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Cardiorespiratory fitness and telomere length: a systematic review

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ABSTRACT

This study aimed to systematically review the association between cardiorespiratory fitness and telomere length (TL). Studies were identified from searches in Cochrane Central, PubMed, Scopus, Sportdiscus, and Web of Science databases through July 2019. Eligibility criteria included: cross-sectional, prospective, and experimental study design; outcomes included TL; results expressed the relationship between cardiorespiratory fitness and TL; studies published in English, Portuguese, or Spanish. A total of 20 articles met the inclusion criteria. Sixteen studies (80%) reported a significant relationship between cardiorespiratory fitness, or training load, and TL. Better cardiorespiratory fitness or a large cardiorespiratory training load are associated with an increase in TL. Although, TL was related to regular moderate-to-vigorous aerobic exercise and cardiorespiratory fitness in older healthy humans, it was not related to cardiorespiratory fitness among young subjects. There seems to be a positive and significant relationship between cardiorespiratory fitness and TL, mainly among middle age and older people, which emphasizes the importance of cardiorespiratory fitness for healthy ageing. Therefore, endurance exercise and better cardiorespiratory fitness may regulate the TL in middle age and older adults, slowing the cellular ageing process.

ARTICLE HISTORY

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KEYWORDS

Aerobic fitness; DNA; exercise; endurance; physical activity; running

Introduction

Telomeres are the region at the end of each strand of deoxyribonucleic acid (DNA), functioning as caps, which maintain genome stability. Telomeres are essential to protect vital information in the DNA and prevent undesired chromosomal rearrangements (Eisenberg, 2011; De Lange, 2009). Telomeres play a vital role in health, as their length is associated with several chronic diseases, such as cardiovascular diseases (Fyhrquist & Saijonmaa, 2012), diabetes (Zhao et al., 2013), psychological disorders (Zhang et al., 2014), and cancer (Ma et al., 2011).

Human cells are constantly copying themselves, and each time a cell copies itself telomeres shorten (Eisenberg, 2011). Therefore, as people age, telomeres are naturally shortened. Telomere length (TL) is associated with cellular ageing and can represent biologic age (Arsenis et al., 2017). With the shortened telomeres, DNA strands eventually become damaged and cell senescence or apoptosis is induced (Eisenberg, 2011; Oeseburg et al., 2010). Even though telomere shortening is a natural ageing process, it can be accelerated by other factors that promote oxidative stress and inflammation (Houben et al., 2008; Wolkowitz et al., 2011). Sedentary behaviour is known to increase the body's oxidative stress. Regular physical activity seems to improve antioxidant activity (Bjork et al., 2012; Gomes et al., 2012) and inflammatory balance (Kasapis & Thompson, 2005; Nimmo et al., 2013).

More substantial than physical activity, is its effects on the organism. Better cardiorespiratory fitness is an outcome of

increased physical activity, which is independently associated with health (Imboden et al., 2018; Lin et al., 2015). Additionally, cardiorespiratory fitness is associated with oxidative stress biomarkers (Shammas, 2011). As oxidative stress can accelerate telomere attrition, and physical activity has been inconstantly related to TL, it is meaningful to investigate the relationship between cardiorespiratory fitness and TL. Some studies have pointed towards a positive relationship (Krauss et al., 2011; LaRocca et al., 2010; Mason et al., 2012), however this evidence was never synthesized or summarized in a review. Thus, the aim of this study was to systematically review the association between cardiorespiratory fitness and TL. Although a previous study has systematically reviewed the relationship between TL and physical activity, concluding that it remains an open question (Mundstock et al., 2015), this is the first study to systematically review the relationship between cardiorespiratory fitness and TL.

Methods

This systematic review was performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines (Moher et al., 2009), and the association of Physical Activity and Academic Performance Protocol for Systematic Reviews and Meta-Analysis (Alvarez-Bueno et al., 2016).

Search strategy

During August 2019, studies were identified by searching, in electronic databases, for peer-reviewed articles published up to July 2019. The search was applied to Cochrane Central, PubMed, Scopus, Sportdiscus, and Web of Science. Additionally, the reference lists of included studies were searched. Articles that assessed the relationship between cardiorespiratory fitness and TL were included in this review. The search was performed using the following combination of terms: fitness OR endurance OR cardiorespiratory OR aerobic AND telomere. Search terms were defined among the research team and were used in each database to identify potential articles with abstracts for review. Two reviewers worked independently and screened titles and abstracts to identify studies that met the inclusion criteria. Duplicate entries were removed. Relevant articles were retrieved for a full read. The same two authors reviewed the full text of potential studies, and decisions to include or exclude studies in the review were made by consensus. Disagreements were solved by consensus and, when necessary, a third reviewer served as a judge.

Inclusion criteria

Source articles published up to July 2019, in peer-reviewed journals, were eligible for inclusion if they presented the relationship between cardiorespiratory fitness and TL. Eligibility criteria included the following: (1) cross-sectional, prospective, and experimental study design (study design criterion); (2) outcomes included TL (outcome measure criterion); (3) cardiorespiratory fitness and TL (relationship criterion); (4) young, adults and older adults (participants criterion); (5) articles published in English, Portuguese, or Spanish (language criterion); (6) articles were excluded if they did not meet inclusion criteria or did not include findings related to the inclusion criteria (exclusion criteria).

Data extraction and harmonization

A data extraction form was developed, based on PRISMA statement (Moher et al., 2009). The following information was extracted from each article: authors' name and year of publication, study design, sample characteristics (number of participants, sex, age), country, tissue or fluid and method of TL evaluation, methods of cardiorespiratory fitness evaluation or training load, study quality, and main results. The extraction was carried out by one author, and coding was verified by other two authors.

Study quality and risk of bias

The methodological quality of the studies was assessed by two independent researchers using the Physiotherapy Evidence Database (PEDro) scale. Agreement between reviewers was assessed using kappa statistics ($\kappa = 0.96$) for full-text screening and rating of relevance and risk of bias. In the disagreement about the risk of bias, a third reviewer checked the data and made the final decision. A data extraction form from Cochrane Consumers and Communication Review Group's data extraction template (Group CCCR, 2016) was modified to this review's study inclusion

requirements and tested on ten randomly selected studies (pilot test). The quality of the included studies was assessed with a total score ranging from zero to 11.

Synthesis of results

The review analysed the relationship between cardiorespiratory fitness and TL. Significant heterogeneity existed within study for several study parameters. These parameters included: the participant characteristics, tissue or fluid used to analyse telomeres, method of TL evaluation, and methods of cardiorespiratory fitness evaluation. The details for each study, including design, measures, participant characteristics and sample size, and study quality and results are presented in a consistent manner.

Results

Search results

Ninety-seven articles were yielded from five databases. Three additional studies, that were found as references in the retrieved articles, were also included. After excluding 55 duplicated articles, 42 were selected for abstract reading. Of those, nine articles were excluded at the abstract level. The remaining 33 articles were read in full. Among these, three were excluded because they utilized animal samples, four were not empirical studies, and six did not report the association between cardiorespiratory fitness and TL. Therefore, 20 articles were included in the systematic review (Figure 1).

Table 1 summarizes the study's characteristics. The review of 20 studies accounts for 9705 subjects, and research was predominantly from the United States of America (7 studies), and Europe (6 studies). The rest of the studies were from Australia (3 studies), Brazil (2 studies), South Africa (1 study), and South Korea (1 study). Among the studies, 13 were cross-sectional, observational and comparative studies, four were randomized control trials (RCT), two were cross-sectional observational, and one was cross-sectional and prospective. The most frequent method to assess TL was polymerase chain reaction (PCR) (12/20), followed by Southern blot (3/20), flow-fluorescence in situ hybridization (FISH) (2/20), terminal restriction fragment (TRF) (1/20), fluorescein isothiocyanate (FITC) (1/20), and repeat copy number/single-gene copy number (1/20). The most frequent method used to evaluate cardiorespiratory fitness or training load was through a maximal graded treadmill or cycle ergometer test to estimate VO₂ max consumption. However, some studies did not assess objectively the cardiorespiratory fitness level because the subjects were experienced endurance athletes (e.g. ultramarathon runners, runners who run ≥ 40 km/week).

Main findings

Sixteen studies (80%) reported a significant relationship between cardiorespiratory fitness, or training load, and TL (Borghini et al., 2015; Denham et al., 2013, 2016; Diman et al., 2016; Edwards & Loprinzi, 2017; Krauss et al., 2011; LaRocca et al., 2010; Mason et al., 2012; Østhus et al., 2012; Puterman et al., 2018; Silva et al., 2016; Soares-Miranda et al., 2015; Sousa et al., 2019; C Werner et al., 2009; CM Werner et al., 2019; Williams et

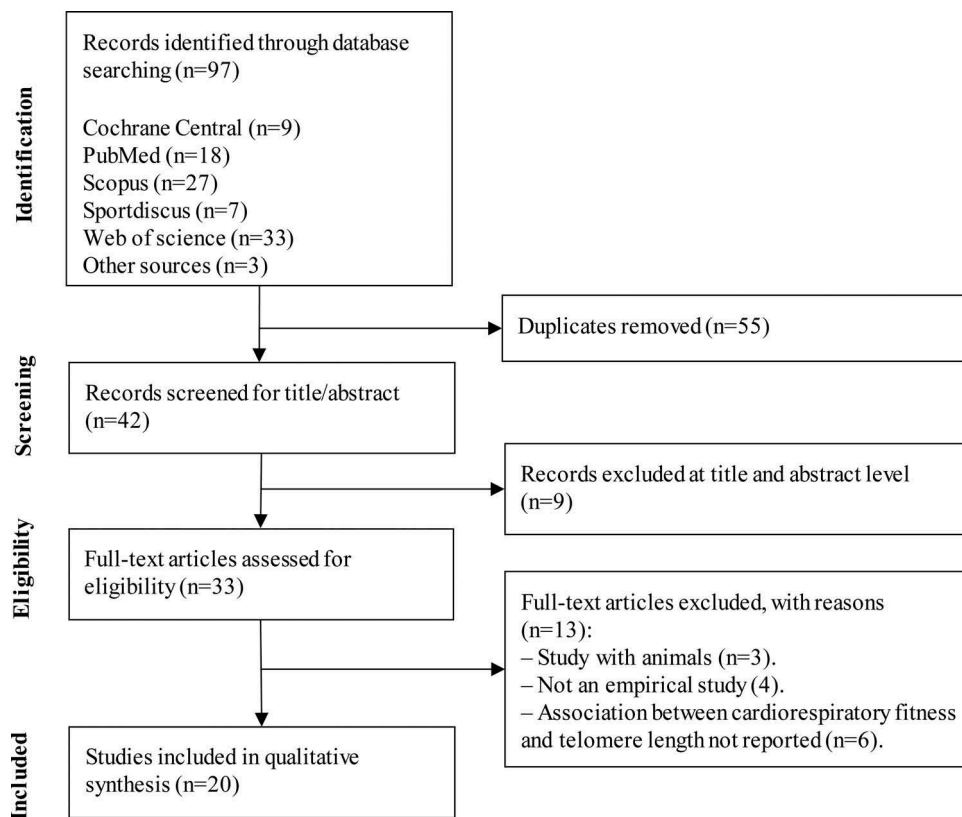


Figure 1. Flow diagram of study selection.

al., 2017). Better cardiorespiratory fitness or a large cardiorespiratory training load are associated with an increase in TL. Among those studies, it was observed that TL is related to regular moderate-to-vigorous aerobic exercise and cardiorespiratory fitness in older healthy humans, but it is not related to cardiorespiratory fitness among young subjects (LaRocca et al., 2010; Østhus et al., 2012). In one RCT study (Mason et al., 2012), at baseline, TL was inversely associated with age and positively associated with VO₂max. However, compared to controls, there were no significant changes in TL over 12-months in intervention groups.

Three cross-sectional comparative studies (Denham, 2017; Mathur et al., 2013; Rae et al., 2010), and one RCT study (Shin et al., 2008) did not find any statistically significant association between cardiorespiratory fitness and TL. Yet, one of those studies (Rae et al., 2010) showed that the telomere terminal restriction fragment length of the athletes who used to run ≥ 40 km/week was negatively correlated to their years of distance running and the time spent training.

Discussion

The current review summarizes studies published up to July 2019 that meet the defined criteria. Twenty studies that used different study designs were systematically reviewed to address the relationship between cardiorespiratory fitness and TL. In general, it was found that TL was better preserved in endurance-trained people and among those with better cardiorespiratory fitness. However, in four studies the TL was not associated with endurance exercise and fitness parameters such as VO₂max. Thus, the

evidence suggests that cardiorespiratory fitness is an important outcome of the physical activity that might be important to preserve TL, but it is still an open question that needs more research in order to be clarified.

In most studies, middle age or older habitual runners, and people with better cardiorespiratory fitness, had longer telomeres than less-trained individuals (LaRocca et al., 2010; Sousa et al., 2019). In one study with young adults and middle age adults, it was observed that middle age runners had longer telomeres than age-matched controls (Sousa et al., 2019). However, the untrained middle age group had shorter telomeres than young untrained, and there was not differences between young untrained and middle age runners. It seems that cardiorespiratory fitness is more important for TL preservation among middle age and older adults than among young adults (LaRocca et al., 2010). In fact, TL and its attrition over time is variable among people, but it is relatively stable from childhood to adulthood (Oeseburg et al., 2010). This can explain the inconsistent results observed among young adults (LaRocca et al., 2010; Østhus et al., 2012; Sousa et al., 2019). Perhaps, TL in young adults have not yet experience attrition, but will be affected by the reduction of telomerase activity associated with sedentary lifestyle (Arsenis et al., 2017). The positive association of TL and active lifestyle indicated that it is a biomarker of healthy ageing (Njajou et al., 2009). Nonetheless, even among young adults some studies have shown that cardiorespiratory fitness can also be important in preserving TL (Borghini et al., 2015; Denham et al., 2013, 2016; Edwards & Loprinzi, 2017; C Werner et al., 2009; Williams et al., 2017).

Although cardiorespiratory fitness seems to be important to resist telomere attrition and attenuate biological ageing, it has

Table 1. Characteristics of the studies, and main results.

Source	Study design, sample characteristics (n, sex, age), country	Tissue or fluid; method of evaluation of telomeres	Evaluation of cardiorespiratory fitness or training load	Study quality*	Main results
Borghini et al., 2015	Cross-sectional, observational, comparative study. 62 (20 endurance athletes, 42 sedentary control), 49 men and 13 women. Age: endurance athletes 45.4 ± 9.2 , sedentary controls 45.9 ± 9.5 . Italy.	Saliva; PCR/TS ratio	Endurance athletes were experienced runners with an average training distance of 59.4 km per week.	6	(+) Chronic endurance training may provide protective effects on TL attenuating biological ageing. However, acute extreme exposures are linked to detrimental effects with increased TL attrition.
Denham et al., 2013	Cross-sectional, observational, comparative study. 123 men (67 ultramarathon athletes, 56 sedentary controls). Age: ultramarathon athletes 43.6 ± 9.2 , sedentary controls 42.8 ± 9.2 . Australia.	Peripheral whole-blood; PCR/TS ratio	Ultramarathon runners average training distance of 40–100 km per week and had trained for a minimum of two years.	6	(+) The ultramarathon runners had 11% longer telomeres than controls in age-adjusted analysis. The difference remained significant after adjustment for cardiovascular risk factors. The magnitude of this association translates into 16.3 ± 0.3 years difference in biological age.
Denham et al., 2016	Cross-sectional, observational, comparative study. 122 (61 endurance athletes, 61 recreationally active controls), 93 men, 29 women. Age: endurance athletes 33.7 ± 11 , recreationally active controls 28.7 ± 10.6 . Australia.	Blood leukocytes; PCR/TS ratio	CRF was assessed through a maximal graded treadmill or cycle ergometer test via pulmonary analysis.	6	(+) Endurance athletes have preserved leukocyte telomeres length. The longer leukocyte telomeres appear to be associated with lower resting heart rate and superior VO2 max.
Denham et al., 2017	Cross-sectional, observational, comparative study. 84 (44 endurance athletes, 40 recreationally active controls), 63 men, 21 women. Age: endurance athletes 32.1 ± 9.9 , recreationally active controls 29.7 ± 9.9 . Australia.	PBMC; PCR/TS ratio	CRF was assessed through a maximal graded treadmill or cycle ergometer test via pulmonary analysis.	6	(±) PBMC TL is not associated with endurance exercise and exercise parameters such as VO2max.
Diman et al., 2016	Cross-sectional, observational study. 10 healthy and moderately active men. Age: 20 ± 0.6 . Belgium.	Muscle; PCR/TS ratio	Maximal incremental exercise test performed on a cycle ergometer.	6	(+) Cycling endurance exercise increased telomeric repeat-containing RNA levels in skeletal muscle biopsies. This data support the idea that exercise might protect against ageing.
Edwards & Loprinzi, 2017	Cross-sectional, observational, comparative study. 1868 participants; 949 men, 919 women. Age: 33.7 (range 20–49) years. United States of America.	Whole blood; PCR/TS ratio	Treadmill-based cardiorespiratory fitness.	7	(+) Better CRF was associated with higher TL. CRF may be important in preserving TL.
Krauss et al., 2011	Cross-sectional, observational, comparative study. 944 participants (229 low PA, 334 moderate PA, 381 high PA), 786 men, 158 women. Age: low PA 71 ± 11 , moderate PA 68 ± 10 , high PA 63 ± 10 . United States of America.	qPCR/TS ratio	Treadmill-based cardiorespiratory fitness.	5	(+) It was found a strong association between physical fitness and telomere length in a population of patients with stable coronary heart disease.
LaRocca et al. 2010	Cross-sectional, observational, comparative study. 57 (15 young and 15 older sedentary, 10 young and 17 habitually exercising), 34 men, 23 women. Age: young sedentary 23 ± 1 , young exercising 21 ± 1 , older sedentary 65 ± 1 , 62 ± 2 older exercising. United States of America.	Blood leukocytes; Southern blot.	Treadmill-based exercise used as a measure of maximal aerobic exercise capacity.	4	(+) TL is related to regular vigorous aerobic exercise and cardiorespiratory fitness in older healthy humans. TL is not related to cardiorespiratory exercise among young subjects.
Mason et al., 2013	RCT (12-month). The exercise intervention goal was 45 min of moderate-to-vigorous (≥ 4 METs) intensity exercise at a target heart rate of 70–85%, 5 days/week. 439 overweight or obese women (dietary weight control 118, aerobic exercise 117, diet+exercise 117, control 87). Age range 50–75 years. United States of America.	Blood leukocytes; qPCR	Maximal graded treadmill test.	8	(+) At baseline, leukocyte TL was inversely associated with age and positively associated with VO2max. (±) Compared to controls, there were no significant changes in leukocyte TL over 12-months in intervention groups.
Mathur et al., 2013	Cross-sectional, observational, comparative study. 32 (15 athletes, 17 sedentary), 19 men, 13 women. Age: athletes 54 ± 4 , sedentary 55 ± 5 . United States of America.	Blood lymphocyte; FISH.	Treadmill-based cardiorespiratory fitness.	4	(±) There was no association between VO2 max and peripheral blood lymphocyte and granulocyte telomere length.
Østhus et al., 2012	Cross-sectional, observational, comparative study. 20 men (10 young adults, 10 old), 5 out of 10 young adults and 5 out of 10 older were endurance athletes. Age: young athletes 24.4 ± 0.6 , young non-athletes 23.6 ± 2.7 , old athletes 69.2 ± 2.9 , old non-athletes 69.8 ± 4.4 . Norway	Muscle; repeat copy number/single-gene copy number	Treadmill test and a portable mixing chamber gas-analyser.	5	(+) Overall, there was a positive association between TS ratio and VO2max. It was found that TL was better preserved in older athletes than the same age group non-athletes. In young people, it was not found an association between VO2max TL.
Puteman et al., 2018	RCT (24-weeks of MVPA, 30 min/week 4 to 5 times). 68 (34 cardiorespiratory exercise, 34 control), 13 men, 55 women. Age: cardiorespiratory exercise 59.3 ± 5.7 , control 63.3 ± 6.4 . United States of America	Whole blood; qPCR/TS ratio	Cardiopulmonary exercise test at maximal capacity.	10	(+) It was observed that TL were significantly longer after 24-weeks of cardiorespiratory exercise training in previously inactive, highly stressed older adults.

(Continued)

Table 1. (Continued).

Source	Study design, sample characteristics (n, sex, age), country	Tissue or fluid; method of evaluation of telomeres	Evaluation of cardiorespiratory fitness or training load	Study quality*	Main results
Rae et al., 2010	Cross-sectional, observational, comparative study. 37 (18 healthy runners, 19 sedentary), 23 men, 14 women. Age: runners 42.4 ± 6.9, untrained 38.7 ± 9.5. South Africa	Muscle; TRF	Runners run ≥ 40 km/week in training for ≥ 7 years and often participated in long-distance races. Sedentary had done <2 sessions of exercise/week and had not participated in competitive sports. Maximal graded treadmill test.	4	(±) Although exposure exercise may increase the demand for regeneration of muscle, the replicative history of the muscle of runners was similar to that of sedentary individuals.
Shin et al., 2008	RCT (6-month training, 3 days/week. Session consisted of 10 min of warming up, 45 min of treadmill walking/running at 60% of VO2 R). 16 women (8 experimental group, 8 control group). Age: 46.8 ± 6.4 years. South Korea.	Blood leukocytes; Southern blot		4	(±) Results showed that, after the acute exercise test in both before and after 6-month cardiorespiratory exercise training.
Silva et al., 2016	Cross-sectional, observational, comparative study. 61 (15 untrained, 16 moderately trained, 15 intensely trained). Moderately trained participated sport activities or run ≤ 6 km 2 to 3 times/week; intensely trained engaged ≥ 5 days/week in PA (>50 km/week). Intensely trained had participated in regular training for at least 5 years. Age: untrained 70, moderately trained 69, intensely trained 73. Brazil.	PBMC; FITC fluorescence	Treadmill VO2 max consumption.	6	(+) Moderate and intense cardiorespiratory exercises attenuated some of the effects of ageing on TL.
Soares-Miranda et al., 2015	Cross-sectional and prospective. 582 participants, 211 men, 371 women. Age: 73 ± 5. United States of America.	Peripheral leukocytes; Southern blot	Walk test, seconds for every 15 ft (4.572 metres), and Chair Stand Test.	9	(+) From cross-sectional analyses, greater walking distance and chair test performance are associated with longer TL. In prospective analyses, changes in PA and PF are associated with differences in changes in TL.
Sousa et al., 2018	Cross-sectional, observational, comparative study. 38 (11 young untrained, 17 middle age untrained, 10 middle age runners). Age: young untrained 21.8 ± 4, middle age untrained 46.6 ± 7.1, middle age runners 51.6 ± 5.2. Brazil.	PBMC; qPCR/TS ratio	Middle age runners had ≥ 15 years of competitive practice in endurance races (10 km to marathon), and averaged 7.1 ± 4.1 competitions per year.	8	(+) Middle age runners have longer telomeres than age-matched controls. The untrained middle age group had shorter telomeres than young runners. There was not differences between young untrained and middle age runners.
Werner et al., 2009	Cross-sectional, observational, comparative study. 104 (32 professional young middle and long-distance runners, 25 middle-aged marathon runners and triathletes, 26 young control subjects, 21 middle-aged control subjects), 73 men, 31 women. Age: professional young middle and long-distance runners 20.4 ± 0.6, 25 middle-aged marathon runners and triathletes 51.1 ± 1.6, 26 young control 21.8 ± 0.5, 21 middle-aged control 50.9 ± 1.6.	Blood leukocytes; FISH	Electrocardiogram stress test.	5	(+) Long-term continuous cardiorespiratory exercise leads to an attenuation of telomere erosion in middle-aged athletes.
Werner et al., 2018	RCT. 124 (35 control group, 26 aerobic endurance training, 29 interval training, 34 resistance training), 45 men, 79 women. Age: control group 50.2 ± 7.4, aerobic endurance 49.5 ± 7.0, interval 48.4 ± 6.5, and resistance 48.1 ± 7.5). Germany.	PBMC; PCR/TS ratio	Bicycle spirometry.	8	(+) Endurance training and interval training, but not resistance training, increased telomerase activity and TL.
Williams et al., 2017	Cross-sectional observational study. 4952 participants, 2552 men, 2732 women. Age: 31.2 ± 0.3. Finland.	Blood leukocytes; qPCR/TS ratio	4-minute step test	7	(+) Longer TL was associated with higher cardiorespiratory fitness in models adjusted for age, sex, body mass index, socioeconomic position, diet, smoking, alcohol consumption, physical activity level, and C-reactive protein.

Abbreviations: CRF, cardiorespiratory fitness; FITC, fluorescein isothiocyanate; FISH, flow-fluorescence in situ hybridization; METs, metabolic equivalents; MVPA, moderate-to-vigorous physical activity; PA, physical activity; PBMC, peripheral blood mononuclear cells; PCR, polymerase chain reaction; qPCR, quantitative-polymerase chain reaction; RCT, randomized control trial; TL, telomere length; TRF, terminal restriction fragment; TS, telomere subunit; VO2 R, VO reserve (difference between maximal VO2 and resting VO2).

* According to Physiotherapy Evidence Database (PEDro) scale.

been reported that there is an inverse U curve associated to an increase in physical activity (Ludlow et al., 2008) and cardiorespiratory exercise (Borghini et al., 2015; Østhus et al., 2012). Time spent sedentary and high intensity activities are associated with shorter telomeres, while on the other hand, moderate and vigorous activities are associated with longer telomeres (Borghini et al., 2015; Ludlow et al., 2008; Østhus et al., 2012; Silva et al., 2016). Acute exposure to extreme activity could shorten telomeres because of excessive reactive oxygen species production (Saretzki & Von Zglinicki, 2002). Extreme exercise is responsible for oxidative stress (Bjork et al., 2012) which is known to induce persistent telomeric DNA damage (Coluzzi et al., 2014). Telomere transcription is activated by NRF1 antioxidant factor. Thus, it can be speculated that telomeric repeat-containing RNA up-regulation might be part of the antioxidant reaction that muscles set up to counteract exercise-induced reactive oxygen species (Powers et al., 1999).

The potential molecular mechanisms underlying the relationship between cardiorespiratory fitness and TL are unclear. However, there are several potential explanations (Arsenis et al., 2017). It has been proposed that regular physical activity and increasing cardiorespiratory fitness lead to an improvement of REDOX balance and the hindering of inflammatory activity (Gomes et al., 2012). The improvement in the antioxidant response increases DNA-repairing enzymes (Radak et al., 2003), and naturally decreases the production of reactive oxygen species (Bjork et al., 2012). Furthermore, acute exercise sessions temporarily increase the inflammatory process (Liburt et al., 2010). The effect of the inflammatory process is compensated by regular exercise practice that increases an anti-inflammatory response (Kasapis & Thompson, 2005). The antioxidant response to cardiorespiratory exercise, and the anti-inflammatory reaction, leads to the hormones processed in response to low and high doses of stressors (Kendig et al., 2010; Ristow & Zarse, 2010). These potential mechanisms are in accordance with the observed U curve found in some studies (Borghini et al., 2015; Ludlow et al., 2008). Furthermore, cardiorespiratory exercise is positively related to: activation of telomerase (Kadi & Ponsot, 2010), improved body composition, and a decrease in low-density lipoproteins (Sirabella et al., 2013). All of which are important to preserve TL through the modulation of telomerase dynamics (Kadi & Ponsot, 2010; Ludlow et al., 2008).

Some study limitations have to be addressed. First, the differences in sample size, tissue sources, methods of evaluation of telomeres and cardiorespiratory fitness may have weakened the evidence. Second, the wide variety among study methodologies precludes the possibility of performing a meta-analysis. Third, in spite of the fact that studies were assessed according to their methodological quality, they were not weighted or ranked. As a result, findings from studies with a weaker methodological quality and smaller sample size were given no less importance than findings from others with strong research designs and larger sample sizes.

Conclusion

This review suggests a positive and significant relationship between cardiorespiratory fitness and TL, mainly among middle age and older people. The positive association between

cardiorespiratory fitness and TL emphasizes the importance of cardiorespiratory fitness for healthy ageing. Endurance exercise and better cardiorespiratory fitness may regulate the TL in middle age and older adults, slowing the cellular ageing process. Large-scale longitudinal studies are necessary to better assess the role of long-term cardiorespiratory fitness on TL with ageing.

Disclosure statement

The authors report no conflict of interest.

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