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REVIEW

Resistance Training Following Median Sternotomy: A Systematic Review and Meta-Analysis

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Objective Despite no evidence to support weight limitations following median sternotomy, sternal precautions continue to be routinely prescribed. Moreover, international cardiac rehabilitation guidelines lack sufficient detail for the implementation of resistance training. This systematic review and meta-analysis aimed to determine what the literature defines as resistance training; how resistance training is applied, progressed and evaluated; and, whether resistance training improves physical and functional recovery postoperatively in the cardiac surgical population.

Data Sources Five (5) electronic databases were searched from inception to 28 September 2018 for studies published in English that investigated the effects of a resistance training intervention on physical and functional recovery following median sternotomy.

Results Eighteen (18) trials (n = 3,462) met eligibility criteria and were included in the analysis. Seven (7) randomised controlled trials shared common outcome measures, allowing meta-analysis. The performance of resistance training appears to be safe and feasible, and resulted in similar improvements in both cardiopulmonary capacity and anthropometry, when compared to aerobic training alone. However, the definition and application of resistance training is frequently a lower intensity and volume than recommended by the American College of Sports Medicine. Furthermore, sternal precautions are not reflective of the kinematics and weights used when performing many activities of daily living. For this reason, resistance training needs to be task-specific, reflecting functional tasks to promote recovery.

Abbreviations: ACSM, American College of Sports Medicine; CPET/GXT, Cardiopulmonary Exercise Testing/Graded Exercise Test; 6MWT, Six minute walk test

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Conclusion Resistance training, in isolation or when combined with aerobic training, may lead to greater improvements in physical and functional recovery following cardiac surgery via median sternotomy; however, further research is required to inform clinical guidelines.

Keywords Cardiac surgery • Median sternotomy • Resistance training • Cardiac rehabilitation • Exercise

Introduction

Median sternotomy is the gold standard in providing optimal access during cardiac surgical procedures, including coronary artery bypass graft and cardiac valve repair/replacement surgery; despite recent developments in minimally invasive surgical techniques. [1–5] Over 1.5 million procedures are performed annually, worldwide [6]. Despite evidence to support moderate intensity exercise [7], and a more active approach to postoperative recovery and cardiac rehabilitation [8,9], sternal precautions are typically prioritised over exercise involving the upper limbs and trunk for 8 to 12 weeks following surgery [10–12], with the rationale that they prevent sternal complications. [13–21] In addition to the restriction of use of the upper limbs and trunk, sternal precautions generally prohibit the lifting of weights >1 kg until the sternum unites. [10–12]. However, there is no evidence to suggest that restricting upper limb and trunk movements improves bone healing and prevents sternal complications [8,13,22]. Furthermore, sternal precautions are inconsistently applied and are contrary to the promotion of physical activity by health professionals to facilitate recovery. Emerging evidence to support the safety and efficacy of moderate intensity exercise, and upper limb and thoracic progressive exercise, has prompted a move away from a restrictive approach following surgery to one that encourages movement and physical activity [7–9,23].

Resistance training refers to exercise techniques that improve musculoskeletal function, including the use of free weights, body weight, machine weights and resistance bands [11,12,24]. Whilst a number of organising bodies recommend the inclusion of resistance training, worldwide cardiac rehabilitation focusses primarily on aerobic training with resistance exercise guidelines varying significantly [25]. The lack of consensus between sternal precautions, cardiac rehabilitation guidelines and emerging evidence is problematic for clinicians who are required to deliver evidence-based exercise interventions [14,15].

Resistance training not only augments improvements in cardiovascular fitness and muscle strength [24,26–29]; recent evidence suggests that it may play a role in the reduction of inflammation, cognitive dysfunction and sarcopaenia [30–39], which can persist for several months after surgery; and improve quality of life [26], psychological wellbeing [40], morbidity [41] and ability to perform household activities [28]. Postoperative recovery can be compromised by physical inactivity, [11] which is inadvertently encouraged when adhering to activity restrictions implied by sternal precautions. However, despite the aforementioned benefits of resistance training, to our knowledge, no systematic reviews have been conducted to investigate the safety, feasibility, application and effectiveness of resistance training in the cardiac population undergoing procedures via median sternotomy, at any time point postoperatively.

Therefore, the specific research questions for this systematic review were:

1 What is 'resistance' training after median sternotomy?
2 How is resistance training applied, progressed and evaluated at any stage of cardiac rehabilitation following median sternotomy?
3 Does resistance training improve physical and functional recovery following median sternotomy in comparison to standard care or aerobic training?

Method

This review follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines and is registered on the International prospective register of systematic reviews (PROSPERO No. CRD42018098623).

Eligibility Criteria and Search Method

Eligible studies were those published in English that reported on an adult (≥18 years) population with coronary artery disease, inclusive of cardiac surgeries via median sternotomy. Studies stating inclusion of resistance training in the exercise intervention with assessment of a patient's physical and functional recovery were included. Where intervention groups were compared to a control group, the trials were only included if the control intervention consisted of treatment as usual (e.g. standard medical care) or no intervention.

For the purpose of this review, the definition of resistance was defined by the included publication authors and was compared to the American College of Sports Medicine's (ACSM) recommended resistance training exercise prescription (Table A.1) [11,12,24]. Outcomes included, but were not limited to, exercise capacity, muscular strength, adherence and adverse events during the intervention. The inclusion of any type of co-intervention was permitted, provided the co-interventions were delivered to both study groups equally.

Electronic databases (PubMed, Medline, EMBASE, Cumulative Index to Nursing and Allied Health Literature [CINAHL] and SportsDiscus) were searched from their inception to 28 September 2018 for studies combining two key concepts: cardiac surgery type and resistance training (Appendix A: Electronic database search strategy). The reference lists of all relevant publications were searched for any

additional references or unidentified trials, however, publications remained limited to English only, due to not having the resources to translate the publications. Grey literature was also excluded.

Study Selection and Data Extraction

One review author (JP) screened the titles of all publications obtained from the searches for inclusion. Two independent reviewers (JP & MP) screened abstracts and full-text review was undertaken to determine publication language, cardiac population, exercise intervention and outcome measures. A third reviewer (DEA) was consulted where any disagreement occurred.

Data extraction and risk of bias assessment were completed independently by two reviewers (JP & MP). The Law and MacDermid Quantitative Review form and guidelines were used to extract data from the included studies [42], whilst a modified Downs & Black tool was used to determine study quality and risk of bias [43]. Study quality was classified according to corresponding Downs and Black score ranges of excellent (26–28); good (20–25); fair (15–19); and poor (≤14) [43]. Where aspects of study design were unclear or could not be clarified by the author, they were graded down. Any disagreement was resolved by discussion.

Where data was presented both numerically and graphically, the numerical data was used to reduce the risk of result misinterpretation when estimating from the figures. Authors were contacted requesting clarification of the missing information where unclear or insufficient data was reported.

Data Synthesis and Meta-Analysis

Exercise prescription variables, including cardiac rehabilitation program length and exercise duration, frequency, intensity and time of commencement after surgery; and the outcome measures used to assess the exercise interventions were summarised into tables. The variability in exercise prescription and outcome measures used meant that a standardised effect for meta-analysis could not be used, instead meta-analysis was conducted where two or more studies reported the same units of outcome measurement. To determine the effectiveness of resistance training, meta-analyses were performed in studies comparing resistance training to standard care, and resistance training to aerobic training. Only randomised trials were included for meta-analysis, which was completed for pre- and post-intervention time points.

Standardised mean differences were used when continuous outcomes were measured on different scales. Data was pooled using a fixed-effect model, unless high heterogeneity was evident, in which case a random-effects model was used. Statistical heterogeneity was assessed using the I^2 statistic, with high heterogeneity determined as $I^2 > 50\%$. Meta-analysis results were reported as means and 95% confidence intervals (CIs). Analyses were performed in Review Manager (RevMan V.5.3, The Cochrane Collaboration). A p-value <0.05 was considered to indicate statistical significance.

Results

Study Selection

The database and reference list searches identified 1,468 unique references for possible inclusion. Review of titles and abstracts identified 70 for full-text reviews, of which, 18 publications met the criteria for inclusion (Figure 1) [26–29,40,41,44–55].

Study Characteristics

The 18 studies included in the qualitative analysis of the review included 3,462 patients with coronary artery disease, inclusive of patients treated surgically via median sternotomy. The included studies consisted of seven randomised controlled trials [26,27,29,47,48,54,55], one quasi-randomised controlled trial [46], eight experimental trials [28,40,44,45,49,50,52,53] and two observational studies [41,51]. Seven (7) studies met the criteria for meta-analysis [26,27,29,46,48,54,55]. A summary of the individual study characteristics are shown in Table 1. Five (5) studies were deemed of good quality [26,27,41,54,55], 10 of fair quality [28,29,40,44,47–49,51–53] and three of poor quality (Figure 2) [45,46,50]. The weakest areas were lack of power calculations and reporting of external validity and confounding (selection) bias.

Intervention Exercise Prescription

The type of resistance used was classified as body weight exercises (n = 2 studies) [51,52], free weights (n = 2 studies) [28,29], weight machines (n = 5 studies) [26,45,46,54,55], calisthenics (n = 3 studies) [40,47,50] or a combination of resistance equipment (n = 4 studies) [27,44,48,53] amongst the included studies. Two studies did not state the type of resistance used [41,49]. None of the included studies met all of the ACSM's exercise guidelines for resistance training in regard to program duration, intensity, frequency and exercise prescription (sets, reps, exercises). However, Maiorana et al. (1997) [48] provided the most rigorous intervention program, implementing a circuit training program that met all ACSM guidelines (frequency, intensity, exercise prescription and commencement after surgery) except for program length. The advised weekly session frequency and program duration were achieved by 10 [26,28,41,44–46,48,49,54,55] and five studies [50–52,54,55], respectively. The exact weight range of the resistance used and specific exercises were not adequately reported for interpretation to be performed. The nine studies (n = 842 participants) that commenced their program earlier than the recommended 12 postoperative weeks reported the incidence of four common adverse events (n = 38 participants); angina (n = 2 participants) [47], new onset atrial fibrillation (n = 21 participants) [47], other arrhythmias (n = 12 participants) [47] and knee pain (n = 3 participants) [26]. Despite the recommendation for assessment of sternal stability prior to commencing resistance training earlier than 12 weeks, no studies assessed sternal stability, therefore it is unclear whether the upper limb

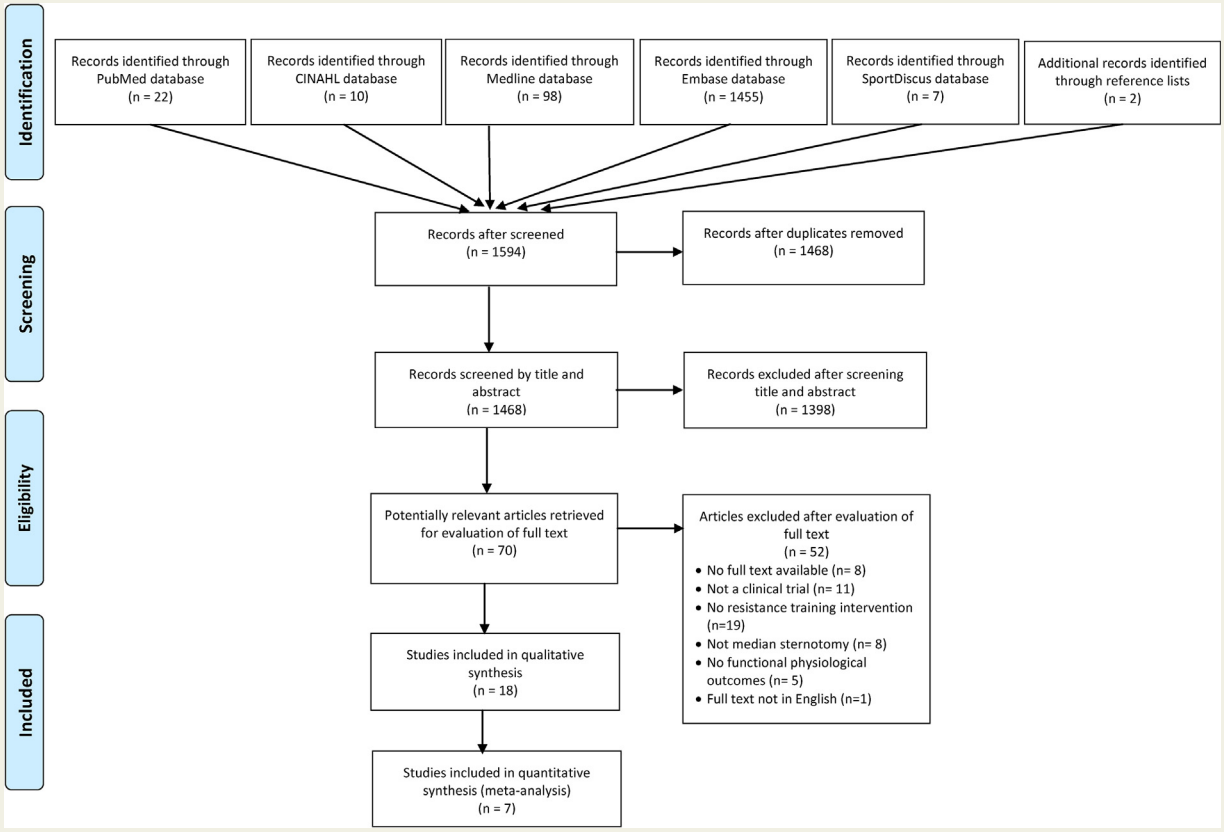

Figure 1 The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flowchart outlining the selection of studies included in the systematic review with meta-analysis. Abbreviations: CINAHL, Cumulative Index to Nursing and Allied Health Literature; EMBASE, the Excerpta Medica Database.

resistance exercises resulted in any sternal micromotion [26,27,29,46,47,49,51,52].

Outcome Measures

Nine (9) physical, and one questionnaire-based, outcome measures were used by two or more studies to assess the resistance training program effects (Table A.2.). A cardiopulmonary exercise test or graded exercise test (CPET/GXT) [26,40,41,44–48,50–55] and the six-minute walk test (6MWT) [26,27,29,41,47] were used to assess cardiovascular capacity; body mass index, [41,49,51,54,55] waist circumference, [13,14,24] skinfolds [46,51,54,55] and muscle girths [48,49,51,52] were used to assess anthropometric changes; and, one-repetition maximum [28,45,48], isokinetic dynamometry [46,51,52] and isometric knee flexion and extension [26,27] were used to assess changes in muscular strength. Health-related quality of life was assessed in three studies, using the Medical Outcomes Study short form-36 survey [26,44,47]. The CPET/GXT, one-repetition maximum and isokinetic dynamometry are the only cardiac rehabilitation outcome measures recommended for use by the ACSM (Table A.2.) [11,12]. Despite all studies implementing a resistance training protocol, muscular strength was only assessed in eight of the 18 studies [26–28,45,46,48,51,52]. No studies assessed sternal stability prior to commencing or progressing resistance training, which is recommended by the ACSM before commencing upper limb resistance exercises [11,12].

Effect of the Addition of Resistance Training to Standard Care

Cardiopulmonary Capacity

Four (4) studies assessed cardiopulmonary capacity, as either a measure of VO_{2peak} [46,48] or treadmill time in seconds (Figure 3A) [54,55]. Pooling results across studies showed a trend toward improved cardiopulmonary capacity compared to controls, however the result was not statistically significant (standardised mean difference = 0.26; 95% CI = -0.08–0.60; p = 0.14). There was no evidence of statistical heterogeneity (I^2 = 42%, p = 0.16).

Functional Capacity

Meta-analysis showed that the addition of resistance training to standard care did not result in significant improvements, however, there was a trend towards improved functional capacity, measured using the 6MWT (mean difference = 13.76; 95% CI= -4.07–31.59; p = 0.13). High heterogeneity was evident (I^2 = 54%; p = 0.14) (Figure 3B) [27,29].

Table 1 **Study characteristics and intervention details in reviewed trials.**

Author	Country	Design	n=	Age	Time After Surgery	Study Duration	Frequency	Session Duration	Intensity	Equipment Used
Brubaker et al. 2003 [25]	USA	Experimental	52	73	*Not stated*	12 weeks	3x/week	1 hour	50-70% HRmax Borg RPE 11-13	Free weights Weight machines
Busch et al. 2012 [26]	Germany	RCT	173	78	2 weeks	3 weeks	5x/week	1 set 8-12 reps	60% 1RM Borg RPE 13/20	Free weights Weight machines
Chludilova et al. 2007 [27]	Czech Republic	Experimental	10	64	8 weeks	12 weeks	3x/week	3-5 sets 10 reps	30-60% 1RM	Weight machines
Coke et al. 2008 [28]	USA	Experimental	32	65	14 weeks	12 weeks	2x/week	1 set 12 reps 5 exercises	40-60%1RM Borg RPE 13/20	Free weights
Ghroubi et al. 2013 [29]	Tunisia	RCT	32	59	2 months	8 weeks	3x/week	20-40 reps 10 x 1 minute bouts	70% HRR. Lower limbs- 20-30% peak toque max. 1:1 Work-to-rest ratio	Weight machines
Haennel et al. 1991 [30]	Canada	Quasi-RCT	24	52	9-10 weeks	8 weeks	3x/week	3 x 20 sec work intervals (8-16 reps)	1:1 Work-rest ratio. 60 seconds rest after 3rd interval.	Weight machines
Macchi et al. 2007 [31]	Italy	RCT	300	67	2-4 weeks	7-12 days	*Not stated*	2 hours/day	65-75% HR_{max}	Calisthenics- single body segment weight
Maiorana et al. 1997 [32]	Australia	RCT	31	60	3 months	10 weeks	3x/week	1-3 sets 10-15 reps 12 exercises	40-60%MVC Work-to-rest ratio 1:1	Weight machines Free weights
Nalini et al. 2013 [33]	Iran	Experimental	167	52	8 weeks	8 weeks	3x/week	10 reps 3 exercises	60-80% HR_{max}	*Not stated*
Newell et al. 1980 [34]	UK	Experimental	24	39	2 weeks	24 weeks	5x/week	11-12 minutes	*Not stated*	Calisthenics- single body segment weight
Nishitani et al. 2013 [35]	Japan	Observational	78	63	7 weeks	6 months	1-2x/week	1-2 sets 10-15 reps	3-5 minutes rest between sets	Body weight
Perski et al. 1999 [36]	Sweden	Experimental	152	54	12 months	4 weeks	2x/day 5x/week	45 minutes	*Not stated*	Calisthenics- single body segment weight
Pollmann et al. 2017 [37]	Denmark	Observational	211	63	*Not stated*	3 months	2x/week	3 × 15	60% maximum strength	*Not stated*
Sumide et al. 2009 [38]	Japan	Experimental	104	56	4 weeks	6 months	1-2x/week	*Not stated*	*Not stated*	Body weight
Turner et al. 2002 [39]	UK	Experimental	1,902	60	*Not stated*	6 weeks to 6 months	1-2x/week	3 sets 5-10 reps, initially	*Not stated*	Body weight Therabands

Table 1. (continued).

Author	Country	Design	n=	Age	Time After Surgery	Study Duration	Frequency	Session Duration	Intensity	Equipment Used
								8 exercises		
								3 sets	2-5 kg	
Wosornu et al. 1992 [40]	UK	RCT	81	57	12 weeks	6 months	3x/week	10 reps	45 seconds rest between each element	Weight machines
Wosornu et al. 1996 [41]	UK	RCT	55	58	12 weeks	6 months	3x/week	3 sets	2-5 kg	Weight machines
								10 reps	45 seconds rest between each element	
Ximenes et al. 2015 [42]	Brazil	RCT	34	61	Immediately after extubation	10-14 days	2x/day	1-3 sets	0.5 kg upper limb	Free weights
								10 reps	1 kg lower limb	Ankle weights

Abbreviations: RCT, randomised controlled trial; reps, repetitions; kg, kilogram; HR_{max}, heart rate maximum; MVC, maximal voluntary contraction.

Anthropometric Measures

Excessive body mass index and skinfold measurements are indicative of worse health outcomes. As the included studies deemed a reduction in these values as a favourable outcome, the scores were multiplied by -1 so that the score direction would be the same as that of other variables. A fixed effects model was used to determine that resistance training resulted in a trend towards improved anthropometric measures, assessed via skinfolds [48,55] and body weight [48,54,55], however this did not reach statistical significance (standardised mean difference = 0.11; 95% CI= -0.16–0.39; I^2 = 0%, p = 0.42) (Figure 3C).

Effect of Resistance Training Compared to Aerobic Training

Cardiopulmonary Capacity

Due to evidence of significant statistical heterogeneity (I^2 = 58%, p = 0.07), a random effects model was used during meta-analysis of cardiopulmonary capacity, assessed by change in VO_{2peak} [26,46] and treadmill time (in seconds) [54,55] following aerobic training and resistance training (Figure 4A). The pooling of results showed no significant difference between aerobic training and resistance training in the improvement of cardiopulmonary capacity (standardised mean difference = 0.24; 95% CI= -0.32–0.80; p = 0.40).

Anthropometric Measures

Meta-analysis of three studies comparing improvements in anthropometric parameters, measured by a change in body mass index [26,55] or body weight, [54,55] following either aerobic training or resistance training found that the two modalities were comparable (Figure 4B). No statistical significance existed between the two modalities (standardised mean difference= -0.06; 95% CI= -0.36–0.24; p = 0.70) and no statistical heterogeneity was evident (I^2 = 0%, p = 0.91).

Discussion

Resistance Training Following Median Sternotomy

This systematic review found that the definition and application of resistance training was inconsistent with the ACSM guidelines. Resistance training was applied in varying forms, including the use of free weights, weight machines, resistance bands, body weight and calisthenics exercises. The ACSM states that the types of resistance training used can include free weights (i.e. barbells, dumbbells, and ankle weights), body weight (i.e. push-ups, squats), machine weights and resistance bands. [11,12,24] Three (3) studies reported using calisthenics as the method of applying of resistance, [40,47,50] however, in accordance with the aforementioned ACSM definition, the use of calisthenics does not constitute resistance training and thus, should not be reported as such.

The ACSM recommends that cardiac rehabilitation following median sternotomy should include resistance training,

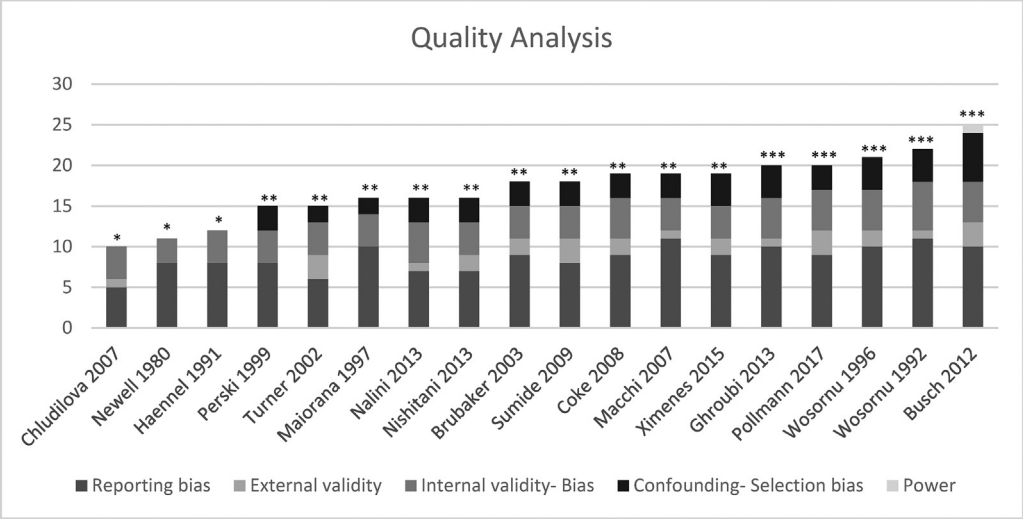

Figure 2 Quality analysis of the included studies using a modified Downs and Black tool.
*Poor quality (≤14), **Fair quality (15-19), ***Good quality (20-25), ****Excellent quality (26-28)

performed at a frequency of 2–3 days per week frequency, 2–4 sets of 12–15 repetitions for 8–10 exercises duration, resistance of 0.5–0.9 kg until 12 weeks postoperatively at an intensity of 40–50% maximum voluntary contraction and a program duration of 4–6 months (Table A.1.). [11,12,24] Maiorana et al. (1997) [48] provided the most robust resistance training intervention, meeting all ACSM recommendations in their 10-week circuit training intervention, except program length. Whilst the majority of studies achieved the recommended frequency of 2–3 sessions per week, the duration of sessions was not achieved, with an insufficient number of exercises, sets and reps commonly prescribed. As highlighted in Table 1, resistance training programs were typically commenced at 6 or more postoperative weeks, with patients predominantly completing one to three sets of 10 repetitions using machine weights or a combination of resistance equipment. Given the widespread understanding that exercise and physical activity enhance surgical outcomes, it appears that aerobic training has been prioritised over resistance training so as to not contradict the sternal precautions. This contradiction is likely to be responsible for the poor translation of resistance exercise in cardiac rehabilitation settings. Furthermore, the variability in international cardiac rehabilitation resistance training guidelines noted by Price et al. (2016), [25] and the varied definition, application and duration of sternal precautions are likely to also be a contributing factor in the preferential use, and prioritisation, of aerobic training to facilitate postoperative recovery.

An increasing volume of studies have demonstrated the feasibility of early moderate intensity physical activity and upper limb exercise following cardiac surgery via a median sternotomy. [7–9,56] This has been supported by emerging evidence that modified sternal precautions, encouraging greater use of the upper limbs, can be safely performed without compromising sternal healing, [9,23] provided movement is pain free and upper limbs are kept close to the body [13]. For this reason, future research exploring the safety and efficacy of early resistance training, which utilises the muscles and movements required for daily tasks; and investigation into the effect of resistance training on postoperative recovery, is urgently needed.

Assessment and Progression of Resistance Training in Relation to Sternal Stability

In this review, only five studies reported commencing resistance training after 12 postoperative weeks, [28,40,48,54,55] which is reflective of the duration of time that sternal precautions, in the form of movement restriction to the upper limb and trunk, are applied. However, sternal stability was not assessed when commencing or progressing upper limb exercises in any of the studies included in this review; and therefore, sternal instability was not considered or reported as an adverse event. Furthermore, only two of the included studies reported the harvest sites and stratification for surgical heterogeneity did not occur in the two studies that mentioned the grafts harvested. [27,55] This is important, as further comment cannot be made in regard to sternal healing and the grafts harvested, with the number of mammary grafts harvested likely to affect sternal healing and, in turn, sternal stability and micromotion. [22]

The ACSM guidelines stipulate that upper limb movements that produce tension on the sternal wound should be avoided until there is no evidence of sternal instability, as no clinical studies have investigated the effect of weighted upper limb exercises and exercise programing on sternal

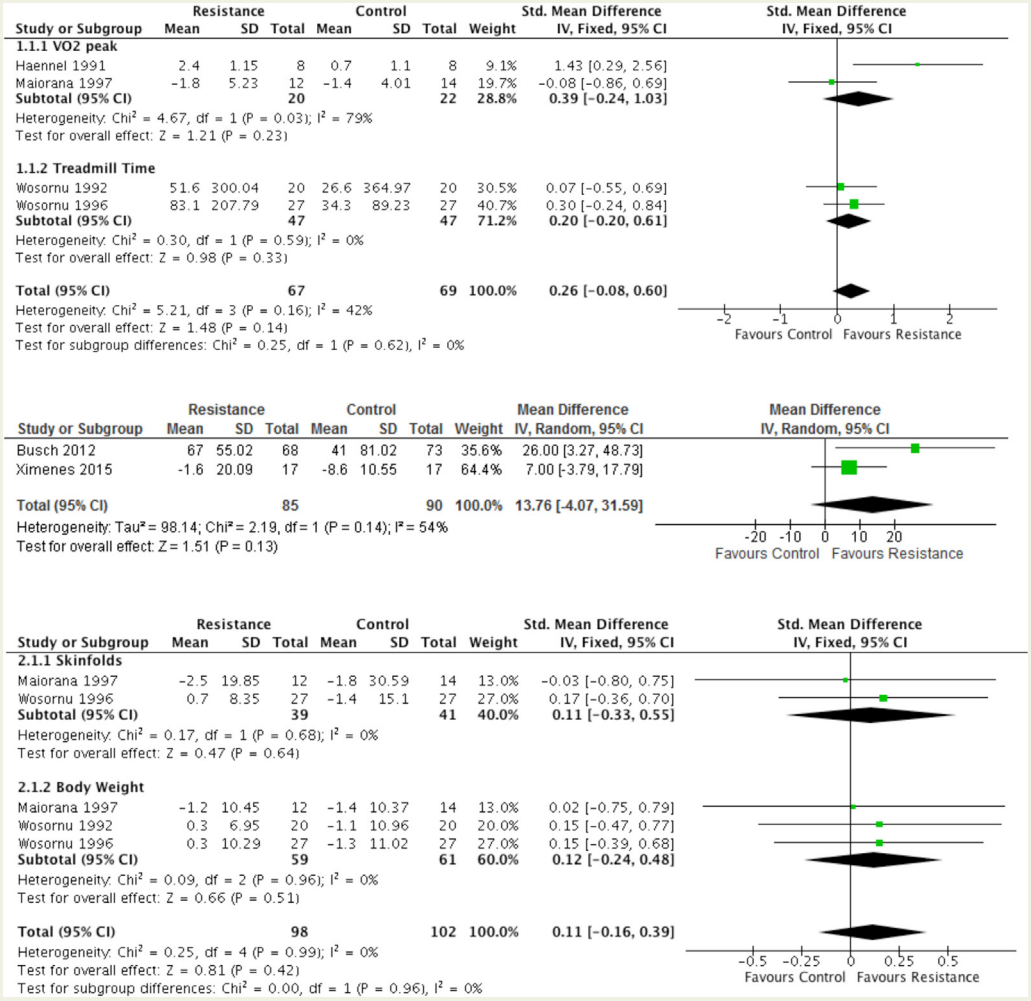

Figure 3 A) Meta-analysis of cardiopulmonary capacity in control versus resistance training interventions. B) Meta-analysis of functional capacity in control versus resistance training interventions. C) Meta-analysis of anthropometry in control versus resistance training interventions. The solid vertical line indicates no effect. The solid squares indicate the mean difference and are proportional to the weights used in the meta-analysis. The diamond indicates the weighted mean difference, and the lateral tips of the diamond indicate the associated confidence intervals (CI). The horizontal lines represent the 95% CI.

healing and sternal stability. [11,12] Prior research suggests that less than 2 mm of micromotion is within the safe limits for bone healing and sternal stability, whilst micromotion beyond this is an indicator of compromised sternal healing, particularly in the first 12 weeks postoperatively [1,8]. The safety of unweighted upper limb and functional tasks (deep inspiration, cough, unilateral and bilateral upper limb elevation and sit to stand) has been demonstrated by Balachandran et al. (2018) [8], who found these tasks resulted in less than 2 mm of sternal separation and micromotion, as measured by ultrasound. However, no studies have investigated the safety and efficacy of weighted upper limb exercises. Furthermore, the use of sternal ultrasound may not be practical or cost-effective for some clinicians. For this reason, the sternal instability scale [57] may be a more feasible screening tool prior to commencing and progressing upper limb exercises, to identify patients who may need further medical follow-up.

Effects of Resistance Training on Postoperative Recovery

This review has found that, the effect of aerobic training and resistance training on improvements in cardiopulmonary capacity or changes in anthropometry are comparable following cardiac surgery via median sternotomy. Although not significant, there was a trend toward greater improvements in physical and functional recovery when resistance training is combined with aerobic training, compared to aerobic training alone. However, future studies with larger sample sizes, that consistently apply and assess the effects of resistance training following cardiac surgery, are warranted. With reports that 15–60% of patients experience long-term postoperative functional and cognitive deficits following cardiac surgery, [30–35] and evidence to suggest that resistance training augments the effects on insulin-like growth factor-1 and insulin sensitivity, and mediates inflammation and

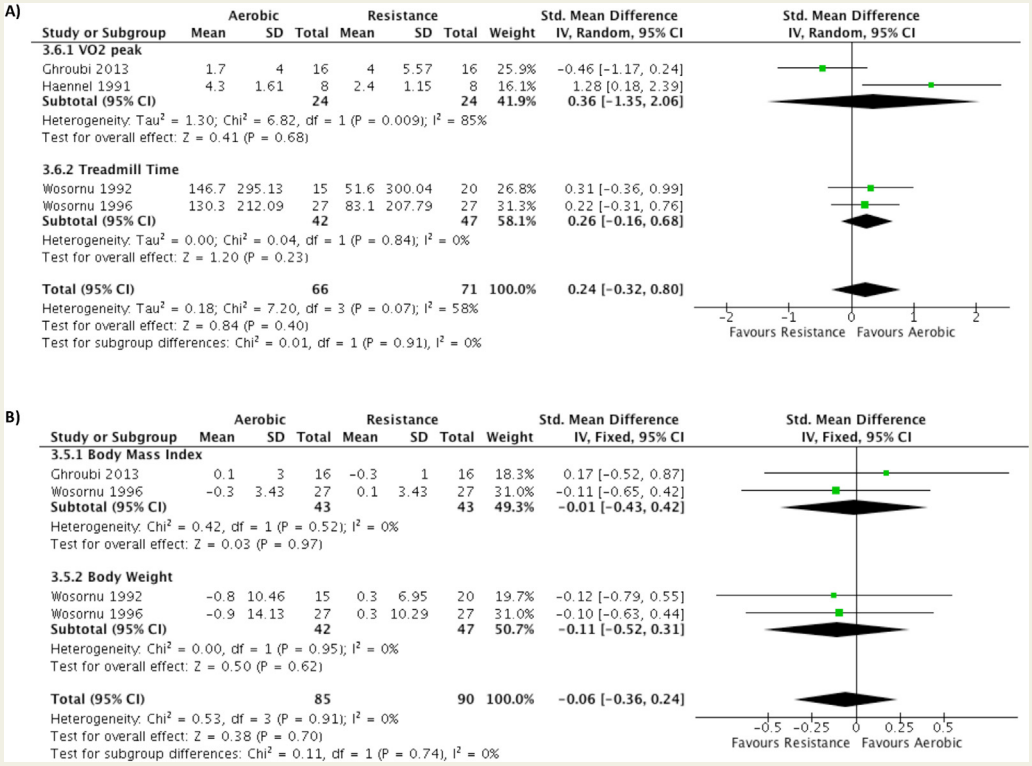

Figure 4 A) Meta-analysis of cardiopulmonary capacity in aerobic versus resistance training interventions. B) Meta-analysis of anthropometry in aerobic versus resistance training interventions. The solid vertical line indicates no effect. The solid squares indicate the mean difference and are proportional to the weights used in the meta-analysis. The diamond indicates the weighted mean difference, and the lateral tips of the diamond indicate the associated confidence intervals (CI). The horizontal lines represent the 95% CI.

neurotrophic factor pathways associated with cognitive decline and sarcopaenia [37,38]; resistance training may be the key to optimising all aspects of postoperative recovery following cardiac surgery. As such, future research should investigate the safety, feasibility and effect of early resistance training following median sternotomy and the effects of resistance training on cognitive recovery following cardiac surgery.

Limitations

Several limitations need to be acknowledged. The searches were limited to full-text publications written in English, due to a lack of resources and personnel able to translate and insufficient detail required for interpretation, respectively. This may have led to the exclusion of additional studies, potentially affecting the results of this review. The findings of this review need to be interpreted with caution due to the quality of the included studies. Common weaknesses in study design were the small sample sizes and lack of blinding. Blinding of outcome assessors was inconsistently reported, thus increasing risk of bias and decreasing overall study design quality. The assessment of bias was also limited due to incomplete reporting in all of the study types; therefore, the effect of exercise could have potentially been underestimated in this review. Due to the lack of consistency amongst the outcome measures used, and the lack of presence of a control group in the experimental studies, meta-analysis was limited to seven studies. These factors limit the strength of the conclusions drawn. Future studies addressing the aforementioned limitations, including larger sample sizes, consistent use of outcome measures and assessor blinding, would help to strengthen evidence for the evolution of cardiac rehabilitation guidelines.

Conclusion

There is evidence to support the safety and efficacy of progressive unweighted upper limb and trunk movements; and moderate intensity exercise in patients following cardiac surgeries via median sternotomy. However, a precautionary approach to cardiac rehabilitation has perpetuated the poor translation of resistance exercise in cardiac rehabilitation settings and has resulted in the preferential use of aerobic training to facilitate postoperative recovery. This study highlighted that there is no consistent definition of resistance training. Furthermore, there is no consistency in how resistance training is applied, progressed and evaluated following median sternotomy. Resistance training, used in isolation or in combination

with aerobic exercise, demonstrated a trend towards improvement in physical and functional recovery following cardiac surgery. Future research should aim to investigate the effects and optimal timing of weighted upper limb and trunk resistance exercises on functional, cognitive and physical recovery.

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Competing Interests

Nil to declare.

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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.hlc.2019.05.097.

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