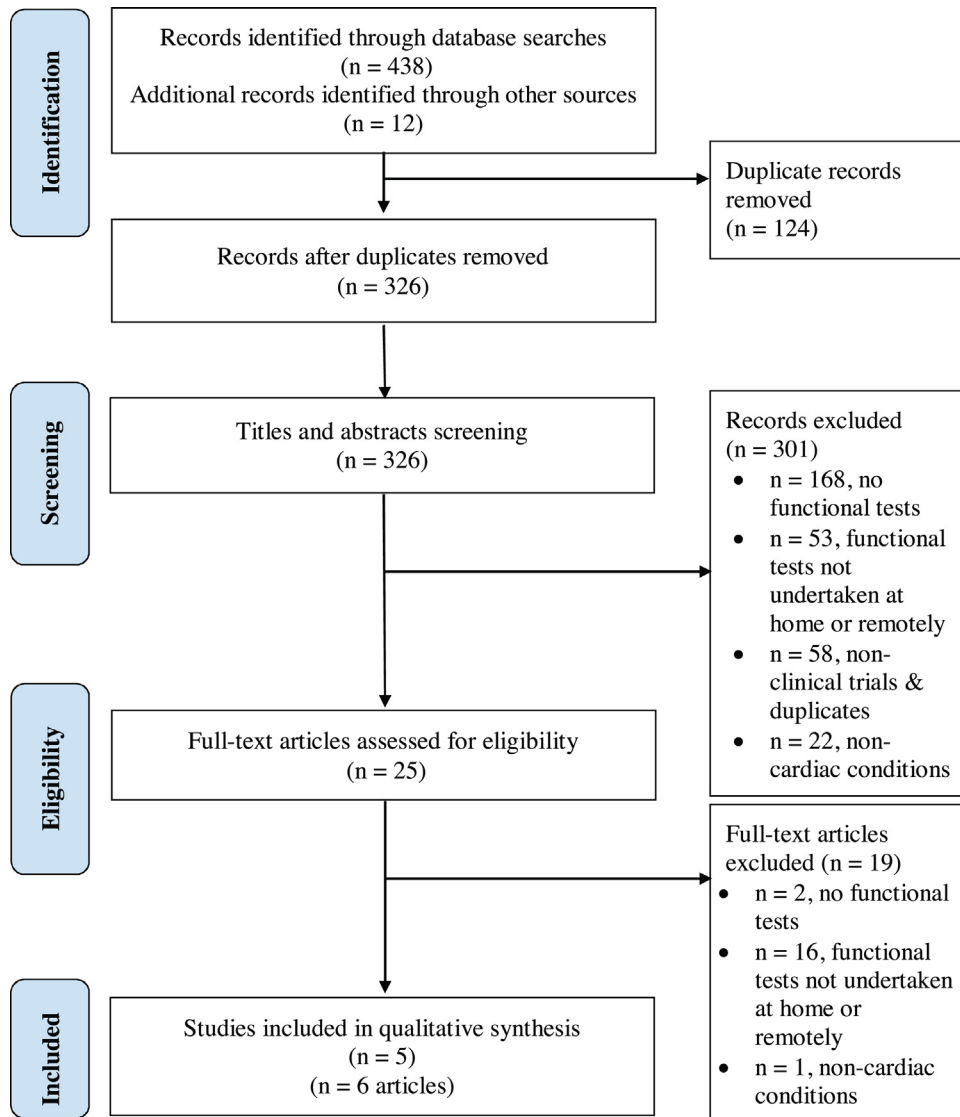


Fig. 1. Study flowchart.

devices including electrocardiogram, sphygmomanometer and weight scales. In this sub-study, the participants also wore a matchbox-sized accelerometer customised to record step numbers and walking speed during the monthly 6MWT. The device used a start button, with automatic data recording and transmission over a mobile network.

Remote

Two studies were undertaken remotely. The study by Brooks *et al.*, using a smartphone application in the home, also reported an initial remote validation in-clinic [13]. The other study used a video-based telerehabilitation assessment to administer the 6MWT, for patients who were familiar with the 6MWT [12]. In this study, the assessor supervised participants undertaking the exercise tests remotely, whilst maintaining real-time audiovisual communications via commercially available software on a laptop. Pulse oximetry and

sphygmomanometer were supplied with participants required to manually report these physiological measurements.

Clinimetrics

The feasibility of the home or remotely administered 6MWT seems to be variable. In the study by Brooks *et al.*, 24% (6/25) of consented participants did not download the smartphone application at home [13], whilst Du *et al.* reported fewer than 50% of participants completed more than 80% of weekly home-heart-walk during six months [11]. There were also incidences of internet drop-outs, auditory feedback and video freezing during the video-based telerehabilitation assessment [12]. In contrast, other studies reported excellent participation with 95% of participants completing accelerometer-based 6MWT over six months [8] and all 29 participants completing 100% (8/8) of home-heart-walk tests over seven days [10].

Table 2
Clinimetric properties of functional exercise tests.

Test	Criterion validity	Concurrent validity	Test re-test reliability	Other reliability	Responsiveness	Other outcomes
6-min walk test						
Application (Brooks 2015 [13])	r = 0.88 (95% CI, 0.87 to 0.89) MD (SD) = 7.6 (26) m Accuracy within 15%		Repeatable (coefficient of variation = 4.6%)			The application was simple and easy to use independently
Rope (Du, 2010, 2018 [10,11])	r = 0.99		ICC = 0.98		Improved self-care behaviour (F _(1,129) = 4.75, p = 0.031) and self-reported physical activity level (U = 1713, z = -2.12, p = 0.034) compared with control group	The intervention was well-received by participants including enjoyable and motivational
Videoconferencing (Hwang 2017 [12])	ICC = 0.9 (95% CI, 0.74 to 0.96) MD = 4 (95% CI, -25 to 17) m			Inter-rater reliability ICC > 0.99 Intra-rater reliability ICC > 0.99		Mean (SD) system usability scale = 85 (15)/100
Accelerometer (Jehn 2013 [8] and Prescher 2016 [9])	Accuracy of step count was 99% r = 0.80 to 0.90	Stronger associations with quality of life questionnaire (Short Form-36) physical component score than NYHA	Reproducibility within 95% margin for all performance parameters		Initial accelerometer-based 6MWT a predictor for all-cause mortality and heart failure hospitalisation, with 495 steps to be the best cut-off risk prediction value.	
TUG test						
Videoconferencing (Hwang 2017 [12])	ICC = 0.85 (95% CI, 0.64 to 0.94) MD = 0.24 (95% CI, -0.56 to 1.03) seconds			Inter-rater reliability ICC = 0.95 (95% CI, 0.86 to 0.98) Intra-rater reliability ICC = 0.96 (95% CI, 0.90 to 0.99)		

CI, confidence intervals; ICC, intra-class correlation coefficient; MD, mean difference; NYHA, New York Heart Association functional classification; r, Pearson's correlation coefficient; SD, standard deviation; TUG test, timed up and go test.

Results pertaining to the validity, reliability and responsiveness of the 6MWT are presented in Table 2. The validity of the home or remotely administered 6MWT appears variable. Strong associations were reported between the distance measured in-clinic and those measured at home with the smartphone application ($r = 0.88$) [13], the rope ($r = 0.99$) [10] and remotely using the videoconferencing ($r = 0.90$) [12]. However, the limits of agreement for the video-based 6MWT were between -84 and 76 m, and outside of the clinically acceptable level [12]. The accuracy of accelerometer-based step count compared to hand-counted steps was 99% and a correlation of 0.80 to 0.90 was shown between accelerometer-based 6MWT step count and manually measured distance [8].

Reliability of the home or remotely administered 6MWT appears high. For example, distances estimated from a smartphone application during the home 6MWT were repeatable with a coefficient of variation of 4.6% [13]. Test–retest reliability for the home-heart-walk test was high with an intra-class correlation coefficient (ICC) of 0.98 [10] and the inter- and intra-rater reliabilities for the video-based telerehabilitation assessment had ICC of greater 0.99 [12].

Responsiveness of the home or remotely administered 6MWT appears variable. The home-heart-walk protocol did not improve the participants' perceived physical functioning, distance on the 6MWT, quality of life or exercise self-efficacy, but there was an improved self-care behaviour and self-reported physical activity level compared with the control group [11]. The initial accelerometer-based 6MWT was also shown to be a predictor for all-cause mortality and heart failure hospitalisation, with 495 steps appearing to be the best cut-off value for risk prediction with 90% specificity and 26% sensitivity [9].

Safety assessment and exercise prescription

Three of the five studies encountered no adverse events during these alternative approaches in the administration of the 6MWT [10,11,13]. However, one study recorded symptoms of angina, which resolved with rest and administration of glyceryl trinitrate [12]. In the study by Jehn *et al.*, there was one severe adverse event reported from 2265 walk tests performed [8]. This incident involved an episode of ventricular tachycardia and implantable cardiac defibrillator shock following test completion in a participant with previous episodes of ventricular tachycardia.

Although one study used the home-heart-walk test as the intervention [11], it is unclear how the test was used to assess the safety and prescribe exercise intensity.

TUG test

Home

No studies reported the administration of a TUG test at home.

Remote

One study undertook the test remotely [12]. This study employed a video-based telerehabilitation assessment to administer the TUG test, using the same approach as the 6MWT.

Clinimetrics

Video-based telerehabilitation assessment using the TUG test was reported to be valid and reliable in patients with chronic heart failure in this one study (Table 2) [12]. In particular, the limits of agreement of telerehabilitation compared with face-to-face assessments were within the clinically acceptable limits for the TUG test. However, no information was available on responsiveness.

Safety assessment and exercise prescription

No studies used the TUG test to assess the safety and prescribe exercise.

Discussion

The recent COVID-19 pandemic highlights a need for valid and reliable functional exercise tests which can be conducted within the home or remote setting, whilst not compromising on the quality of information or patient safety. Exercise tests are important to guide safe and appropriate exercise prescription, monitor an individual's response to an exercise-based rehabilitation program, and provide an outcome measure to determine the overall effectiveness of the intervention. Despite the broad inclusion criteria, this systematic review yielded only five studies specific to people with cardiac conditions. All of the included studies examined the 6MWT and one study also investigated the TUG test. Results of this review identified that there is a sparsity of research on alternative exercise tests in this population.

The traditional 6MWT is one of the most commonly used outcome measures in exercise-based rehabilitation programs [1] and has prognostic values [14]. However, it is recommended that the test is administered by a trained assessor and performed using a preset 30-m course, making it more difficult to undertake at home or remotely. This review has identified a range of alternative approaches for administering the 6MWT including smartphone application, fixed-length rope, videoconferencing and accelerometer. These alternative approaches to administer the 6MWT were shown to be somewhat feasible, valid and highly reliable. For instance, Brooks *et al.* [13] highlighted the multiple advantages of using a smartphone application including motion sensor, delivery of scripted prompts at the appropriate time, and interactivity. Although this approach enabled participants to choose their test course (identified hallways or other spaces), a potentially shorter walk track would require participants to make more turns, thereby reducing the distance achieved on the 6MWT. The impact of track length on walk-

ing distance has been reported previously in patients with chronic obstructive pulmonary disease, where shorter distances were reported with a 10-m track compared with the standard 30-m track [15]. Furthermore, results obtained with a shorter track should be interpreted with caution, as studies on prognosis and normative values were generated on standard track lengths. It is also unclear if any of the alternative approaches to administer the 6MWT were undertaken outdoors and thereby subject to the effect of elements and temperature.

The relatively few studies examining alternative exercise tests in the cardiac patient population was a surprising finding. In recent years, there has been a shift towards flexible service delivery models including home-based exercise programs. The COVID-19 pandemic has accelerated this shift but has also unveiled some gaps in the model. Whilst it is accepted that exercise programs can be delivered at home or remotely, existing studies have all undertaken exercise assessments in health facilities. During the peak pandemic months, a range of different tests was adopted by cardiac clinicians around the world to prevent service disruptions. Experiences from these services are yet to be reported. To work towards a fully flexible model (which is also important for people in the rural and remote areas), safe and valid options for assessments performed within the home or remotely, are needed. This review has therefore highlighted gaps in the current evidence and the necessity for further research in the area.

In other patient populations, however, there is emerging evidence to support their use. Recent reviews have confirmed that the sit-to-stand, TUG and step tests can be performed at home in patients with chronic respiratory disease [4,16,17]. As these tests do not accurately measure desaturation during walking and have not been validated to prescribe exercise, it is recommended that patients at risk of desaturation should be prioritised for centre-based exercise testing when available [4]. In people with cardiac conditions, some of these exercise tests have been undertaken at health facilities. For instance, sit-to-stand tests have been used as outcome measures for cardiac patients in interventions such as functional electrical stimulation [18], exercise training [19–21] and hydrotherapy and yoga [22]. Similarly, TUG tests have been used in health facilities to evaluate cardiac rehabilitation outcomes [23]. The Chester step tests have also been reported to be valid and safe in predicting mean, but not individual-level changes in peak aerobic power following cardiac rehabilitation [24]. It remains unclear whether these exercise tests can be safely administered at home or remotely, or whether they can elicit a similar physiological response as the 6MWT. Their use for exercise prescription also remains unclear in this population.

Tests such as the sit-to-stand, TUG and step tests are promising tools. They require limited space and are representative of functional daily activities, thus making them ideal for this purpose. Further research is required to determine the feasibility, validity and responsiveness of these tests in people with cardiac conditions. Specifically, the safety of these tests

in terms of adverse events such as postural hypotension, chest pain and other cardiac symptoms, is necessary. Finally, as the exertional work associated with undertaking these alternative exercise tests is currently unknown for cardiac patients, future physiological studies should be undertaken to determine which, if any tests, provide an effective alternative to the 6MWT for exercise prescription. This information may help clinicians to choose the optimal assessment approaches and increase the uptake of alternative functional exercise tests in clinical practice.

This systematic review has some weaknesses. Search criteria were limited to studies published in the English language, which could predispose to publication bias. Contrary to our expectations, most of the included studies were non-interventional studies and were, therefore, better suited to the consensus-based standards for the selection of health measurements instruments (COSMIN) risk-of-bias checklist [25] rather than the Downs and Black checklist [6]. Given the small number and heterogeneity of the studies, we were unable to undertake a meta-analysis as planned. However, the strengths of this review include the rigour of the search strategy, study selection by two independent reviewers, broad inclusion criteria and its clinical relevance.

Conclusion

In summary, the 6MWT is the most reported functional exercise test undertaken either in person within the home environment or remotely in people with cardiac conditions. Whilst these alternative approaches in administering the 6MWTs were shown to be somewhat feasible, valid and reliable, information related to other exercise tests in this population were lacking. Future studies are necessary to identify which functional exercise tests are most suited for performance in the home environment and to determine efficacy for exercise prescription in this population.

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Conflicts of interest: None declared.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:<https://doi.org/10.1016/j.physio.2021.12.004>.

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