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Safety and efficacy of aerobic exercise commenced early after cardiac surgery: A systematic review and meta-analysis

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Abstract

Background: Aerobic exercise is a critical component of cardiac rehabilitation following cardiac surgery. Aerobic exercise is traditionally commenced 2–6 weeks following hospital discharge and most commonly includes stationary cycling or treadmill walking. The initiation of aerobic exercise within this early postoperative period not only introduces the benefits associated with aerobic activity sooner, but also ameliorates the negative effects of immobilization associated with the early postoperative period.

Methods: A systematic review identified all studies reporting safety and efficacy outcomes of aerobic exercise commenced within two weeks of cardiac surgery. A meta-analysis was performed comparing functional, aerobic and safety outcomes in patients receiving early postoperative aerobic exercise compared with usual postoperative care.

Results: Six-minute walk test distance at hospital discharge was 419 ± 88 m in early aerobic exercise patients versus 341 ± 81 m in those receiving usual care (mean difference 69.5 m, 95% confidence interval (CI) 39.2–99.7 m, $p < 0.00001$). Peak aerobic power was $18.6 \pm 3.8\ ml\cdot kg^{-1}\cdot min^{-1}$ in those receiving early exercise versus $15.0 \pm 2.1\ ml\cdot kg^{-1}\cdot min^{-1}$ in usual care (mean difference $3.20\ ml\cdot kg^{-1}\cdot min^{-1}$, 95% CI 1.45–4.95, $p = 0.0003$). There was no significant difference in adverse events rates between the two groups (odds ratio 0.41, 95% CI 0.12–1.42, $p = 0.16$).

Conclusion: Aerobic exercise commenced early after cardiac surgery significantly improves functional and aerobic capacity following cardiac surgery. While adverse event rates did not differ significantly, patients included were very low risk. Further studies are required to adequately assess safety outcomes of aerobic exercise commenced early after cardiac surgery.

Keywords

Early rehabilitation, aerobic exercise, cardiac rehabilitation, exercise rehabilitation, cardiac surgery, rehabilitation safety

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Introduction

As the average age and medical complexity of patients undergoing cardiac surgery increases, functional capacity has become an important clinical parameter as both a pre-operative assessment and postoperative outcome measure. Functional capacity is the term ascribed to the physiologic reserve required to complete activities of everyday living without undue fatigue, and has been identified as an independent characteristic that can impact outcomes following cardiac surgery.[1–3] A reduction in functional capacity is underpinned by a loss of physiological reserve, which is the primary mechanism for the early sensation of fatigue.[4] Patients experience a loss of physiologic and therefore functional capacity in the immediate and early postoperative recovery following cardiac surgery, particularly those patients with pre-existing reduced physiologic reserve such as

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the elderly.[4] Recent studies have quantified this functional reduction as well as the negative impact this can have on postoperative outcomes.[1,2,5] The incorporation of strategies such as early mobilization and respiratory based exercises may provide some benefits in preventing postoperative pulmonary complications; however, improvements in functional capacity have not been consistently demonstrated.[6–8]

Aerobic exercise is a critical component of cardiac rehabilitation for patients who have undergone cardiac surgery. Exercise based cardiac rehabilitation in the modern era aims to improve aerobic and functional capacity through the use of aerobic based exercise such as walking and stationary cycling, providing benefits of symptom amelioration, attenuation of cardiac disease progression and reduced hospital admissions and mortality.[9–13] The vast majority of cardiac rehabilitation research has focused primarily on formalized outpatient programmes, typically commencing several weeks following surgery.[9,14] However, patients from some institutions begin aerobic exercise as early as the first postoperative week and continue to outpatient cardiac rehabilitation with little or no interruption in exercise training. Currently, there is a paucity of literature evaluating the outcomes of patients commencing aerobic exercise early after cardiac surgery. This systematic review and meta-analysis aims to assess the clinical outcomes of aerobic exercise commenced within two weeks of cardiac surgery.

Methods

Search strategy and study selection

The electronic databases Medline, ProQuest, Web of Science, ScienceDirect and Cochrane Central Register of Controlled Trials were searched from their dates of inception to July 2017. The search terms 'cardiac surgery' or 'heart surgery' or 'heart valve surgery' or 'coronary artery bypass' or 'CABG' were combined with 'early' and ('rehabilitation' or 'exercise' or 'mobilization' or 'physiotherapy') as both keywords and MeSH terms. This was supplemented by manually searching the reference lists of key reviews and all potentially relevant studies. Two reviewers (MPD and DTT) independently screened the title and abstract of records identified in the search and performed data abstraction. Full-text publications were subsequently reviewed separately if either reviewer considered the manuscript as potentially eligible for inclusion. Disagreements regarding study selection or data abstraction were resolved by discussion and consensus with a third reviewer (PI).

Studies were categorized according to timing of postoperative exercise commencement as (i) immediate aerobic exercise (exercise commenced in the immediate postoperative period and completed at hospital discharge) or (ii) early aerobic exercise (exercise following surgical discharge commenced within two weeks of undergoing cardiac surgery).

Eligibility criteria

Selected studies included those reporting outcomes of aerobic exercise training commenced within two weeks following cardiac surgery. Aerobic exercise was defined as physical activity that induces a steady and sustainable increase in aerobic metabolism when performed at intensity below anaerobic threshold. Non-comparative studies required the intensity of the exercise to be clearly defined according to established physiologic exercise intensity measures (rate of perceived exertion (RPE), metabolic equivalents (METs), percentage of actual or calculated maximum heart rate or volume of oxygen uptake or calculated workload, such as power output in watts). Studies comparing exercise interventions with other care required the difference in exercise intensity to be clearly defined. Isolated walking programmes were only included for analysis if walking intensity was deemed to exceed simple ambulation. Simple postoperative mobilization was also excluded, as an aerobic workload suitable for the purpose of this review is not consistently induced. Studies that performed isolated respiratory exercises were also excluded.

Efficacy analysis was performed if functional or metabolic capacity were assessed following an aerobic exercise intervention. Studies reporting on postoperative adverse events and mortality following prescribed exercise were included for safety analysis. All publications were limited to those involving human subjects and written in English. Studies with fewer than 10 patients in an intervention cohort were excluded.

Statistical analysis

Baseline characteristics and intervention details were presented as raw values (%) or mean ± standard deviation unless otherwise indicated. Pooled values for clinical outcomes were reported as mean ± standard deviation or as otherwise specified. Meta-analysis was performed by combining results of outcome variables. Data were summarized as standard mean difference, with overall weighted mean presented where appropriate. I^2 statistic was used to estimate the percentage of total variation across studies, due to heterogeneity rather than chance. An I^2 value of greater than 50% was considered substantial heterogeneity. If there was substantial heterogeneity, the possible clinical and methodological reasons for this were explored qualitatively. In the present meta-analysis, the results using the random-effects model were presented to take into account the possible clinical diversity and methodological variation amongst studies. Specific analyses considering confounding factors were not possible because raw data were not available. All p values were two-sided. A significant difference was defined as $p < 0.05$. Statistical analysis was conducted with Review Manager Version 5.3 (Cochrane Collaboration, Software Update, Oxford, UK).

Results

Using the predefined search criteria, a total of 1222 studies were identified through the database and bibliographic search. Duplicated studies and irrelevant articles were excluded, with 55 studies remaining for full-text evaluation. Of these, 18 studies met the inclusion criteria. Two of these studies provided separate data for both immediate and early aerobic exercise. A total of six studies were included for analysis in the immediate exercise group[15–21]and 14 studies included for analysis in the early exercise group.[19–32] The study selection process is presented in Figure 1 as per the PRISMA statement.[33] A summary of study characteristics is presented in Table 1.[17–34]

All studies were prospective, reporting on efficacy or safety outcomes for a total of 2175 patients who underwent immediate or early aerobic exercise interventions following cardiac surgery.

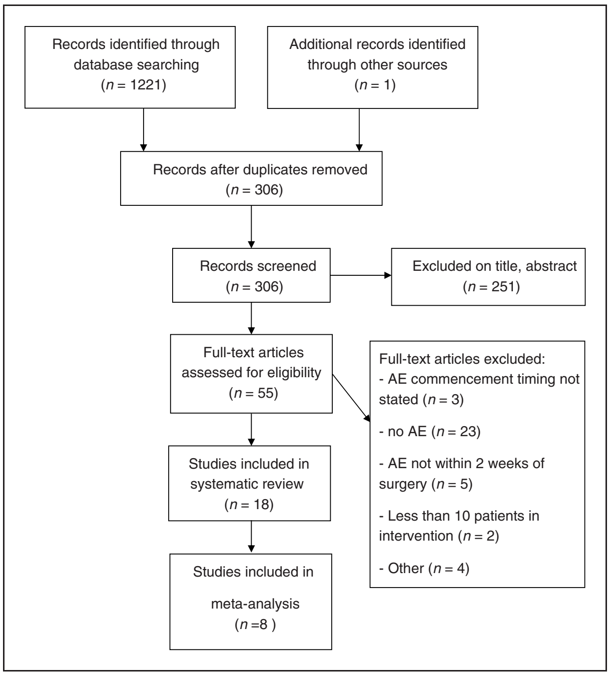

Figure 1. Summary of search results.
AE: aerobic exercise

A total of 420 patients performed aerobic exercise in the immediate postoperative period, and 1846 patients performed aerobic exercise after acute inpatient discharge but within two weeks of cardiac surgery. Pooled mean age was 66 ± 10 years, and pooled mean percentage of male patients was 73%. The presence of hypertension, prior myocardial infarction and diabetes was reported in 66%, 42% and 28% in patients respectively. Pooled mean body mass index was 28.1 ± 4.4 m^2 and mean estimated left ventricular ejection fraction was 54 ± 8%. A summary of baseline patient characteristics is provided as Supplementary Material online.

Walking was used as aerobic exercise in four studies, stationary cycling in six studies and both walking and cycling in eight studies. Aerobic exercise sessions were performed for 3–20 min in the immediate postoperative setting, increasing to 12–60 min in the early postoperative period. Intensity ranged from 'fairly light' to 'anaerobic threshold' (RPE of 11–15 on the Borg scale, 3–7 on a modified Borg scale, 65–85% of predicted maximum heart rate or 1–4 METs). A summary of exercise intervention protocols is presented in Table 2.

Efficacy – immediate postoperative exercise

Four studies reported outcomes of the six-minute walk test (6MWT) for immediate aerobic exercise (commencing during inpatient recovery, completed at hospital discharge).[15,16,19,21] Overall pooled mean distance walked during the 6MWT at hospital discharge by the exercise intervention group was 420 ± 89 m compared with 341 ± 81 m in the usual care group. Three studies were included in a meta-analysis comparing six-minute walk distance (6MWD) at hospital discharge.[15,19,20] There was a statistically significant increase in the 6MWD at hospital discharge for patients who performed aerobic exercise following cardiac surgery compared with those who received usual care (419 ± 88 m *vs.* 341 ± 81 m, mean difference 69.5 m, 95% confidence interval (CI) 39.2–99.7 m, $p < 0.00001$; Figure 2). In the two studies that did not measure 6MWD, those performing high frequency aerobic exercise reached most functional milestones significantly earlier than those performing low-frequency exercise,[20] and aerobic exercise significantly improved cardiac autonomic function assessed by heart rate variability, compared with usual care.[19]

Efficacy – early postoperative exercise

Four studies reported peak oxygen consumption outcomes following early aerobic exercise intervention.[19,22,23,28] There was a statistically significant increase in the peak oxygen consumption for patients

Table 1. Study characteristics.

Study	Year	Ref.	Location	Study period	Study type	Exercise patients	Total patients	Intervention duration
Borges	2016	15	Brazil	2015	Randomized	15	34	<1 week
Hirschhorn	2012	16	Australia	2008–2009	Randomized	64	64	<1 week
Mendes	2010	17	Brazil	NR	Randomized	24	47	<1 week
Van Der Peijl	2009	18	Netherlands	2000–2001	Randomized	246	246	<1 week
Stein	2009	19	Brazil	NR	Randomized	10	20	<1 week
Hirschhorn	2008	20	Australia	2004–2005	Randomized	61	92	<1 week, 4 weeks
Fiorina	2007	21	Italy	2003–2004	Prospective	348	348	2 weeks
Adachi	2001	22	Japan	NR	Randomized	34	57	2 weeks
Takeyama	2000	23	Japan	NR	Randomized	13	28	2 weeks
Scalvini	2013	24	Italy	2006–2010	Prospective	200	200	3 weeks
Polcaro	2008	25	Italy	2005–2006	Prospective	459	459	3 weeks
Macchi	2007	26	Italy	NR	Randomized	150	300	3 weeks
Massaro	2014	27	Italy	2010–2011	Prospective	60	60	4 weeks
Eder	2010	28	Austria	NR	Randomized	41	70	4 weeks
Galante	2000	29	Italy	1998	Prospective	260	260	4 weeks
Fletcher	1984	30	USA	NR	Randomized	46	46	12 weeks
Pack	2015	31	USA	2009–2013	Prospective	112	112	6 months
Onishi	2009	32	Japan	NR	Prospective	32	32	6 months
					Total	2175	2475	

Ref.: reference; NR: not reported

who performed early aerobic exercise following cardiac surgery compared with those who received usual care ($18.6 \pm 3.8\,\text{ml.kg}^{-1}\cdot\text{min}^{-1}$ *vs.* $15.0 \pm 2.1\,\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, mean difference $3.20\,\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, 95% CI 1.45–4.95, $p = 0.0003$; Figure 3).

Seven studies reported 6MWT outcomes following the completion of early aerobic exercise (commencing within two weeks of surgery) after cardiac surgery.[20,21,24–28] Pooled mean comparison was not performed as the number of patients studied in the usual care group totalled only 50, while the early exercise intervention group had 1156 patients. The mean distance improved was 105 m in the early aerobic exercise group and 111 m in the control group.

Exercise safety: adverse events

Of a possible 18 studies, 16 reported on adverse events or mortality during immediate and early aerobic exercise interventions.[15–20,22–31] One study did not report adverse events separately for each intervention group and therefore could not be included in the safety analysis.[28] Six studies were included in a meta-analysis of adverse events in all patients performing immediate or early aerobic exercise after cardiac surgery compared with usual care. There was no significant difference in the overall adverse event rate following cardiac surgery in the aerobic exercise group compared with usual care (odds ratio 0.41, 95% CI 0.12–1.42, $p = 0.16$; Figure 4).

Pooled incidence of atrial tachyarrhythmia, stroke, myocardial infarction and death during all aerobic exercise interventions were 15.1%, 0.3%, 0.10% and 0.06% respectively. All six studies performing aerobic exercise in the immediate postoperative period reported adverse clinical events. The rates of atrial tachyarrhythmia, stroke and myocardial infarction in the immediate postoperative period were 28.8%, 1.1% and 1.1% respectively. Re-sternotomy was required in 6.2% of patients and sternal wound infection was reported in 0.5% of patients.

Early exercise programme withdrawal and mortality

The pooled programme withdrawal from an early aerobic exercise intervention following cardiac surgery was 2.7%. All six studies performing aerobic exercise in the immediate postoperative period reported voluntary programme withdrawal and mortality. The pooled voluntary withdrawal rate in the immediate and early aerobic exercise group was 1.4%. There were no deaths during the exercise interventions.

A summary of all adverse outcomes is provided in the Supplementary Material online. There were insufficient data to statistically summarize clinical outcomes following early aerobic exercise interventions that

Table 2. Early aerobic exercise intervention protocols.

Intervention duration	Study (ref)	Year	Aerobic exercise intervention						Outcome
			Mode	Frequency	Intensity	Time (min)	Commence (POD)	Completion	
<1 week (immediate)	Borges (15)	2016	Cycling	Twice daily (ICU) Daily (ward)	NR	5–20	1	Hospital D/C	6MWT
	Hirschhorn (16)	2012	Cycling Walking	Twice daily	RPE 3–4	10	3	Hospital D/C	6MWT
	Mendes (17)	2010	Walking	Daily	2–4 METs	5–10	1	Hospital D/C	HRV
	Stein (19)	2009	Walking	Twice daily	RPE 7/10[a]	>9	2	POD 7	6MWT
	Hirschhorn (20)	2008	Walking	Twice daily	RPE 3–4	3–10	1	Hospital D/C	6MWT
	Van der Peijl (18)	2004	Walking Walking	Twice daily Daily	1–3.5 METs	<20	1 1–3	POD 6	Functional milestones
2–4 weeks	Fiorina (21)	2007	Cycling/walking	Twice daily	NR	<60	9 ± 3	15 ± 3 days	6MWT
	Adachi (22)	2001	Cycling/walking	Twice daily	AT	30	14	2 weeks	VO_2
	Takeyama (23)	2000	Cycling	Twice daily	AT	30	7	2 weeks	VO_2, HRV
	Scalvini (24)	2013	Cycling	Twice daily	25–50 W	40	5–11	3 weeks	6MWT
	Polcaro (25)	2008	Cycling	NR	NR	NR	10 ± 7	3 weeks	6MWT
	Macchi (26)	2007	Cycling	Daily	65–75% MHR	NR	7.8 ± 2.7	3 weeks	6MWT
	Massaro (27)	2014	Cycling/walking	Twice daily	NR	30–60	< 14	4 weeks	6MWT
	Eder (28)	2010	Cycling/walking	Daily	RPE 10–13	12–30	12.3 ± 4.9	4 weeks	6MWT,VO_2
	Stein (19)	2009	Walking	Twice daily	NR	NR	1	4 weeks	VO_2
	Hirschhorn (20)	2008	Walking	Twice daily	RPE 3–4	NR	Hospital D/C	4 weeks	6MWT
	Galante (29)	2000	Cycling	Twice daily	<85% MHR	3–30	<10	4 weeks	Arrhythmia
3–6 months	Fletcher (30)	1984	Cycling Walking	3–5 times weekly	1.5–5.3 METs 3.3 METs	10–36 5–10	7.6 (5–12)	12 weeks	Safety
	Pack (31)	2015	Cycling/walking	NR	HI aerobic	NR	10 (IQR 8–15)	6 months	Safety
	Onishi (32)	2009	Cycling/walking	1–2 per week	RPE 11–13 or AT	60	5–14	6 months	VO_2

POD: postoperative day; ICU: intensive care unit; NR: not reported; D/C: discharge; 6MWT: six-minute walk test; RPE: rate of perceived exertion; MET: metabolic equivalent; HRV: heart rate variability; AT: anaerobic threshold; VO_2: volume of oxygen consumption; W: watts; MHR: maximum heart rate; HI: high intensity; IQR: interquartile range

[a]Intensity given for six-minute walk test performed following intervention.

Study or subgroup	Early exercise Mean	SD	Total	Usual care Mean	SD	Total	Weight	Mean difference IV, Random, 95% CI
Borges 2016	348	84	15	292	73	15	28.8%	56.00 (–0.32, 112.32)
Hirschhorn 2007	444	84	31	377	90	31	48.7%	67.00 (23.66, 110.34)
Stein 2009	415	78	10	323	67	10	22.5%	92.00 (28.27, 155.73)
Total (95% CI)			56			56	100.0%	69.46 (39.22, 99.69)

Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 0.71$, df = 2 ($p = 0.70$); $I^2 = 0\%$
Test for overall effect: $Z = 4.50$ ($p < 0.00001$)

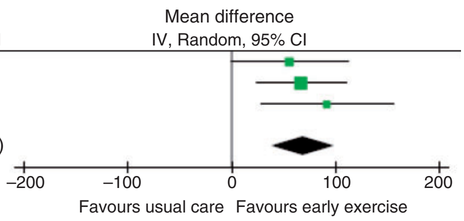

Figure 2. Six-minute walk distance (metres) at the time of hospital discharge comparing immediate aerobic exercise with usual care.
IV: Inverse variance; CI: confidence interval.

Study or subgroup	Early exercise Mean	SD	Total	Usual care Mean	SD	Total	Weight	Mean difference IV, Random, 95% CI	Year
Takeyama 2000	16.1	2	13	14.8	2.3	13	23.8%	1.30 (–0.36, 2.96)	2000
Adachi 2001	20.3	5.4	34	14.3	2.3	23	21.4%	6.00 (3.96, 8.04)	2001
Stein 2009	18	0.3	10	14	0.8	10	29.4%	4.00 (3.47, 4.53)	2009
Eder 2010	18.2	3.1	41	16.5	2.2	19	25.5%	1.70 (0.33, 3.07)	2010
Total (95% CI)			98			65	100.0%	3.20 (1.45, 4.95)	

Heterogeneity: $Tau^2 = 2.64$; $Chi^2 = 22.25$, df = 3 ($p < 0.0001$); $I^2 = 87\%$
Test for overall effect: $Z = 3.58$ ($p = 0.0003$)

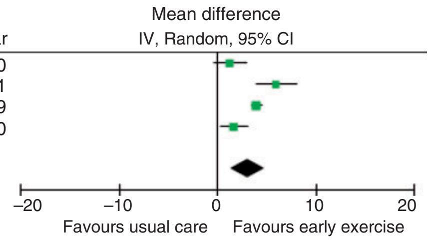

Figure 3. Peak oxygen consumption ($ml \cdot kg^{-1} \cdot min^{-1}$) peak following 2–4 weeks of early aerobic exercise training compared with usual care.
IV: Inverse variance; CI: confidence interval.

Study or subgroup	Early exercise Events	Total	Usual care Events	Total	Weight	Odds ratio M-H, Random, 95% CI
Adachi 2001	0	34	0	23		Not estimable
Borges 2016	0	15	0	19		Not estimable
Hirschhorn 2007	4	61	4	31	74.1%	0.47 (0.11, 2.04)
Mendes 2010	0	24	0	23		Not estimable
Stein 2009	1	10	3	10	25.9%	0.26 (0.02, 3.06)
Takeyama 2000	0	13	0	15		Not estimable
Total (95% CI)		157		121	100.0%	0.41 (0.12, 1.42)
Total events	5		7			

Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 0.17$, df = 1 ($p = 0.68$); $I^2 = 0\%$
Test for overall effect: $Z = 1.41$ ($p = 0.16$)

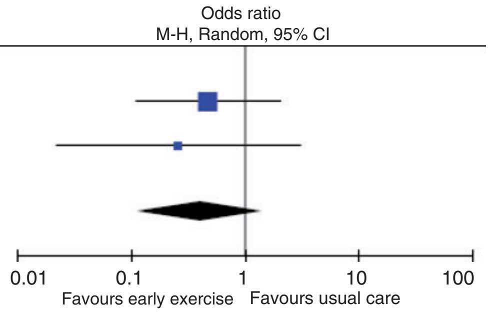

Figure 4. Adverse events comparing immediate and early aerobic exercise training with usual care.
M–H: Mantel-Haenszel; CI: confidence interval.

persisted beyond four weeks due to the limited number and heterogeneity of studies.

Discussion

This current systematic review and meta-analysis describes three evident findings. First, adverse event rates in medically supervised aerobic exercise performed in the immediate and early postoperative period following cardiac surgery do not differ significantly from usual physiotherapy care. Second, a significant improvement in functional capacity, as measured by 6MWD at hospital discharge, was evident when aerobic exercise was performed in the immediate postoperative setting. Finally, early aerobic exercise improved peak aerobic capacity in the short to medium term following cardiac surgery. However, these results must be considered within both their clinical context and the limitations of this review.

Patients performing aerobic exercise early after cardiac surgery experienced similar rates of adverse events (myocardial infarction, stroke, infection, re-sternotomy and mortality) compared with those receiving usual care (odds ratio 0.41, $p = 0.16$). In both groups, overall pooled rates of postoperative atrial tachyarrhythmia, stroke and myocardial infarction were low. Furthermore, no single adverse event, other than arrhythmia, was experienced during an exercise session. It is important to recognize that arrhythmias had a wide range of reported events, with some authors reporting no arrhythmias while others reported rates of up to 41%. This represents variability in patient monitoring, as studies that were conducted with safety endpoints as primary outcomes demonstrated higher rates of overall events, including arrhythmias.[29–31] There were also no significant differences in adverse events when patients performed either walking or stationary cycling exercise.[18] Exercise sessions were well tolerated with low voluntary withdrawal rates in both immediate and early postoperative aerobic exercise interventions, and only two deaths were reported in over 2000 patients performing early aerobic exercise. These results provide assurance that low-risk patients can perform appropriately prescribed aerobic exercise following cardiac surgery with risks of adverse events comparable to usual care.

Stationary cycling or walking exercise commenced in the immediate postoperative period and continued until hospital discharge demonstrated a significant increase in 6MWD compared with patients receiving usual physiotherapy care, regardless of exercise modality and intensity (mean difference 69.5 m, $p < 0.00001$). These results translate as a mean walking speed of nearly $1.2\,m{\cdot}s^{-1}$ for the exercise group, and less than $1\,m{\cdot}s^{-1}$ for the usual care group. This may have significant clinical impact, as a gait speed of less than $1\,m{\cdot}s^{-1}$ is an independent predictor of morbidity and mortality following cardiac surgery,[36,37] cardiac rehabilitation[38] and in wider geriatric populations.[39] Methods of mobilization following cardiac surgery have reversed completely from early ideas of complete bed rest to now early mobilization and functional activities in order to try to overcome the deleterious effects of immobilization.[35,40–42] With elderly patients now representing the fastest growing cohort of patients referred for cardiac surgery, and an improvement in recognition and measurement of frailty,[43] minimizing the time patients spend immobile and non-ambulant after surgery is imperative. While early mobilization alone may reduce the risk of some postoperative complications, a recent systematic review did not find improvements in 6MWT outcomes.[6] This subtle yet clinically significant increase in physical activity from gentle ambulation to light aerobic exercise was an important distinction when including studies for this review, as the physiological demand of even mild exercise is much greater than simple ambulation in patients with central haemodynamic decompensation.[44] Mechanisms for the improvement in functional capacity following aerobic exercise include peripheral muscle adaptations as well as central haemodynamic and gas exchange properties, all of which require physical exertion beyond that of gentle walking.[13,15,41–44]

Aerobic exercise has also demonstrated functional improvements across a wide spectrum of other patients with severe physiologic and functional limitations resulting from other chronic health ailments such as chronic obstructive pulmonary disease and heart failure.[42,44–46] Patients with pre-existing physiologic limitations such as these may experience the greatest benefits of early aerobic exercise after cardiac surgery.[47] Age, sex and the presence of comorbidities negatively impact 6MWD following cardiac surgery, as well as increasing the risk of postoperative complications.[21,48,49] In this review, patients with left ventricular ejection fraction of less than 40% had poorer overall 6MWT results than those with normal ventricular function. Their mean 6MWD, however, improved significantly more than those with normal ventricular function following three weeks of stationary cycling (relative increase 36% *vs.* 23%, $p < 0.001$).[25] Patients with impaired glucose tolerance and type 2 diabetes exhibited the same phenomenon, with the greatest amount of improvement in 6MWD seen in patients with fulminate type 2 diabetes, followed by impaired glucose tolerance and then normal glucose tolerance (73%, 53% and 47% mean improvement respectively).[27] Interestingly, though, elderly patients showed a similar relative increase in 6MWD following early aerobic exercise compared with younger patients (92 m (38%) *vs.* 120 m (36%).[26] However, in the case of low 6MWDs such as those achieved by the elderly group, the absolute distance may also be important in predicting overall risk for postoperative complications, rather than the relative increase alone. Improving absolute 6MWD to over 300 m can improve the overall risk profile following aortic valve surgery, regardless of the relative increase.[2] Additionally, a gait speed of less than $1\,m{\cdot}s^{-1}$ is an independent predictor of morbidity and mortality following cardiac surgery.[50,51] These patients have dual mechanisms responsible for the loss of functional capacity; the loss of physiologic reserve required to maintain gait speed during sub-maximal exercise[47] and a relative increase in metabolic 'cost' of this activity compared with healthy individuals.[4,38] These summative mechanisms contribute to the early fatigue experienced by chronically ill and deconditioned patients, which can be modified somewhat through the application of skeletal muscle loading performed during walking and cycling.[39,47] The inability of cardiovascular physiologic mechanisms to respond to an increase in cardiovascular demand, as well as the skeletal muscle fatigue, opens up avenues of rehabilitation not only involving aerobic exercise in its traditional sense (concentric) but also by changing the mode of contraction to a lengthening action (eccentric).[52] Therefore, the results of this review suggest that aerobic exercise in the immediate and early postoperative period may impact functional capacity via similar mechanisms, given the greater improvement apparent in patients with comorbidities.

Aerobic exercise commenced early (within the first two weeks) following surgery and continued for 2–4 weeks demonstrated a significant increase in peak oxygen consumption compared with patients receiving usual care (mean difference $3.20\,ml\cdot kg^{-1}\cdot min^{-1}$, $p = 0.0003$). Aerobic exercise training improves peak oxygen consumption in healthy, elderly and cardiac patients[53–55] and an improvement in peak aerobic power is associated with fewer hospital admissions, higher quality of life and reduced mortality in cardiac patients.[9,11,56] There was, however, substantial heterogeneity in the studies measuring outcomes of aerobic exercise commenced following inpatient discharge ($I^2 = 87\%$). Time of aerobic exercise commencement, modality and intensity of exercise and duration of the intervention were likely contributors to this variation. Nonetheless, the well-established training effects of aerobic exercise may also be experienced by post-acute cardiac surgical patients with appropriate intensity aerobic exercise.

There are several limitations to this review. First, sample size is relatively small in most trials, with studies powered for outcome improvements rather than formal safety analysis. Patients included in most studies were also very low risk, with mean left ventricular ejection fraction over 50% and diabetes present in only 28% of patients. There is significant heterogeneity in the characteristics of aerobic exercise interventions performed, with many studies also excluding higher risk patients from performing aerobic exercise prior to randomization. Secondary exclusion criteria were often applied immediately prior to performing the exercise intervention, with subsequent results not including intention-to-treat analysis. However, the results of this review should allow future high-quality randomized trials to further investigate the efficacy and safety of aerobic exercise in higher risk cardiac surgery cohorts.

All patients were included in the analysis assuming no difference in baseline characteristics. While this is not statistically confirmed, no individual study identified any significant difference in comparison demographics or clinical features prior to performing an intervention. Furthermore, the pooled mean 6MWD of studies included in this review at one to two weeks following cardiac surgery with no intervention was $303\,m \pm 97\,m$ (mean age 67 ± 11 years old; results not shown). This is comparable to large registry studies reporting mean 6MWD performed within two weeks of surgery of $296 \pm 11\,m$ and $248 \pm 98\,m$ respectively.[5,45] This provides some confidence that the patient groups in the studies in this review are in fact similar to larger low-risk populations undergoing cardiac surgery and therefore the likelihood that the exercise intervention effect will be applicable to most patients undergoing cardiac surgery is strengthened.

Conclusion

Aerobic exercise performed in the early postoperative period significantly improves functional capacity at hospital discharge compared with current usual physiotherapy care and may provide improvements in aerobic capacity in the short to medium term. While we found no difference in adverse event rates, trials appropriately powered for safety endpoints are required to definitively answer questions regarding the safety of early aerobic exercise. The acute derangement of cardiovascular physiology following cardiac surgery in addition to a pre-existing limit of physiologic reserve places elderly and medically complex patients in greatest need of appropriate, tailored therapies in order to maintain and restore functional capacity following cardiac surgery. Interventions comprising appropriately prescribed and supervised aerobic exercise should be further investigated in larger randomized trials, with particular interest in safety outcomes and higher-risk patient groups that more accurately represent the modern-day cardiac surgical patient.

Author contribution

MPD and SCSP contributed to the conception of the work. MPD, DTT and GEP contributed to the design of the systematic search criteria. MPD, DTT, PI and GEP contributed to the acquisition, analysis and interpretation of data for the work. MPD and DTT drafted the manuscript. PI, SCSP and GEP critically revised the manuscript. All gave final approval and agree to be accountable for all aspects of work ensuring integrity and accuracy.

Declaration of conflicting interests

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