Resistance Training for People with COVID-19

Subjects: Health Policy & Services

Contributor: Paulo Gentil , Claudio Andre Barbosa de Lira , Carlos Alexandre Vieira , Rodrigo Ramirez-Campillo , Amir Hossein Haghighi , Filipe Manuel Clemente , Daniel Souza

Among different physical exercise models that might help to prevent and treat COVID-19-related conditions, resistance training (RT) might be particularly relevant. Among its benefits, RT can be adapted to be performed in many different situations, even with limited space and equipment, and is easily adapted to an individual's characteristics and health status.

human physical conditioning | resistance training | coronavirus | muscle strength

1. Introduction

In December of 2019, there was an outbreak of a severe acute respiratory syndrome caused by a new coronavirus (SARS-CoV-2). The virus was first noticed in China and rapidly spread across the country and then across the world [1]. As a consequence, many authorities imposed extreme measures such as quarantines, social distancing, and isolation [2]. Measures included banning sports competition and closing exercise facilities, such as health clubs, gyms, and sport courts [3][4]. These restrictions were accompanied by a reduction in mobility due to public transportation and gathering restrictions, working from home adoption, and school closures. These measures had a negative impact on physical activity levels [5] and decreased the involvement with muscle strengthening exercises [6], which might induce muscle atrophy, loss of muscle strength, and reductions in neuro and mechanical abilities [7][8].

Even when exercise facilities were reopened, many regulations were sustained, such as social distancing, limited gathering, the use of protective masks, and hygiene measures [9][10], which, along with the fear of contamination, might preclude regular exercise performance. Therefore, it is important to propose solutions to stimulate physical activity performance, especially considering that physical inactivity [11][12][13][14][15] and low physical capacity [16][17][18] are associated with worse outcomes and an increased mortality risk in cases of infection [19][20][21].

Moreover, although COVID-19 is commonly associated with the respiratory system, it is a multisystem disease [22]. Coronaviruses may also induce neurological damage by invading the central nervous system and result in severe muscle pain [23] and loss of muscle strength [24]. Although COVID-19 has relevant morbidity for up to 6 months [25], COVID-19 survivors might develop psychological, physical and cognitive impairments that require rehabilitation and medical care for more than 12 months [26][27]. Among the secondary consequences of the disease and its treatment, physical function is unlikely to recover to normal values spontaneously, even under nutritional and physical exercise counselling [28]. Therefore, specific prescriptions are needed.

Considering physical exercise models that might help to prevent and treat the different consequences of COVID-19, resistance training (RT) might be particularly relevant. RT has been consistently used to increase muscle mass and strength in many different populations, being considered an essential part of a physical exercise program aiming to improve or restore physical functioning [29][30][31]. Its benefits, largely mediated by strength gains, culminate in reductions in mortality rates in different populations [32][33][34][35][36].

2. Before: Considerations for Preventing COVID-19 Complications

Although it is not possible to attribute a direct cause–effect relationship between RT practice and the mortality risk during the COVID-19 pandemic, current evidence suggests that it might be important to perform RT to improve general health and promote a better prognosis in cases of contamination [11][12][13][14][15][16][17][18][37]. Physical inactivity [11][12][13][14][15] and low muscle strength have been associated with an increased risk of hospitalization and death [16][17][18][37]. The importance of muscle strength should not be underestimated, since it may explain the protective effect of physical activity against COVID-19 hospitalization [17].

Moreover, RT can modulate important risk factors associated with increased morbidity and mortality due to COVID-19, such as high blood glucose, arterial hypertension, obesity, and dyslipidemia [38][39][40][41][42]. In this regard, previous evidence shows that RT can help to control blood pressure [43][44], blood glucose [45], body weight [46], and blood lipids [47]; therefore, it can mitigate complications in cases of contamination.

Another possible benefit of RT is its impact on the immune system. Physical exercise has been consistently shown to modulate immune function [48][49][50][51]. Higher levels of physical activity [52][53][54] and fitness [54] decrease the risk of respiratory symptoms and illness. In this regard, people who carry out strength and power activities [55][56][57][58] usually have a better immunological profile than people who perform long-duration aerobic activities [59], which might be a positive point for RT [60][61]. Strategies for RT prescription for improving or maintaining immune function involve using a low exercise volume (4–6 exercises, with 1–2 sets per exercise), avoiding metabolic stress (perform ≤ 6 repetitions and ≥2 min of rest between sets and exercises) and preferring exercising during the afternoon/evening [60].

If one decides to avoid exercise facilities, RT can be adapted to be performed in many different situations, even with limited space and equipment, and it can easily be adapted to an individual's characteristics and health status [61]. For example, previous studies have shown that bodyweight exercises [62][63][64], stationary bike training [65], plyometric training [66], elastic band training [67][68][69], and even exercises with no external load [70][71][72] promote similar responses to traditional RT. These exercises might be performed as basic multi-joint exercises (i.e., squats, pushups, pullups, rows, etc.) as this has been shown to be sufficient to promote gains in muscle strength and size in most muscles involved [73][74][75][76][77]; the addition of isolated exercises, in general, does not seem to bring benefits [76][78][79]. This allows the possibility to exercise at parks, outdoors, and even at home, and still obtain relevant results [80][81].

3. During: Resistance Training for People with COVID-19

COVID-19 involves an inflammatory response that affects different systems, including the neuromuscular system [82][83][84]. Its effects on muscle strength can be detected even in the absence of symptoms, with a strength loss of as much as 30% in 2 weeks of asymptomatic contamination [24]. COVID-19 patients under intensive care can lose 30% of the rectus femoris muscle cross-sectional area in the first 10 days [83], and 44% of them still have severely limited function for up to one month after weaning [85].

Previous studies have shown that reduced muscle strength is associated with physical inactivity in pulmonary patients [86] and is an important predictor of morbidity and mortality independent of the degree of respiratory limitation [87]. In agreement with this, muscle strength and mass are predictors of length of stay in patients with moderate to severe COVID-19 [88]. Consequently, it seems important to adopt strategies to maintain or increase muscle strength for all, from asymptomatic patients to those under intensive care, since exercise training during hospitalization due to acute respiratory conditions seems to be well tolerated and have infrequent adverse events [89][90][91]. In line with this, previous studies have suggested that rehabilitation programs starting within 30 days seem to bring the most benefits, as early exercise prevents neuromuscular complications; improves functional status in critical illness; and is considered effective, safe, and feasible [27][92].

In this regard, RT has been shown to promote benefits during pulmonary rehabilitation due to improvement in functional capacity, either performed alone or combined with aerobic training [93][94][95]. RT can be successfully performed as a stand-alone exercise strategy without increasing adverse events in chronic obstructive pulmonary disease patients under pulmonary rehabilitation [95].

COVID-19 pathogenesis involves a delayed anti-viral response, which is followed by an excessive proinflammatory state [96]. The systemic inflammation is associated with disease severity, as shown by the higher serum levels of proinflammatory cytokine in the most affected patients [97]. This grants importance to interventions with anti-inflammatory properties, which is the case for RT [98][99][100].

4. After: Resistance Training after COVID-19 Treatment

Respiratory diseases are associated with impairments in muscle function and the loss of lean body mass [101][102]. Survivors of severe acute respiratory diseases (SARS) might present a functional disability for as long as one year after discharge [103][104], and muscle wasting and weakness are frequent extrapulmonary conditions [104]. The manifestations include limb muscle weakness, muscle atrophy, and impairments in deep tendon reflexes [105].

COVID-19 patients show muscular disfunction similar to that observed in chronic obstructive pulmonary disease and IHD patients [106]. More than 80% of hospitalized COVID-19 patients, all without previous disability, showed reduced quadriceps muscle strength at discharge [107]. Studies carried out in COVID-19 patients who recovered from mild and moderate disease showed handgrip and quadricep weakness in 39.6% and 35.4% of the participants 12 weeks after discharge, respectively [108]. This might persist for a longer time, since persistent pulmonary function was impaired in up to 37% of the patients who suffered from SARS one year after discharge; their health status was also significantly decreased in comparison with healthy subjects [109][110], and exercise capacity was also remarkably lower than those found in the normal population for many months [110]. Moreover, patients admitted to intensive care units commonly present persistent dyspnea, anxiety, depression, impaired physical function, and a poor quality of life for up to 12 months after discharge [111][112][113]. Among these, physical function is one of the least likely to recover to normal values over the long term [28].

The high prevalence of impairment in skeletal muscle strength and physical performance in patients recovering from COVID-19 suggests the need for rehabilitation programs after discharge. However, reduced muscle strength has been identified six months after discharge in one in six COVID-19 survivors, even when they were admitted to post-care facilities or received dietary counseling, physical activity guidance, or physiotherapy assistance [114]. Therefore, it is important to adopt specific strategies aimed at increasing muscle strength, such as working at adequate intensities and using blood flow restriction [115].

It is important to consider possible risk factors when prescribing RT, as COVID-19 might be associated with cardiac complications that persist after discharge, especially arrhythmias, heart failure, myocardial injury, and increased risk of thromboembolism [116][117][118][119]. Nevertheless, RT has been shown to be safe and effective for several cardiac patients and has been recommended as a core component of cardiac rehabilitation for many decades [120][121][122]. However, it is important to consider proper program design to avoid complications, such as working with a lower number of repetitions, increasing rest intervals and reducing training volume [60].

References

1. Zu, Z.Y.; Jiang, M.D.; Xu, P.P.; Chen, W.; Ni, Q.Q.; Lu, G.M.; Zhang, L.J. Coronavirus Disease 2019 (COVID-19): A Perspective from China. Radiology 2020, 296, 200490.
2. Adhikari, S.P.; Meng, S.; Wu, Y.J.; Mao, Y.P.; Ye, R.X.; Wang, Q.Z.; Sun, C.; Sylvia, S.; Rozelle, S.; Raat, H.; et al. Epidemiology, causes, clinical manifestation and diagnosis, prevention and control of coronavirus disease (COVID-19) during the early outbreak period: A scoping review. Infect. Dis. Poverty 2020, 9, 29.
3. Corsini, A.; Bisciotti, N.G.; Eirale, C.; Volpi, P. Football cannot restart soon during the COVID-19 emergency! A critical perspective from the Italian experience and a call for action. Br. J. Sports Med. 2020, 17, 259–260.
4. Jukic, I.; Calleja-González, J.; Cos, F.; Cuzzolin, F.; Olmo, J.; Terrados, N.; Njaradi, N.; Sassi, R.; Requena, B.; Milanovic, L.; et al. Strategies and Solutions for Team Sports Athletes in Isolation due to COVID-19. Sports 2020, 8, 56.
5. Tison, G.H.; Avram, R.; Kuhar, P.; Abreau, S.; Marcus, G.M.; Pletcher, M.J.; Olgin, J.E. Worldwide Effect of COVID-19 on Physical Activity: A Descriptive Study. Ann. Intern. Med. 2020, 173, 767–

770.

6. Steele, J.; Androulakis-Korakakis, P.; Carlson, L.; Williams, D.; Phillips, S.; Smith, D.; Schoenfeld, B.J.; Loenneke, J.P.; Winett, R.; Abe, T.; et al. The Impact of Coronavirus (COVID-19) Related Public-Health Measures on Training Behaviours of Individuals Previously Participating in Resistance Training: A Cross-Sectional Survey Study. Sports Med. 2021, 51, 1561–1580.
7. Krogh-Madsen, R.; Thyfault, J.P.; Broholm, C.; Mortensen, O.H.; Olsen, R.H.; Mounier, R.; Plomgaard, P.; Van Hall, G.; Booth, F.W.; Pedersen, B.K.; et al. A 2-wk reduction of ambulatory activity attenuates peripheral insulin sensitivity. J. Appl. Physiol. 2010, 108, 1034–1040.
8. Narici, M.; De Vito, G.; Franchi, M.; Paoli, A.; Moro, T.; Marcolin, G.; Grassi, B.; Baldassarre, G.; Zuccarelli, L.; Biolo, G.; et al. Impact of sedentarism due to the COVID-19 home confinement on neuromuscular, cardiovascular and metabolic health: Physiological and pathophysiological implications and recommendations for physical and nutritional countermeasures. Eur. J. Sport Sci. 2020, 21, 614–635.
9. Gentil, P.; de Lira, C.A.B.; Souza, D.; Jimenez, A.; Mayo, X.; de Fátima Pinho Lins Gryschek, A.L.; Pereira, E.G.; Alcaraz, P.; Bianco, A.; Paoli, A.; et al. Resistance Training Safety during and after the SARS-CoV-2 Outbreak: Practical Recommendations. BioMed Res. Int. 2020, 2020, 3292916.
10. Sortwell, A.; Ramirez-Campillo, R.; Knijnik, J.; Forte, P.; Marinho, D.; Ferraz, R.; Trimble, K. Commentary: Face masks in physical education classes during the COVID-19 delta variant wave: A call for awareness. Ger. J. Exerc. Sport Res. 2021.
11. de Souza, F.R.; Motta-Santos, D.; dos Santos Soares, D.; de Lima, J.B.; Cardozo, G.G.; Guimarães, L.S.P.; Negrão, C.E.; dos Santos, M.R. Association of physical activity levels and the prevalence of COVID-19-associated hospitalization. J. Sci. Med. Sport 2021, 24, 913.
12. Salgado-Aranda, R.; Pérez-Castellano, N.; Núñez-Gil, I.; Orozco, A.J.; Torres-Esquivel, N.; Flores-Soler, J.; Chamaisse-Akari, A.; Mclnerney, A.; Vergara-Uzcategui, C.; Wang, L.; et al. Influence of Baseline Physical Activity as a Modifying Factor on COVID-19 Mortality: A Single-Center, Retrospective Study. Infect. Dis. Ther. 2021, 10, 801–814.
13. Sallis, R.; Young, D.R.; Tartof, S.Y.; Sallis, J.F.; Sall, J.; Li, Q.; Smith, G.N.; Cohen, D.A. Physical inactivity is associated with a higher risk for severe COVID-19 outcomes: A study in 48,440 adult patients. Br. J. Sports Med. 2021, 55, 1099–1105.
14. Després, J.P. Severe COVID-19 outcomes—The role of physical activity. Nat. Rev. Endocrinol. 2021, 17, 451–452.
15. Vancini, R.L.; Camargo-Neto, L.; de Lira, C.A.B.; Andrade, M.S.; Viana, R.B.; Nikolaidis, P.T.; Knechtle, B.; Gentil, P.; Piacezzi, L.H.V.; Lopes, M.C.B.T.; et al. Physical activity and sociodemographic profile of brazilian people during COVID-19 outbreak: An online and cross-sectional survey. Int. J. Environ. Res. Public Health 2020, 17, 7964.

16. Cheval, B.; Sieber, S.; Maltagliati, S.; Millet, G.P.; Formánek, T.; Chalabaev, A.; Cullati, S.; Boisgontier, M.P. Muscle strength is associated with COVID-19 hospitalization in adults 50 years of age or older. J. Cachexia Sarcopenia Muscle 2021, 12, 1136–1143.
17. Maltagliati, S.; Sieber, S.; Sarrazin, P.; Cullati, S.; Chalabaev, A.; Millet, G.P.; Boisgontier, M.P.; Cheval, B. Muscle strength explains the protective effect of physical activity against COVID-19 hospitalization among adults aged 50 years and older. J. Sports Sci. 2021, 39, 2796–2803.
18. Kara, Ö.; Kara, M.; Akın, M.E.; Özçakar, L. Grip strength as a predictor of disease severity in hospitalized COVID-19 patients. Heart Lung 2021, 50, 743–747.
19. Peçanha, T.; Goessler, K.F.; Roschel, H.; Gualano, B. Social isolation during the COVID-19 pandemic can increase physical inactivity and the global burden of cardiovascular disease. Am. J. Physiol. Circ. Physiol. 2020, 318, H1441–H1446.
20. Silva, L.R.B.; Seguro, C.S.; de Oliveira, C.G.A.; Santos, P.O.S.; de Oliveira, J.C.M.; de Souza Filho, L.F.M.; de Paula Júnior, C.A.; Gentil, P.; Rebelo, A.C.S. Physical Inactivity Is Associated with Increased Levels of Anxiety, Depression, and Stress in Brazilians During the COVID-19 Pandemic: A Cross-Sectional Study. Front. Psychiatry 2020, 11, 565291.
21. Kirwan, R.; McCullough, D.; Butler, T.; Perez de Heredia, F.; Davies, I.G.; Stewart, C. Sarcopenia during COVID-19 lockdown restrictions: Long-term health effects of short-term muscle loss. GeroScience 2020, 42, 1547–1578.
22. Kreutz, R.; Algharably, E.A.E.H.; Azizi, M.; Dobrowolski, P.; Guzik, T.; Januszewicz, A.; Persu, A.; Prejbisz, A.; Riemer, T.G.; Wang, J.G.; et al. Hypertension, the renin-angiotensin system, and the risk of lower respiratory tract infections and lung injury: Implications for COVID-19. Cardiovasc. Res. 2020, 116, 1688–1699.
23. Li, Y.C.; Bai, W.Z.; Hashikawa, T. The neuroinvasive potential of SARS-CoV2 may play a role in the respiratory failure of COVID-19 patients. J. Med. Virol. 2020, 92, 552–555.
24. Trinity, J.D.; Craig, J.C.; Fermoyle, C.C.; McKenzie, A.I.; Lewis, M.T.; Park, S.H.; Rondina, M.T.; Richardson, R.S. Impact of presymptomatic COVID-19 on vascular and skeletal muscle function: A case study. J. Appl. Physiol. 2021, 130, 1961–1970.
25. Logue, J.K.; Franko, N.M.; McCulloch, D.J.; McConald, D.; Magedson, A.; Wolf, C.R.; Chu, H.Y. Sequelae in Adults at 6 Months after COVID-19 Infection. JAMA Netw. Open 2021, 4, 10–13.
26. Bellan, M.; Baricich, A.; Patrucco, F.; Zeppegno, P.; Gramaglia, C.; Balbo, P.E.; Carriero, A.; Amico, C.S.; Avanzi, G.C.; Barini, M.; et al. Long-term sequelae are highly prevalent one year after hospitalization for severe COVID-19. Sci. Rep. 2021, 11, 22666.
27. Barker-Davies, R.M.; O’Sullivan, O.; Senaratne, K.P.P.; Baker, P.; Cranley, M.; Dharm-Datta, S.; Ellis, H.; Goodall, D.; Gough, M.; Lewis, S.; et al. The Stanford Hall consensus statement for post-COVID-19 rehabilitation. Br. J. Sports Med. 2020, 54, 949–959.

28. Gerth, A.M.J.; Hatch, R.A.; Young, J.D.; Watkinson, P.J. Changes in health-related quality of life after discharge from an intensive care unit: A systematic review. Anaesthesia 2019, 74, 100–108.
29. Fragala, M.S.; Cadore, E.L.; Dorgo, S.; Izquierdo, M.; Kraemer, W.J.; Peterson, M.D.; Ryan, E.D. Resistance Training for Older Adults: Position Statement from the National Strength and Conditioning Association; NLM (Medline): Bethesda, MD, USA, 2019; Volume 33, pp. 2019–2052.
30. ACSM American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. Med Sci. Sport. Exerc. 2009, 41, 687–708.
31. Garber, C.E.; Blissmer, B.; Deschenes, M.R.; Franklin, B.A.; Lamonte, M.J.; Lee, I.M.; Nieman, D.C.; Swain, D.P. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: Guidance for prescribing exercise. Med. Sci. Sports Exerc. 2011, 43, 1334–1359.
32. Artero, E.G.; Lee, D.C.; Ruiz, J.R.; Sui, X.; Ortega, F.B.; Church, T.S.; Lavie, C.J.; Castillo, M.J.; Blair, S.N. A prospective study of muscular strength and all-cause mortality in men with hypertension. J. Am. Coll. Cardiol. 2011, 57, 1831–1837.
33. Ruiz, J.R.; Sui, X.; Lobelo, F.; Morrow, J.R.; Jackson, A.W.; Sjöström, M.; Blair, S.N. Association between muscular strength and mortality in men: Prospective cohort study. BMJ 2008, 337, a439.
34. Hardee, J.P.; Porter, R.R.; Sui, X.; Archer, E.; Lee, I.M.; Lavie, C.J.; Blair, S.N. The effect of resistance exercise on all-cause mortality in cancer survivors. Mayo Clin. Proc. 2014, 89, 1108–1115.
35. Dankel, S.J.; Loenneke, J.P.; Loprinzi, P.D. Determining the Importance of Meeting Muscle-Strengthening Activity Guidelines: Is the Behavior or the Outcome of the Behavior (Strength) a More Important Determinant of All-Cause Mortality? Mayo Clin. Proc. 2016, 91, 166–174.
36. Ortega, F.B.; Silventoinen, K.; Tynelius, P.; Rasmussen, F. Muscular strength in male adolescents and premature death: Cohort study of one million participants. BMJ 2012, 345, e7279.
37. Af Geijerstam, A.; Mehlig, K.; Börjesson, M.; Robertson, J.; Nyberg, J.; Adiels, M.; Rosengren, A.; Åberg, M.; Lissner, L. Fitness, strength and severity of COVID-19: A prospective register study of 1,559,187 Swedish conscripts. BMJ Open 2021, 11.
38. Shahid, Z.; Kalayanamitra, R.; McClafferty, B.; Kepko, D.; Ramgobin, D.; Patel, R.; Aggarwal, C.S.; Vunnam, R.; Sahu, N.; Bhatt, D.; et al. COVID-19 and Older Adults: What We Know. J. Am. Geriatr. Soc. 2020, 68, 926–929.
39. Muniyappa, R.; Gubbi, S. COVID-19 Pandemic, Corona Viruses, and Diabetes Mellitus. Am. J. Physiol. Endocrinol. Metab. 2020, 318, 5.
40. Singh, A.K.; Gupta, R.; Misra, A. Comorbidities in COVID-19: Outcomes in hypertensive cohort and controversies with renin angiotensin system blockers. Diabetes Metab. Syndr. Clin. Res. Rev.

2020, 14, 283–287.

41. Zhou, F.; Yu, T.; Du, R.; Fan, G.; Liu, Y.; Liu, Z.; Xiang, J.; Wang, Y.; Song, B.; Gu, X.; et al. Clinical course and risk factors for mortality of adult inpatients with COVID-19 in Wuhan, China: A retrospective cohort study. Lancet 2020, 395, 1054–1062.
42. Salerno, M.; Sessa, F.; Piscopo, A.; Montana, A.; Torrisi, M.; Patanè, F.; Murabito, P.; Volti, G.L.; Pomara, C. No Autopsies on COVID-19 Deaths: A Missed Opportunity and the Lockdown of Science. J. Clin. Med. 2020, 9, 1472.
43. MacDonald, H.V.; Johnson, B.T.; Huedo-Medina, T.B.; Livingston, J.; Forsyth, K.C.; Kraemer, W.J.; Farinatti, P.T.V.; Pescatello, L.S. Dynamic resistance training as stand-alone antihypertensive lifestyle therapy: A meta-analysis. J. Am. Heart Assoc. 2016, 5, e003231.
44. Seguro, C.S.; Rebelo, A.C.S.; Silva, A.G.; dos Santos, M.M.A.; Cardoso, J.S.; Apolinário, V.; Jardim, P.C.V.; Gentil, P. Use of low volume, high effort resistance training to manage blood pressure in hypertensive patients inside a public hospital: A proof of concept study. Eur. J. Transl. Myol. 2021, 31, 2021.
45. Codella, R.; Ialacqua, M.; Terruzzi, I.; Luzi, L. May the force be with you: Why resistance training is essential for subjects with type 2 diabetes mellitus without complications. Endocrine 2018, 62, 14–25.
46. Paoli, A.; Moro, T.; Bianco, A. Lift weights to fight overweight. Clin. Physiol. Funct. Imaging 2014, 35, 1–6.
47. Mann, S.; Beedie, C.; Jimenez, A. Differential Effects of Aerobic Exercise, Resistance Training and Combined Exercise Modalities on Cholesterol and the Lipid Profile: Review, Synthesis and Recommendations. Sports Med. 2014, 44, 211.
48. Nieman, D.C.; Wentz, L.M. The compelling link between physical activity and the body’s defense system. J. Sport Health Sci. 2019, 8, 201–217.
49. Peake, J.M.; Neubauer, O.; Walsh, N.P.; Simpson, R.J. Recovery of the immune system after exercise. J. Appl. Physiol. 2017, 122, 1077–1087.
50. Pedersen, B.K.; Rohde, T.; Ostrowski, K. Recovery of the immune system after exercise. Acta Physiol. Scand. 1998, 162, 325–332.
51. Souza, D.; Vale, A.F.; Silva, A.; Araújo, M.A.S.; de Paula Júnior, C.A.; de Lira, C.A.B.; Ramirez-Campillo, R.; Martins, W.; Gentil, P. Acute and Chronic Effects of Interval Training on the Immune System: A Systematic Review with Meta-Analysis. Biology 2021, 10, 868.
52. Matthews, C.E.; Ockene, I.S.; Freedson, P.S.; Rosal, M.C.; Merriam, P.A.; Hebert, J.R. Moderate to vigorous physical activity and risk of upper-respiratory tract infection. Med. Sci. Sports Exerc. 2002, 34, 1242–1248.

53. Fondell, E.; Lagerros, Y.T.; Sundberg, C.J.; Lekander, M.; Bölter, O.; Rothman, K.J.; Bölter, K. Physical activity, stress, and self-reported upper respiratory tract infection. Med. Sci. Sports Exerc. 2011, 43, 272–279.
54. Nieman, D.C.; Henson, D.A.; Austin, M.D.; Sha, W. Upper respiratory tract infection is reduced in physically fit and active adults. Br. J. Sports Med. 2011, 45, 987–992.
55. Horn, P.L.; Pyne, D.B.; Hopkins, W.G.; Barnes, C.J. Lower white blood cell counts in elite athletes training for highly aerobic sports. Eur. J. Appl. Physiol. 2010, 110, 925–932.
56. Timpka, T.; Jacobsson, J.; Bargoria, V.; Périard, J.D.; Racinais, S.; Ronsen, O.; Halje, K.; Andersson, C.; Dahlström, Ö.; Spreco, A.; et al. Preparticipation predictors for championship injury and illness: Cohort study at the Beijing 2015 International Association of Athletics Federations World Championships. Br. J. Sports Med. 2017, 51, 272–277.
57. Alonso, J.M.; Tscholl, P.M.; Engebretsen, L.; Mountjoy, M.; Dvorak, J.; Junge, A. Occurrence of injuries and illnesses during the 2009 IAAF World Athletics Championships. Br. J. Sports Med. 2010, 44, 1100–1105.
58. Alonso, J.M.; Edouard, P.; Fischetto, G.; Adams, B.; Depiesse, F.; Mountjoy, M. Determination of future prevention strategies in elite track and field: Analysis of Daegu 2011 IAAF Championships injuries and illnesses surveillance. Br. J. Sports Med. 2012, 46, 505–514.
59. Nieman, D.C. Marathon training and immune function. Sports Med. 2007, 37, 412–415.
60. Gentil, P.; de Lira, C.A.B.; Coswig, V.; Barroso, W.K.S.; Vitorino, P.V.d.O.; Ramirez-Campillo, R.; Martins, W.; Souza, D. Practical Recommendations Relevant to the Use of Resistance Training for COVID-19 Survivors. Front. Physiol. 2021, 12.
61. Gentil, P.; Ramirez-Campillo, R.; Souza, D.C. Resistance training in face of the coronavirus outbreak: Time to think outside the box. Front. Physiol. 2020, in press.
62. Kikuchi, N.; Nakazato, K. Low-load bench press and push-up induce similar muscle hypertrophy and strength gain. J. Exerc. Sci. Fit. 2017, 15, 37–42.
63. Calatayud, J.; Borreani, S.; Colado, J.C.; Martin, F.; Tella, V.; Andersen, L.L. Bench press and push-up at comparable levels of muscle activity results in similar strength gains. J. Strength Cond. Res. 2015, 29, 246–253.
64. Soligon, S.D.; da Silva, D.G.; Bergamasco, J.G.A.; Angleri, V.; Júnior, R.A.M.; Dias, N.F.; Nóbrega, S.R.; de Castro Cesar, M.; Libardi, C.A. Suspension training vs. traditional resistance training: Effects on muscle mass, strength and functional performance in older adults. Eur. J. Appl. Physiol. 2020, 120, 2223–2232.
65. Silva, M.H.; Andre Barbosa De Lira, C.; Steele, J.; Fisher, J.P.; Mota, J.F.; Gomes, A.C.; Gentil, P. Cycle ergometer training and resistance training similarly increase muscle strength in trained

men. J. Sports Sci. 2021.

66. Morris, S.J.; Oliver, J.L.; Pedley, J.S.; Haff, G.G.; Lloyd, R.S. Comparison of Weightlifting, Traditional Resistance Training and Plyometrics on Strength, Power and Speed: A Systematic Review with Meta-Analysis. Sports Med. 2022.
67. Martins, W.R.; de Oliveira, R.J.; Carvalho, R.S.; de Oliveira Damasceno, V.; da Silva, V.Z.M.; Silva, M.S. Elastic resistance training to increase muscle strength in elderly: A systematic review with meta-analysis. Arch. Gerontol. Geriatr. 2013, 57, 8–15.
68. Souza, D.; Barbalho, M.; Vieira, C.A.; Martins, W.R.; Cadore, E.L.; Gentil, P. Minimal dose resistance training with elastic tubes promotes functional and cardiovascular benefits to older women. Exp. Gerontol. 2019, 115, 132–138.
69. Colado, J.C.; Garcia-Masso, X.; Pellicer, M.; Alakhdar, Y.; Benavent, J.; Cabeza-Ruiz, R. A comparison of elastic tubing and isotonic resistance exercises. Int. J. Sports Med. 2010, 31, 810–817.
70. Gentil, P.; Bottaro, M.; Noll, M.; Werner, S.; Vasconcelos, J.C.; Seffrin, A.; Campos, M.H. Muscle activation during resistance training with no external load—Effects of training status, movement velocity, dominance, and visual feedback. Physiol. Behav. 2017, 179, 148–152.
71. Barbalho, M.; Coswig, V.S.; Bottaro, M.; De Lira, C.A.B.; Campos, M.H.; Vieira, C.A.; Gentil, P. “nO LOAD” resistance training increases functional capacity and muscle size in hospitalized female patients: A pilot study. Eur. J. Transl. Myol. 2019, 29, 302–306.
72. Counts, B.R.; Buckner, S.L.; Dankel, S.J.; Jessee, M.B.; Mattocks, K.T.; Mouser, J.G.; Laurentino, G.C.; Loenneke, J.P. The acute and chronic effects of “NO LOAD” resistance training. Physiol. Behav. 2016, 164, 345–352.
73. Gentil, P.; Soares, S.; Bottaro, M. Single vs. Multi-Joint Resistance Exercises: Effects on Muscle Strength and Hypertrophy. Asian J. Sport. Med. 2015, 6, e24057.
74. Paoli, A.; Gentil, P.; Moro, T.; Marcolin, G.; Bianco, A. Resistance training with single vs. multi-joint exercises at equal total load volume: Effects on body composition, cardiorespiratory fitness, and muscle strength. Front. Physiol. 2017, 8, 1105.
75. Barbalho, M.; Coswig, V.; Souza, D.; Serrão, J.C.; Campos, M.H.; Gentil, P. Back Squat vs. Hip Thrust Resistance-training Programs in Well-trained Women. Int. J. Sports Med. 2020, 41, 306–310.
76. Barbalho, M.; Souza, D.; Coswig, V.; Steele, J.; Fisher, J.; Abrahin, O.; Paoli, A.; Gentil, P. The Effects of Resistance Exercise Selection on Muscle Size and Strength in Trained Women. Int. J. Sports Med. 2020, 41, 371–376.

77. Gentil, P.; Fisher, J.; Steele, J. A Review of the Acute Effects and Long-Term Adaptations of Single- and Multi-Joint Exercises during Resistance Training. Sport. Med. 2017, 47, 843–855.
78. Gentil, P.; Soares, S.R.; Pereira, M.C.; Cunha, R.R.; Martorelli, S.S.; Martorelli, A.S.; Bottaro, M. Effect of adding single-joint exercises to a multi-joint exercise resistance-training program on strength and hypertrophy in untrained subjects. Appl. Physiol. Nutr. Metab. 2013, 38, 341–344.
79. De França, H.S.; Branco, P.A.N.; Guedes Junior, D.P.; Gentil, P.; Steele, J.; Teixeira, C.V.L.S. The Effects of Adding Single-Joint Exercises To a Multi-Joint Exercise Resistance Training Program on Upper Body Muscle Strength and Size in Trained Men. Appl. Physiol. Nutr. Metab. 2015, 40, 822–826.
80. Chaabene, H.; Prieske, O.; Herz, M.; Moran, J.; Höhne, J.; Kliegl, R.; Ramirez-Campillo, R.; Behm, D.G.; Hortobágyi, T.; Granacher, U. Home-based exercise programmes improve physical fitness of healthy older adults: A PRISMA-compliant systematic review and meta-analysis with relevance for COVID-19. Ageing Res. Rev. 2021, 67, 101265.
81. Carneiro, L.; Rosenbaum, S.; Ward, P.B.; Clemente, F.M.; Ramirez-Campillo, R.; Monteiro-Júnior, R.S.; Martins, A.; Afonso, J. Web-based exercise interventions for patients with depressive and anxiety disorders: A systematic review of randomized controlled trials. Rev. Bras. Psiquiatr. 2021.
82. Ali, A.M.; Kunugi, H. Skeletal Muscle Damage in COVID-19: A Call for Action. Medicina 2021, 57, 372.
83. de Andrade-Junior, M.C.; de Salles, I.C.D.; de Brito, C.M.M.; Pastore-Junior, L.; Righetti, R.F.; Yamaguti, W.P. Skeletal Muscle Wasting and Function Impairment in Intensive Care Patients with Severe COVID-19. Front. Physiol. 2021, 12, 640973.
84. Tuzun, S.; Keles, A.; Okutan, D.; Yildiran, T.; Palamar, D. Assessment of musculoskeletal pain, fatigue and grip strength in hospitalized patients with COVID-19. Eur. J. Phys. Rehabil. Med. 2021, 57, 653–662.
85. Medrinal, C.; Prieur, G.; Bonnevie, T.; Gravier, F.E.; Mayard, D.; Desmalles, E.; Smondack, P.; Lamia, B.; Combret, Y.; Fossat, G. Muscle weakness, functional capacities and recovery for COVID-19 ICU survivors. BMC Anesthesiol. 2021, 21, 64.
86. Osthoff, A.K.R.; Taeymans, J.; Kool, J.; Marcar, V.; Van Gestel, A.J.R. Association between peripheral muscle strength and daily physical activity in patients with COPD: A systematic literature review and meta-analysis. J. Cardiopulm. Rehabil. Prev. 2013, 33, 351–359.
87. Swallow, E.B.; Reyes, D.; Hopkinson, N.S.; Man, W.D.C.; Porcher, R.; Cetti, E.J.; Moore, A.J.; Moxham, J.; Polkey, M.I. Quadriceps strength predicts mortality in patients with moderate to severe chronic obstructive pulmonary disease. Thorax 2007, 62, 115–120.
88. Gil, S.; Jacob Filho, W.; Shinjo, S.K.; Ferriolli, E.; Busse, A.L.; Avelino-Silva, T.J.; Longobardi, I.; de Oliveira Júnior, G.N.; Swinton, P.; Gualano, B.; et al. Muscle strength and muscle mass as

predictors of hospital length of stay in patients with moderate to severe COVID-19: A prospective observational study. J. Cachexia Sarcopenia Muscle 2021, 12, 1871–1878.

89. Rice, H.; Harrold, M.; Fowler, R.; Watson, C.; Waterer, G.; Hill, K. Exercise training for adults hospitalized with an acute respiratory condition: A systematic scoping review. Clin. Rehabil. 2020, 34, 45–55.
90. Troosters, T.; Probst, V.S.; Crul, T.; Pitta, F.; Gayan-Ramirez, G.; Decramer, M.; Gosselink, R. Resistance training prevents deterioration in quadriceps muscle function during acute exacerbations of chronic obstructive pulmonary disease. Am. J. Respir. Crit. Care Med. 2010, 181, 1072–1077.
91. Ozyemisci Taskiran, O.; Turan, Z.; Tekin, S.; Senturk, E.; Topaloglu, M.; Yurdakul, F.; Ergonul, O.; Cakar, N. Physical rehabilitation in Intensive Care Unit in acute respiratory distress syndrome patients with COVID-19. Eur. J. Phys. Rehabil. Med. 2021, 57, 434–442.
92. Sosnowski, K.; Lin, F.; Mitchell, M.L.; White, H. Early rehabilitation in the intensive care unit: An integrative literature review. Aust. Crit. Care 2015, 28, 216–225.
93. José, A.; Dal Corso, S. Inpatient rehabilitation improves functional capacity, peripheral muscle strength and quality of life in patients with community-acquired pneumonia: A randomised trial. J. Physiother. 2016, 62, 96–102.
94. Li, N.; Li, P.; Lu, Y.; Wang, Z.; Li, J.; Liu, X.; Wu, W. Effects of resistance training on exercise capacity in elderly patients with chronic obstructive pulmonary disease: A meta-analysis and systematic review. Aging Clin. Exp. Res. 2019, 32, 1911–1922.
95. Liao, W.H.; Chen, J.W.; Chen, X.; Lin, L.; Yan, H.Y.; Zhou, Y.Q.; Chen, R. Impact of resistance training in subjects with COPD: A systematic review and meta-analysis. Respir. Care 2015, 60, 1130–1145.
96. Castelli, V.; Cimini, A.; Ferri, C. Cytokine Storm in COVID-19: “When You Come Out of the Storm, You Won’t Be the Same Person Who Walked in”. Front. Immunol. 2020, 11, 8–11.
97. Chen, G.; Wu, D.; Guo, W.; Cao, Y.; Huang, D.; Wang, H.; Wang, T.; Zhang, X.; Chen, H.; Yu, H.; et al. Clinical and immunological features of severe and moderate coronavirus disease 2019. J. Clin. Investig. 2020, 130, 2620–2629.
98. Santiago, L.; Ǎngelo, M.; Neto, L.G.L.; Pereira, G.B.; Leite, R.D.; Mostarda, C.T.; De Oliveira Brito Monzani, J.; Sousa, W.R.; Pinheiro, A.J.M.R.; Navarro, F. Effects of resistance training on immunoinflammatory response, TNF-alpha gene expression, and body composition in elderly women. J. Aging Res. 2018, 2018, 1467025.
99. Lammers, M.D.; Anéli, N.M.; de Oliveira, G.G.; de Oliveira Maciel, S.F.V.; Zanini, D.; Mânica, A.; de Resende e Silva, D.T.; Bagatini, M.D.; Sévigny, J.; De Sá, C.A.; et al. The anti-inflammatory effect of resistance training in hypertensive women. J. Hypertens 2020, 38, 2490–2500.

100. Chupel, M.U.; Direito, F.; Furtado, G.E.; Minuzzi, L.G.; Pedrosa, F.M.; Colado, J.C.; Ferreira, J.P.; Filaire, E.; Teixeira, A.M. Strength training decreases inflammation and increases cognition and physical fitness in older women with cognitive impairment. Front. Physiol. 2017, 8, 377.
101. Steiner, M.C. Sarcopaenia in chronic obstructive pulmonary disease. Thorax 2007, 62, 101–103.
102. Bone, A.E.; Hepgul, N.; Kon, S.; Maddocks, M. Sarcopenia and frailty in chronic respiratory disease: Lessons from gerontology. Chron. Respir. Dis. 2017, 14, 85–99.
103. Tansey, C.M.; Louie, M.; Loeb, M.; Gold, W.L.; Muller, M.P.; De Jager, J.A.; Cameron, J.I.; Tomlinson, G.; Mazzulli, T.; Walmsley, S.L.; et al. One-year outcomes and health care utilization in survivors of severe acute respiratory syndrome. Arch. Intern. Med. 2007, 167, 1312–1320.
104. Herridge, M.S.; Cheung, A.M.; Tansey, C.M.; Matte-Martyn, A.; Diaz-Granados, N.; Al-Saidi, F.; Cooper, A.B.; Guest, C.B.; Mazer, C.D.; Mehta, S.; et al. One-year outcomes in survivors of the acute respiratory distress syndrome. N. Engl. J. Med. 2003, 348, 683–693.
105. Li, Z.; Cai, Y.; Zhang, Q.; Zhang, P.; Sun, R.; Jiang, H.; Wan, J.; Wu, F.; Wang, X.; Tao, X. Intensive care unit acquired weakness. Medicine 2020, 99, e21926.
106. Pleguezuelos, E.; Del Carmen, A.; Llorensi, G.; Carcole, J.; Casarramona, P.; Moreno, E.; Ortega, P.; Serra-Prat, M.; Palomera, E.; Miravitlles, M.M.; et al. Severe loss of mechanical efficiency in COVID-19 patients. J. Cachexia Sarcopenia Muscle 2021, 12, 1056–1063.
107. Paneroni, M.; Simonelli, C.; Saleri, M.; Bertacchini, L.; Venturelli, M.; Troosters, T.; Ambrosino, N.; Vitacca, M. Muscle Strength and Physical Performance in Patients Without Previous Disabilities Recovering from COVID-19 Pneumonia. Am. J. Phys. Med. Rehabil. 2021, 100, 105–109.
108. Tanriverdi, A.; Savci, S.; Kahraman, B.O.; Ozpelit, E. Extrapulmonary features of post-COVID-19 patients: Muscle function, physical activity, mood, and sleep quality. Ir. J. Med. Sci. 2021.
109. Ong, K.C.; Ng, A.W.K.; Lee, L.S.U.; Kaw, G.; Kwek, S.K.; Leow, M.K.S.; Earnest, A. 1-Year pulmonary function and health status in survivors of severe acute respiratory syndrome. Chest 2005, 128, 1393–1400.
110. Hui, D.S.; Wong, K.T.; Ko, F.W.; Tam, L.S.; Chan, D.P.; Woo, J.; Sung, J.J.Y. The 1-year impact of severe acute respiratory syndrome on pulmonary function, exercise capacity, and quality of life in a cohort of survivors. Chest 2005, 128, 2247–2261.
111. Denehy, L.; Elliott, D. Strategies for post ICU rehabilitation. Curr. Opin. Crit. Care 2012, 18, 503–508.
112. Jackson, J.C.; Ely, E.W.; Morey, M.C.; Anderson, V.M.; Denne, L.B.; Clune, J.; Siebert, C.S.; Archer, K.R.; Torres, R.; Janz, D.; et al. Cognitive and physical rehabilitation of intensive care unit survivors: Results of the RETURN randomized controlled pilot investigation. Crit. Care Med. 2012, 40, 1088–1097.

113. Oeyen, S.G.; Vandijck, D.M.; Benoit, D.D.; Annemans, L.; Decruyenaere, J.M. Quality of life after intensive care: A systematic review of the literature. Crit. Care Med. 2010, 38, 2386–2400.

114. Gérard, M.; Mahmutovic, M.; Malgras, A.; Michot, N.; Scheyer, N.; Jaussaud, R.; Nguyen-Thi, P.L.; Quilliot, D. Long-Term Evolution of Malnutrition and Loss of Muscle Strength after COVID-19: A Major and Neglected Component of Long COVID-19. Nutrients 2021, 13, 3964.

115. Gobbi, M.; Bezzoli, E.; Ismelli, F.; Trotti, G.; Cortellezzi, S.; Meneguzzo, F.; Arreghini, M.; Seitanidis, I.; Brunani, A.; Aspesi, V.; et al. Skeletal Muscle Mass, Sarcopenia and Rehabilitation Outcomes in Post-Acute COVID-19 Patients. J. Clin. Med. 2021, 10, 5623.

116. Wang, D.; Hu, B.; Hu, C.; Zhu, F.; Liu, X.; Zhang, J.; Wang, B.; Xiang, H.; Cheng, Z.; Xiong, Y.; et al. Clinical Characteristics of 138 Hospitalized Patients with 2019 Novel Coronavirus-Infected Pneumonia in Wuhan, China. J. Am. Med. Assoc. 2020, 323, 1061–1069.

117. Madjid, M.; Safavi-Naeini, P.; Solomon, S.D.; Vardeny, O. Potential Effects of Coronaviruses on the Cardiovascular System: A Review. JAMA Cardiol. 2020, 5, 831–840.

118. Kochi, A.N.; Tagliari, A.P.; Forleo, G.B.; Fassini, G.M.; Tondo, C. Cardiac and arrhythmic complications in patients with COVID-19. J. Cardiovasc. Electrophysiol. 2020, 31, 1003–1008.

119. Goshua, G.; Pine, A.B.; Meizlish, M.L.; Chang, C.-H.; Zhang, H.; Bahel, P.; Baluha, A.; Bar, N.; Bona, R.D.; Burns, A.J.; et al. Endotheliopathy in COVID-19-associated coagulopathy: Evidence from a single-centre, cross-sectional study. Lancet Haematol. 2020, 7, e575–e582.

120. Yamamoto, S.; Hotta, K.; Ota, E.; Mori, R.; Matsunaga, A. Effects of resistance training on muscle strength, exercise capacity, and mobility in middle-aged and elderly patients with coronary artery disease: A meta-analysis. J. Cardiol. 2016, 68, 125–134.

121. McKelvie, R.S.; McCartney, N. Weightlifting Training in Cardiac Patients: Considerations. Sport. Med. 1990, 10, 355–364.

122. Verrill, D.; Shoup, E.; McElveen, G.; Witt, K.; Bergey, D. Resistive Exercise Training in Cardiac Patients: Recommendations. Sport. Med. 1992, 13, 171–193.