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SYSTEMATIC REVIEW **Open Access**

Right ventricular function in athletes engaged in endurance exercise using speckle tracking echocardiography: a meta-analysis

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Abstract

Background Long-term endurance training is associated with structural, functional, and biochemical markers of cardiac dysfunction in highly trained athletes. Many studies have focused on structural changes in the right ventricle (RV) and few have examined functional adaptation of the right ventricle. This meta-analysis aims to compare the changes in right ventricular systolic function between endurance athletes and controls before and after exercise using speckle tracking echocardiography (STE).

Methods A comprehensive search of relevant studies published before March 19, 2024 that examined RV systolic function using speckle tracking technology was conducted. Weighted mean differences (WMDs) and 95% confidence intervals (CIs) were used as pooled statistics. Meta regression was employed to identify sources of heterogeneity and publication bias was evaluated by Egger's test and funnel plots. Sensitivity analysis was performed by removing sources of significant change from the results of a single publication to evaluate the stability of the results.

Results Twenty studies were included with 1186 participants. A fixed effect meta-analysis revealed RV global longitudinal strain (GLS) WMD = 0.40, 95% CI (-0.08 ~ 0.89), $p = 0.102$ and free wall longitudinal strain (FWLS) WMD = 0.62, 95% CI (0.28 ~ 0.96), $p < 0.001$, random effect models of RV basal strain WMD = 2.94, 95% CI (2.00 ~ 3.88), $p < 0.001$ and RV apical strain WMD = -0.79, 95% CI (-1.95, 0.37), $p = 0.245$ between endurance athletes and controls. In addition, a random-effects meta-analysis revealed significant impairments in RV function when assessed by comparing RV GLS pre-endurance versus post endurance exercise WMD = 2.51, 95% CI (1.634 ~ 3.40), $p < 0.001$.

Conclusion The evidence obtained thus far suggests that reporting only global right ventricular strain data may obscure segment-specific adaptation changes, and the use of global and segmental strain analysis may help to identify potential functional changes in the right ventricle while differentiating between normal endurance athletes and non-active controls.

Keywords Function, Speckle tracking, Endurance athletes

Introduction

Long-term training causes hemodynamic load on the left and right ventricles, leading to an increase in wall thickness, ventricular diameter, and mass. These changes are commonly referred to as 'athlete's heart' [1, 2]. The degree of remodeling and wall thickening varies among athletes in different sports. Research results indicate that [3], endurance-trained athletes have higher right ventricular structural measurement parameters than

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strength-trained athletes. In endurance athletes who participate in long-term high-intensity aerobic training, ventricular remodeling is mainly manifested as an increase in left and right ventricular diameter, accompanied by an increase in wall thickness and left ventricular stroke volume proportional to the volume overload, and left ventricular eccentric hypertrophy [4, 5]. Most studies have focused on structural changes in the right ventricle, and there is little research on the functional adaptation of the right ventricle.

A study demonstrates that prolonged endurance exercise is associated with structural, functional, and biochemical markers of cardiac dysfunction in highly trained athletes [6], a mechanism called 'cardiac fatigue' has been proposed to explain the decline in resting heart function of athletes after intense exercise. Compared with the left ventricle, it appears to affect the right ventricle earlier and to a greater extent [6, 7]. There are also conflicting conclusions about whether right ventricular function is temporarily reduced after high-intensity endurance exercise [8, 9].

RV contraction is mainly determined by deep longitudinal muscle fibers, which account for 80% of the right ventricular ejection capacity [10]. Like ventricular structural remodeling, changes in right ventricular function may also be segmental rather than global [11, 12]. Speckle tracking technology (STE), as a new technique for evaluating myocardial function, overcomes the influence of the angle between the sound beam direction and the wall motion direction of traditional echocardiography, has no angle dependence, and can more accurately reflect myocardial strain.

The use of speckle tracking technology allows for the detection of early subtle abnormalities in myocardial function and enables the quantification of both segmental and global myocardial deformation [13]. This makes it a valuable tool in evaluating the right ventricular function of endurance athletes. However, there are few studies on this aspect, and most prior studies focused on individual factors such as age, gender, and training time, and their consistency needs to be verified [8].Therefore, we intended to observe whether right ventricular systolic function changes early in endurance athletes participating in a variety of different sports and were assessed using only STE parameters to determine its independent predictive value, in addition to explore whether right ventricular systolic function changes transiently before and after an endurance exercise event.

The aim of this study was to compare the changes in global and segmental right ventricular strain in endurance athletes. It also aims to the changes in global longitudinal strain values before and after an endurance exercise, to explore the value of speckle tracking technology in evaluating the right ventricular function of endurance athletes.

Methods

Search strategy

A comprehensive search of relevant studies published before March 19, 2024, that examined RV systolic function using speckle tracking technology was conducted. Both English and Chinese databases were searched. English databases include Cochrane Library, Embase, PubMed, and Chinese databases, including the CNKI, Wanfang, and VIP database. Studies were identified by using Me-SH terms and crossing the following terms: 'athletes', 'endurance', 'speckle tracking', 'right ventric* strain', 'longitudinal strain'. Relevant references of the literature were manually searched.

Eligibility criteria and exclusion criteria

The inclusion criteria for the meta-analysis were as follows: (1) studies recruiting healthy participants aged 18 years and over; (2) studies including highly trained endurance athletes(rowing, triathlon, cycling, and marathon) and nonathletic control groups,(3) studies providing data on global, free-wall or regional (base and apex) longitudinal strain by speckle tracking echocardiography or studies examining RV function following an exercise event of at least 90 min in duration and recording RVGLS immediately (< 1 h) following endurance exercise.

The exclusion criteria were as follows: (1) participants with a history or evidence of current or chronic cardiovascular, respiratory, or metabolic disease; (2) participants' mean age were under 18 years old; (3) reviews, conferences, abstracts, letters from readers or editorial comments; (4) non-human, non-Chinese and non-English articles; (5) incomplete data.

Data extraction

Information extracted as follows: first author, study country, publication time, study sample size, age, sex, training hours/week, vendor, and measures of global and regional RV strain. Studies were subcategorized as males (M) and females (F). When there were multiple athletic subgroups but only one control population, data were extracted only from the athletic group performing the greatest volume (hours) of dynamic exercise.

Literature quality evaluation

We followed the quality evaluation method Joanna Briggs Institute (JBI) Reviewers Manual to assess the quality and risk of bias in the included studies. We followed PRISMA 2020 guidelines [14, 15].

Statistical analysis

Stata MP 17.0 was used for statistical analysis and continuous variables were analyzed according to weighted mean difference (WMD) and 95% confidence interval (CI). Heterogeneity was estimated by using I-square and Q values; random or fixed effect models were applied when heterogeneity across studies (I^2) was higher or lower than 50%, respectively [16]. Heterogeneous results were subjected to meta regression to explore the source of heterogeneity. Egger's test and funnel plots were used to evaluate publication bias. Sensitivity analysis was performed by removing sources of significant change from results of a single publication to assess the stability of the results. Statistical significance was shown by $p < 0.05$.

Results

Study selection

A total of 973 publications were initially identified of which 20 [6, 8, 9, 11, 17–32], with a total 1186 cases, satisfied all inclusion and exclusion criteria and entered the meta-analysis (Fig. 1), including 8 publications that measured RVGLS, 9 measured RVFWLS, 7 measured regional strain parameters and 8 measured RV GLS following endurance exercise. All eligible studies for the meta-analysis were summarized in Table 1. The included articles had strong relevance and low bias (Figs. 2 and 3) according to the Joanna Briggs Institute (JBI) standard.

Right ventricular systolic function

1. Athlete-control

Meta-analysis results for conventional 2D and TDI echocardiographic parameters showed that TAPSE was greater in endurance athletes than in controls (Table 2).

Eight publications compared RVGLS values between endurance athletes and control groups with a lack of heterogeneity among the studies (I2 = 7.1%, $p = 0.376$). Analysis by fixed effect model found no significant difference among athletes and controls WMD = 0.40, 95% CI (-0.08 ~ 0.89), $p = 0.102$ (in supplementary material). Egger's test and the funnel plot (in supplementary material) showed a symmetrical distribution of GLS values with no publication bias ($p = 0.095$).

RVFWLS values between endurance athletes and the control group showed no heterogeneity among 9 publications (I2 = 0%, $p = 0.449$) and fixed effect model analysis found lower values in the endurance group than the control group (WMD = 0.62, 95% CI (0.28 ~ 0.96)), $p < 0.001$ (Fig. 4). Egger's test and funnel plot (Fig. 4) showed symmetrical distribution of FWLS values with no publication bias ($p = 0.912$).

All 7 articles evaluated RV basal strain values in endurance athletes compared with controls, and with mildly heterogeneous results (I2 = 65.1%, $p = 0.005$), a random effect model found lower basal strain values in the

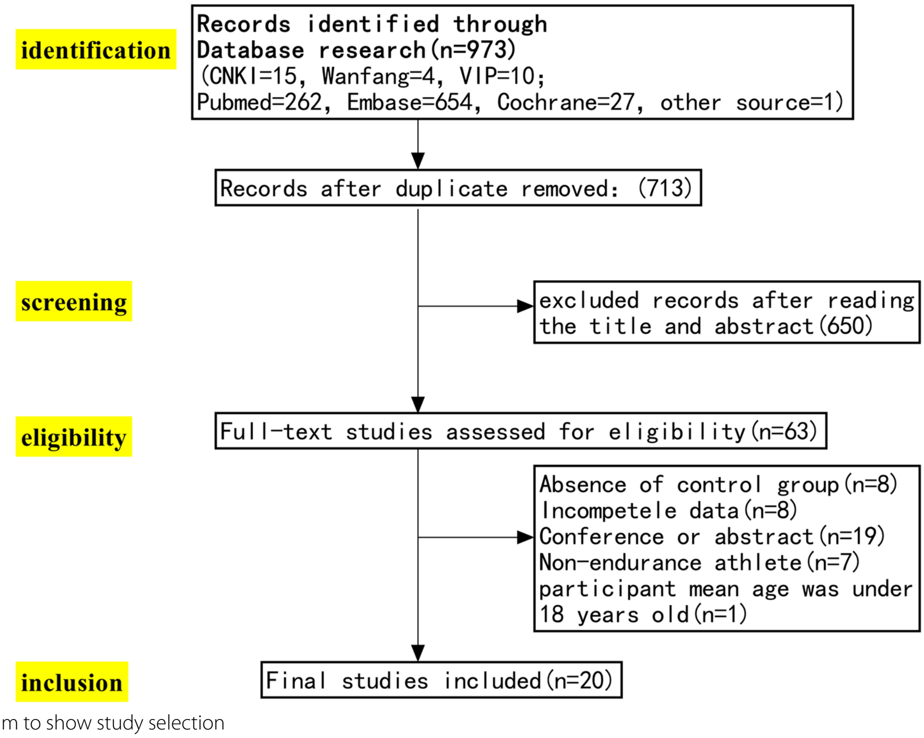


Fig. 1 Flow diagram to show study selection

Table 1 Summary of general information of the studies included

Study(athlete-control)	Country	Sport Type	n athletes	n controls	Age, years Athletes	Age, years Controls	Sex Male (%)	Training hours	Vendor
Zhang 2022*	China	Marathon	33	30	38.7 ± 8.7	38.0 ± 8.5	57.5	NR	Philips
Philipp 2016	Germany	Endurance	26	26	47 ± 8	46 ± 9	100	16.7 ± 4.4	GE
Claeys 2019	Belgium	Endurance	17	12	34 ± 8	37 ± 13	100	14(8–16)	GE
Domenech-Ximenos(M) 2021	Spain	Triathlon	49	42	37 ± 6	34 ± 3	100	≥ 12	GE
Domenech-Ximenos(F) 2021	Spain	Triathlon	44	30	34 ± 6	33 ± 4	0	≥ 12	GE
Rothwell 2018	England	Marathon	40	24	46 ± 8	46 ± 7	20.8	11 ± 4	GE
Garza(M) 2017	Spain	Endurance	20	20	38.0 ± 3.5	36.2 ± 3.5	100	13.5 ± 1.6	GE
Garza(F) 2017	Spain	Endurance	20	20	37.4 ± 6.3	36.9 ± 4.6	0	13.2 ± 1.4	GE
Teske 2009	Holland	Endurance	63	61	27.0 ± 4.7	27.7 ± 5.5	55	24.2 ± 5.7	GE
Utomi 2015	England	Running	19	21	34 ± 5	27 ± 8	100	12	GE
Vitarelli 2013	Italy	Marathon	35	35	28.7 ± 10.7	28.3 ± 11.4	100	> 15	GE
La Gerche 2015	Belgium	Cycling/running	10	7	35 ± 6	34 ± 16	100	11 (6–15)	GE
Missenard 2021	France	Endurance	33	18	47 ± 6	49 ± 1	6.25	9.6 ± 1.7	GE
Pagourelias 2013	Greece	Cycling/running/triathlon	80	26	31.2 ± 10.4	26.6 ± 5.6	100	14.6 ± 5.4	GE
Stewart 2020	United States	Cycling/running/swimming/rowing	30	30	31 ± 10	29 ± 9	100	> 10	GE
Study(pre-post)	**Country**	**Sport Type**	**n athletes**	**n controls**	**Age, years Athletes**	**Age, years Controls**	**Sex Male (%)**	**Training hours**	**Vendor**
Hu 2023	China	Marathon	30	/	38.8 ± 1.2	/	73.3	3.5(3–4)	Philips
Lord 2023	England	Endurance	8	/	40 ± 7	/	100	NR	GE
Banks 2010	Canada	Running/triathlon	18	/	28 ± 1	/	66.7	NR	GE
La Gerche 2012	Belgium	Marathon/endurance cycling/triathlon	40	/	37 ± 8	/	90	16.3 ± 5.1	GE
Oxborough 2011	England	Running	16	/	42 ± 8	/	75	14 ± 4	GE
Cavigli 2021	Italy	Marathon	71	/	47.9 ± 7.8	/	69	6.7 ± 4.4	GE
Garza 2015	Spain	Running	55	/	37.0 ± 6.5	/	100	3.8 ± 1.8	GE

NR *Not* reported, M *Male*, F *Female*

endurance group than control group WMD = 2.94, 95% CI (2.00 ~ 3.88), $p < 0.001$ (Fig. 5). Egger's test and funnel plot (Fig. 5) showed symmetrical distribution of basal strain values with no publication bias ($p = 0.099$).

RV apical strain values between endurance athletes and control group were also compared by 6 publications with high heterogeneity among the studies (I2 = 78.2%, $p < 0.001$). The random effect model showed no statistical difference for apical strain (WMD = -0.79, 95% CI (-1.95, 0.37)), $p = 0.245$ (in supplementary material). Moderate publication bias was seen by Egger's test and funnel plot distribution ($p = 0.049$) (in supplementary material). However, the results of the metatrim method showed that no study cut and filled, and the whole data set did not change.

2. Pre-post

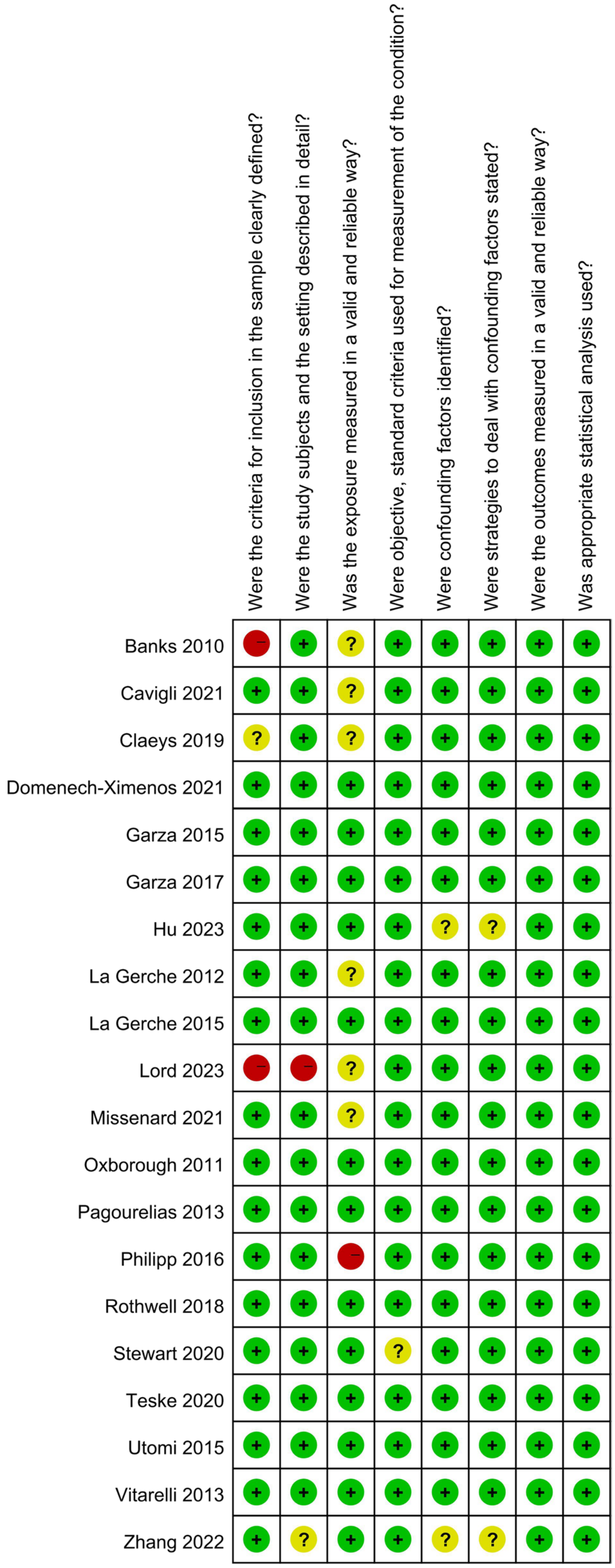
There was significant evidence of high between-study heterogeneity (I2 = 73.5%, $p < 0.001$), so the random effect model showed WMD of RVGLS from pre-exercise to postexercise was 2.51, 95% CI (1.63 ~ 3.40), $p < 0.001$ (Fig. 6) including 8 articles and statistical heterogeneity was observed, showing that RV strain decreased significantly from pre-exercise to postexercise. Egger's test and the funnel plot (Fig. 6) showed above values with no publication bias ($p = 0.272$).

Meta regression

Meta regression and subgroup analysis were applied to explore the source of het-erogeneity. Including sex, age, training hours, and sample size(n) as regression model covariates. The relationship between the source of basal and apical strain heterogeneity with above covariates did not achieve statistical significance (Table 3).

Sensitivity analysis

Sensitivity analysis was conducted by sequential elimination of individual publications. When one papers were excluded, the results changed, proving that the values of RVGLS are unstable. Values for RVFWLS, RV



	Were the criteria for inclusion in the sample clearly defined?	Were the study subjects and the setting described in detail?	Was the exposure measured in a valid and reliable way?	Were objective, standard criteria used for measurement of the condition?	Were confounding factors identified?	Were strategies to deal with confounding factors stated?	Were the outcomes measured in a valid and reliable way?	Was appropriate statistical analysis used?
Banks 2010	−	+	?	+	+	+	+	+
Cavigli 2021	+	+	?	+	+	+	+	+
Claeys 2019	?	+	?	+	+	+	+	+
Domenech-Ximenos 2021	+	+	+	+	+	+	+	+
Garza 2015	+	+	+	+	+	+	+	+
Garza 2017	+	+	+	+	+	+	+	+
Hu 2023	+	+	+	+	?	?	+	+
La Gerche 2012	+	+	?	+	+	+	+	+
La Gerche 2015	+	+	+	+	+	+	+	+
Lord 2023	−	−	?	+	+	+	+	+
Missenard 2021	+	+	?	+	+	+	+	+
Oxborough 2011	+	+	+	+	+	+	+	+
Pagourelias 2013	+	+	+	+	+	+	+	+
Philipp 2016	+	+	−	+	+	+	+	+
Rothwell 2018	+	+	+	+	+	+	+	+
Stewart 2020	+	+	+	?	+	+	+	+
Teske 2020	+	+	+	+	+	+	+	+
Utomi 2015	+	+	+	+	+	+	+	+
Vitarelli 2013	+	+	+	+	+	+	+	+
Zhang 2022	+	?	+	+	?	?	+	+

Fig. 2 Quality assessment per study

basal strain, and RV apical strain did not change significantly after each exclusion, indicating that consolidation effect indicators have a good degree of stability.

Discussion

Our meta-analysis of all studies reporting RV systolic function in endurance athletes using STE technology at rest or pre and post endurance. The main findings are as follows:(i) RV FWLS and RV basal strain were lower at rest in the endurance athletes group compared with the controls; (ii) There were no significant differences in GLS and RV apical strain, between the amateur marathon group and controls; (iii) RV systolic function is reduced following endurance exercise. The use of global and segmental strain analysis would help to identify potential functional changes in the right ventricle while differentiating between normal endurance athletes and non-active controls.

Traditional echocardiographic parameters indicate that a series of changes in right ventricular volume overload and structural remodeling caused by exercise are common and physiological, and although physiological remodeling of the right ventricle occurs with age and cumulative training time, it tends to stabilize after reaching a certain threshold and will not continue to progress [24]. Besides, it is vital that functional adaptation is also considered alongside structural remodeling. Our meta-analysis results for conventional echocardiographic parameters show that the TAPSE of endurance athletes is greater than in athletes compared with controls. TAPSE reflects RV longitudinal displacement and is a quantitative measure of RV systolic function, usually used for patients with pulmonary hypertension [33]. It may be considered as adaptive changes based on changes in the structure and load dependence of the RV. TAPSE is a relatively sensitive indicator and can be used as markers to judge normal physiological adaptation and abnormal pathological changes in the right ventricle of athletes. In contrast to conventional echocardiographic techniques, speckle tracking echocardiography plays an important role in elucidating physiological and pathological myocardial mechanical movement, permitting the assessment of regional deformation and quantitative evaluation of cardiac function. While strain remains a load-dependent measure, its measurement is relatively independent of ventricular morphology and global cardiac motion.

We observed no difference in RV global longitudinal strain, providing evidence that RV function at rest remains within the normal range in endurance athletes regardless of training time, gender and age in line with other studies [23]. The contraction process of the right ventricle is relatively complex. The right ventricular wall is mainly composed of superficial circularly arranged and

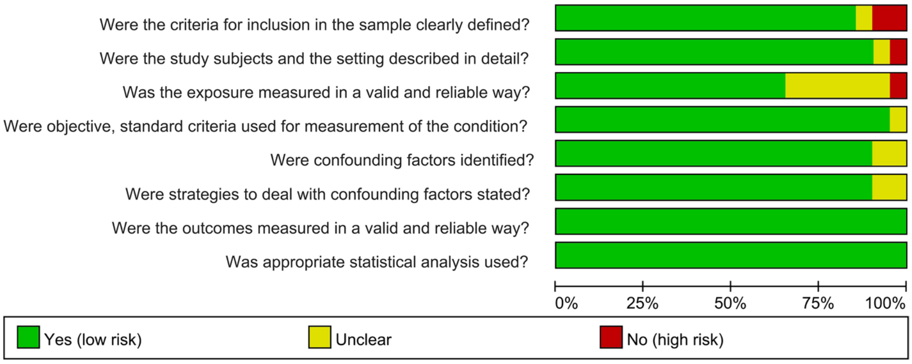


Fig. 3 Summary of quality assessment

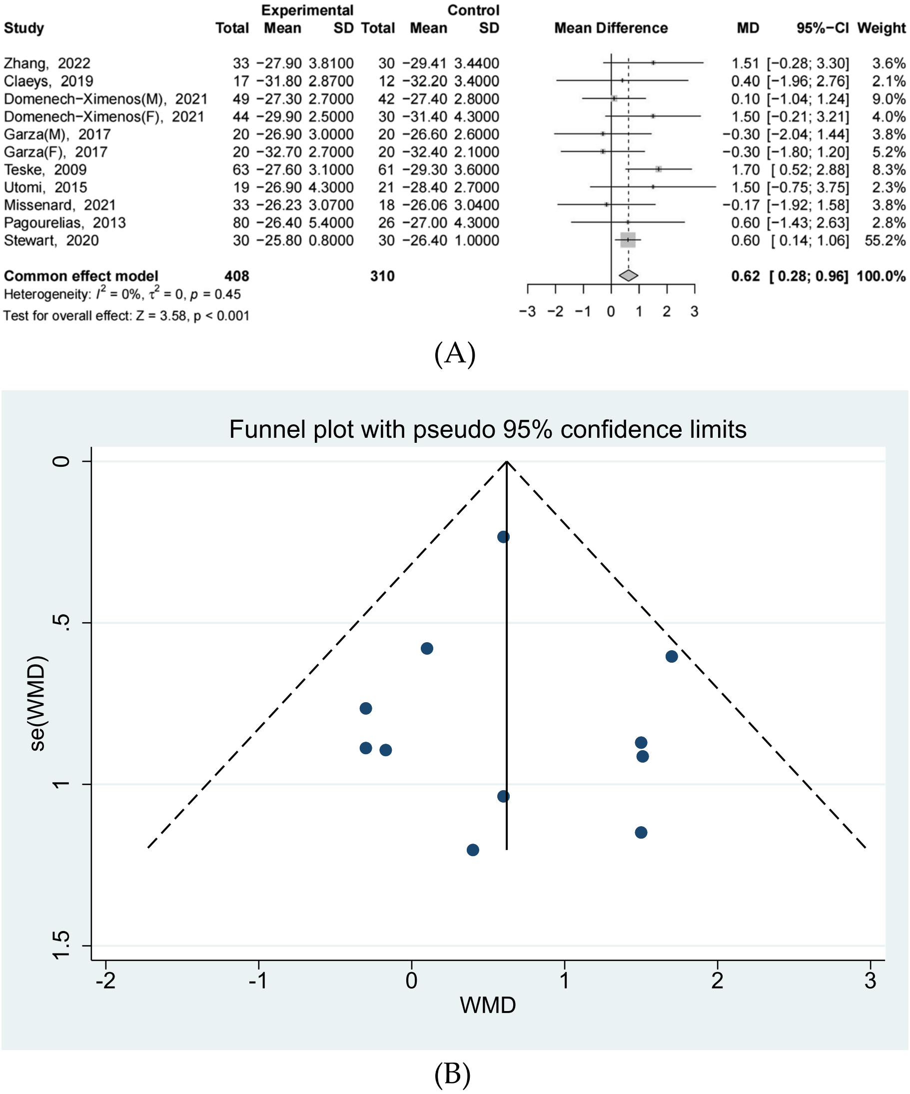
deep longitudinally arranged muscle fibers. Longitudinal fibers determine the contraction movement of the right ventricle from the heart base to the apex and pull the tricuspid valve ring toward the apex. 80% of the right ventricular ejection capacity comes from the contraction of longitudinal muscle fibers [34]. Since speckle tracking technology usually divides the right ventricular wall into six segments, the three segments of the interventricular septum also include the effects of left ventricular contraction during the contraction process. Long-term endurance exercise-induced ventricular eccentric remodeling may not be quantitatively reflected in the overall longitudinal contraction function of the right ventricle, which is the first step of the right ventricular contraction process, and the RV longitudinal strain of athletes is possibly predominated due to the contribution of RV free wall. However, it should not necessarily be implied that preserved RV % global strain at rest also predicts preserved global % strain during exercise. We should contend that RV global strain should be used with caution as an evaluation index of assessing myocardial function, especially at rest.

Our meta-analysis results show that the RV FWLS of endurance athletes is slightly lower than that of the control group. This is inconsistent with the conclusion in some studies that endurance training of athletes does not lead to chronic changes in myocardial function [35, 36]. Under physiological conditions, there is a combination between RV systolic elastance (contractility) and pulmonary arterial elastance that compares ventricular contractility with afterload, called "ventriculoarterial coupling" [37]. Lower RV contractility at rest in athletes may reflect a maintenance of ventricular-arterial coupling, by matching contractility to low afterload. LaGerche et al. [38] demonstrated an enhanced contractile reserve of the RV basal segment upon exercise and suggested that endurance athletes' lower resting values of RV strain may represent physiologic changes rather than subclinical myocardial damage. In this study, athletes' training time was at least 10 h per week for several years. They had a thinner right ventricular wall, which makes them more susceptible to right ventricular dilation caused by endurance exercise. In volume overload states, it has been suggested that the right ventricle preferentially dilates along the free-wall septum axis [39]. Thus, long-term endurance training may lead to sustained volume overload, which may be a mechanism for the decrease in RV FWLS., resulting in subclinical changes in right ventricular systolic function in endurance athletes. In addition, the free wall of the right ventricle does not include the interventricular septal segment related to the left ventricle and is less affected by left ventricular remodeling, making it more specific to the right ventricle. Claeys et al. [19] proposed that RVFWLS during exercise was the most accurate discriminator of RV disease and was better than all other measurements of RV function, so it may be a more sensitive indicator to identify early RV cardiomyopathy.

RV basal and apical strain analysis permits the assessment of regional deformation. The meta-analysis of RV basal and apical strain showed endurance athletes had lower RV basal strain than controls, but no significant difference in apical strain. The mechanism of endurance athlete's reduced basal strain in the right ventricle is not fully understood yet, but it may be related to structural remodeling of the right ventricle caused by endurance exercise, changes in wall stress and load status, or the complexity of myocardial fiber structure [40]. Teske AJ et al. [11] described a decrease in basal strain in the RV of athletes and explained this phenomenon with different curvature changes between the RV apex and base. Long-term endurance exercise affects the basal segment of the right ventricle first, which may be due to different wall stresses in the basal and apical segments of the right ventricle [41]. Due to differences in morphology and local curvature radius, the basal segment of the right ventricle may be more susceptible to the effects of

Table 2 Meta-analysis results for conventional echocardiography parameters

Parameter	Studies (n)	Controls (n)	Athletes (n)	WMD (95% CI)	*P* value	I^2	Eggers test (*P* value)
TAPSE (mm)	7	194	226	1.770(0.412–3.128)	0.011	86.8	0.053
RV S′(cm/s)	9	248	329	0.355(-0.443–1.154)	0.383	86.7	0.503
RVFAC(%)	11	292	378	0.411(-2.080-)	0.747	82.0	0.194



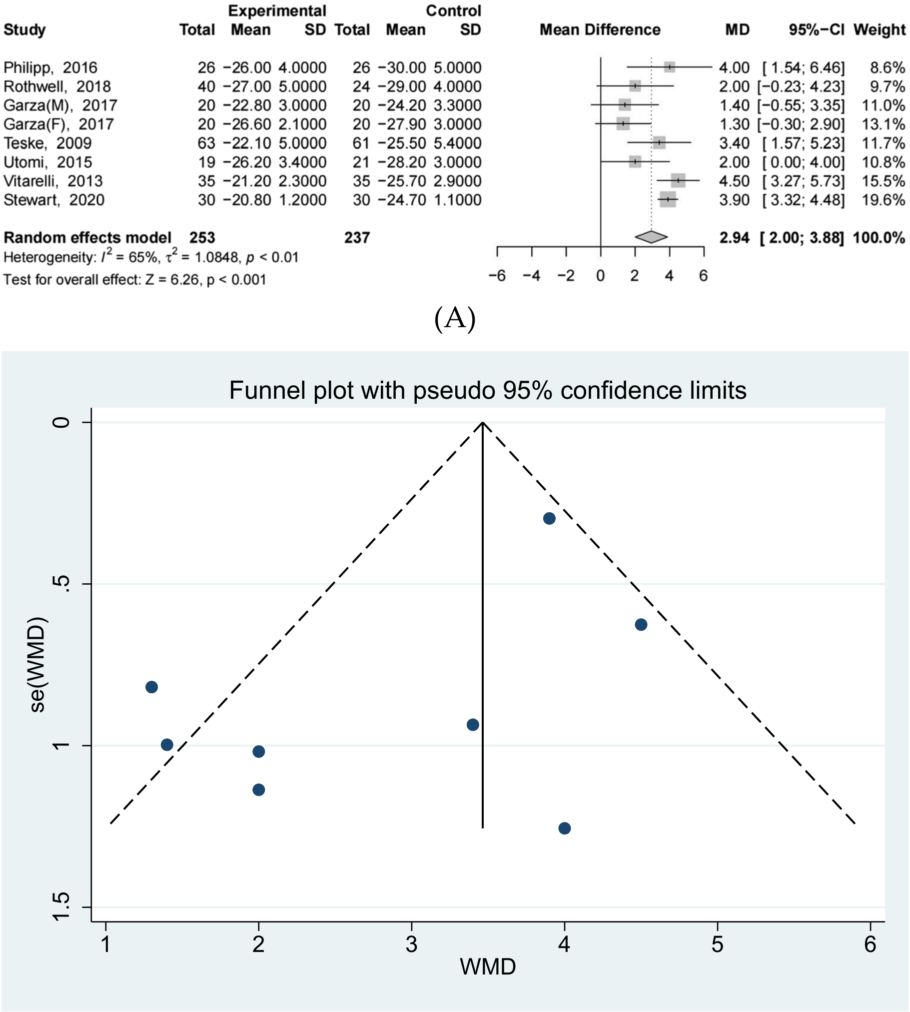
Study	Experimental Total	Experimental Mean	Experimental SD	Control Total	Control Mean	Control SD	MD	95%−CI	Weight
Zhang, 2022	33	−27.90	3.8100	30	−29.41	3.4400	1.51	[−0.28; 3.30]	3.6%
Claeys, 2019	17	−31.80	2.8700	12	−32.20	3.4000	0.40	[−1.96; 2.76]	2.1%
Domenech−Ximenos(M), 2021	49	−27.30	2.7000	42	−27.40	2.8000	0.10	[−1.04; 1.24]	9.0%
Domenech−Ximenos(F), 2021	44	−29.90	2.5000	30	−31.40	4.3000	1.50	[−0.21; 3.21]	4.0%
Garza(M), 2017	20	−26.90	3.0000	20	−26.60	2.6000	−0.30	[−2.04; 1.44]	3.8%
Garza(F), 2017	20	−32.70	2.7000	20	−32.40	2.1000	−0.30	[−1.80; 1.20]	5.2%
Teske, 2009	63	−27.60	3.1000	61	−29.30	3.6000	1.70	[0.52; 2.88]	8.3%
Utomi, 2015	19	−26.90	4.3000	21	−28.40	2.7000	1.50	[−0.75; 3.75]	2.3%
Missenard, 2021	33	−26.23	3.0700	18	−26.06	3.0400	−0.17	[−1.92; 1.58]	3.8%
Pagourelias, 2013	80	−26.40	5.4000	26	−27.00	4.3000	0.60	[−1.43; 2.63]	2.8%
Stewart, 2020	30	−25.80	0.8000	30	−26.40	1.0000	0.60	[0.14; 1.06]	55.2%
Common effect model	**408**			**310**			**0.62**	**[0.28; 0.96]**	**100.0%**

Heterogeneity: $I^2 = 0\%$, $\tau^2 = 0$, $p = 0.45$

Test for overall effect: Z = 3.58, p < 0.001

Fig. 4 **A** FWLS forest plot [Forest plot of weighted mean difference (WMD) of the FWLS comparing athletes and healthy controls]. **B** Funnel plot of FWLS (The symmetry of funnel plot was used to evaluate the publication bias of included studies). M: male; F: female

long-term endurance training-induced volume overload and increased wall stress, leading to earlier dilation or decreased strain than other segments. LaGerche et al. [12] hypothesized that since the volume of the RV basal segment is the largest, only a small degree of deformation is needed to produce the same stroke volume, and the structural remodeling of the right ventricle in athletes, manifested as eccentric hypertrophy, explains why the deformation of the RV in this region may decrease. Our conclusion shows that although the basal strain



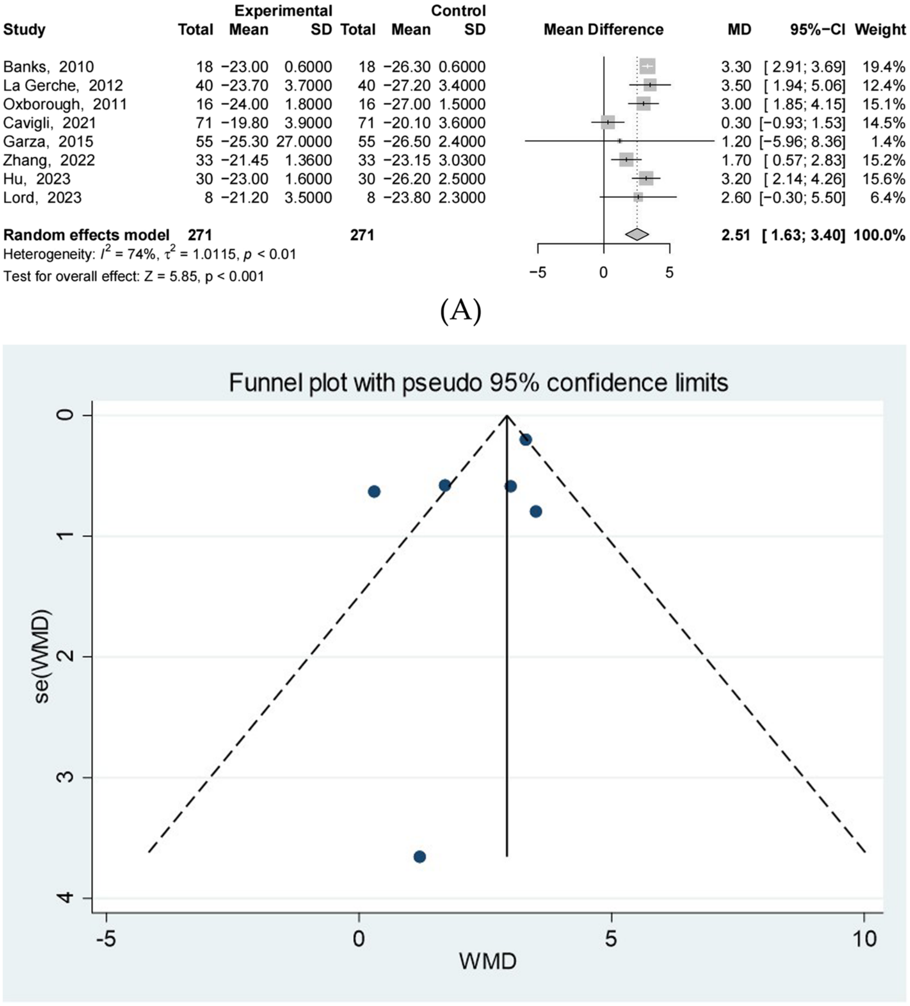
(A)

(B)

Fig. 5 **A** basal strain forest plot [Forest plot of weighted mean difference (WMD) of the basal strain comparing athletes and healthy controls]. **B** Funnel plot of basal strain (The symmetry of funnel plot was used to evaluate the publication bias of included studies). M: male; F: female

of endurance athletes is lower than that of the control group, the value is still within the reference range of basal strain in the right ventricle of ordinary people reported in other studies [42], which can be attributed to physiological adaptations in normal people and there is no substantial functional impairment. In addition, Oxborough et al. [9] found that the changes in RV inflow dimension and diastolic area were smaller in athletes who completed more ultra-marathons, had longer weekly training time and longer running distance. They believed that competition experience and increasing training time may provide some physiological adaptation to protect these athletes from transient changes in RV function caused by increased wall stress. However, it could be recognized that absolute RV physiologic remodeling will reach a threshold, regardless of training longevity.

After analyzing the data of right ventricular global strain before and after endurance exercise, it was found that the global strain of the right ventricle decreased after endurance exercise, indicating that high-intensity endurance exercise has a short-term negative impact on right ventricular function. Although there are a few studies that have reported the segmental strain values of the right ventricle before and after endurance exercise [8, 30, 43], the quantity is small and does not have high analytical value due to varying levels of physical fitness, age, training duration and intensity among endurance athletes. Many studies have shown that the decrease in strain values after endurance exercise is temporary and will return



(A)

(B)

Fig. 6 A Forest plot of weighted mean difference (WMD) comparing right ventricular strain pre-endurance versus post-endurance exercise. **B** Funnel plot of RVGLS from pre-exercise to postexercise (The symmetry of funnel plot was used to evaluate the publication bias of included studies)

Table 3 Strain parameters of meta regression analysis results

Variable	*P*-value(Sex)	*P*-value(Age)	*P*-value(training hours)	*P*-value(n)
TAPSE	0.473	0.380	0.579	0.254
RV basal strain	0.651	0.998	0.821	0.568
RV apical strain	0.324	0.155	0.215	0.161
RVGLS[a]	/	0.558	/	0.102

[a] From pre-exercise to postexercise

to normal within several hours to several days [6, 44, 45]. Garza et al. [30] found that endurance exercise can cause acute injury, and this injury is positively correlated with exercise intensity. A meta-analysis of the acute impact of endurance exercise on RV also supported this conclusion [46]. It found that RVGLS did not significantly change following an endurance event but was significantly decreased following ultra-endurance. Therefore, reporting only the results of overall longitudinal strain after exercise may underestimate the true impact of endurance exercise on some segments of the right ventricle. Another easily overlooked aspect is the fluid and energy intake of athletes during or after endurance events, which would have an impact on results, and more data needs to be collected to make it more comprehensive.

Limitations

This study only included strain parameters from less than 10 studies. The meta regression's result(gender, age, training hours, and sample size) reflected the heterogeneity of the endurance athlete population studied in previous research. We included studies that assessed both males and females within this analysis, and physiological differences between sexes may have influenced the results. However, inclusion of a disproportionately low number of female endurance athletes may interfere with the conclusion. The high degree of heterogeneity across studies for age also should be considered when interpreting the results of this study. Additionally, there is no standardized definition of what constitutes an endurance athlete, both professional and amateur athletes were included in this study, and the different types of sports in athletes may affect the results. Sensitivity analysis showed that the GLS index was unstable, so more evidence is needed to support the conclusion that there is no difference in GLS between endurance athletes and the control group. Since the number of studies included was less than 10, the meta-regression did not find the source of heterogeneity of RV basal and apical strain and GLS before and after exercise. In addition, the change in right ventricular strain during exercise was abandoned due to the small number of studies found, which may ignore individuals with normal right ventricular function at rest and lead to false negative results.

Conclusions

This meta-analysis, based on observational data, shows that no difference in RVGLS and FWLS results in slight damage ($p < 0.05$). The evidence obtained thus far suggests that reporting only global right ventricular strain data may obscure segment-specific adaptation changes, and the use of global and segmental strain analysis may help to identify potential functional changes in the right ventricle while differentiating between normal endurance athletes and patients with organic heart disease.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12872-024-04455-0.

Supplementary Material 1.

Institutional review board statement

Ethical review and approval were waived for this study due to the nature of this meta-analytic study. All the included studies have been approved by their IRBs.

Informed consent statement

Patient consent was waived due to the nature of this meta-analytic study. No identifiable personal information was obtained in the included studies.

Authors' contributions

Conceptualization, C.G., H.Z. and F.G.; methodology, C.G. and H.Z.; software, H.Z.; validation, C.G., H.Z. and C.Y.; formal analysis, C.G. and P.H.; investigation, C.G.; resources, H.Z., F.G.; data curation, C.G., C.Y. and H.M.; writing—original draft preparation, C.G.; writing—review and editing, H.Z.; visualization, Y.M.; supervision, F.G.; project administration, F.G. All authors reviewed the manuscript.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Competing interests

The authors declare no competing interests.

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