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Original

LONG-COVID, MUSCLE STRENGTH AND PHYSICAL ACTIVITY: A BIBLIOMETRIC ANALYSIS

LONG-COVID, FUERZA MUSCULAR Y ACTIVIDAD FÍSICA: ANÁLISIS BIBLIOMÉTRICO

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RESUMEN

El SARS-CoV-2 o COVID-19 es una enfermedad provocada por un coronavirus que ha tenido un gran impacto en todas las esferas de la población mundial, pero con especial impacto en la salud de las personas que han padecido la enfermedad. Aunque actualmente el COVID-19 ha dejado de ser pandemia mundial y una emergencia sanitaria, parte de la población que ha padecido la enfermedad sigue teniendo secuelas de distinto índole. Es el denominado long-COVID. Por ello, el objetivo de este trabajo ha sido realizar un análisis bibliométrico de los artículos relacionados con el long-COVID y su implicación con la fuerza muscular vinculada con la actividad física. Para este trabajo, se revisaron las bases de datos de PubMed, Scopus, Dialnet y SportDiscus. Los resultados obtenidos fueron tratados con el gestor bibliográfico Mendeley Reference Manager y con la hoja de cálculo de Microsoft Excel V. 16.75 para su posterior análisis estadístico. Se identificaron un total de 31 artículos sin restricción temporal dada la actualidad del tema de este trabajo. El año con mayor producción científica sobre este tema fue el 2022 con el 54.84% de la selección total de artículos encabezados por España, Italia y Brasil. Todos los artículos fueron de autoría colaborativa entre un 4.47 y 8.00. Se concluye que es necesario un mayor número de trabajos de investigación relacionados con el long-COVID y la fuerza muscular.

Palabras clave: long-COVID; fuerza muscular; actividad física; salud; ejercicio físico

LONG-COVID, MUSCLE STRENGTH AND PHYSICAL ACTIVITY: A BIBLIOMETRIC ANALYSIS

ABSTRACT

SARS-CoV-2 or COVID-19 is a disease caused by a coronavirus that has had a major impact on all spheres of the world's population, but with a special impact on the health of people who have suffered from the disease. Although COVID-19 is no longer a global pandemic and is no longer a health emergency, part of the population that has suffered from the disease continues to suffer from different types of sequelae. This is the so-called long-COVID. For this reason, the aim of this study was to carry out a bibliometric analysis of articles related to long-COVID and its implication for muscle strength linked to physical activity. For this work, the databases of PubMed, Scopus, Dialnet and SportDiscus were reviewed. The results obtained were processed with the bibliographic manager Mendeley Reference Manager and the Microsoft Excel V. 16.75 spreadsheet for subsequent statistical analysis. A total of 31 articles were identified with no time restriction given the topicality of the subject of this work. The year with the highest scientific production on this topic was 2022 with 54.84% of the total selection of articles led by Spain, Italy and Brazil. All the articles were of collaborative authorship between 4.47 and 8.00. It is concluded that there is a need for more research work related to long-COVID and muscle strength.

Keywords: long-COVID; muscle strength; physical activity; health; physical exercise



INTRODUCTION

In December 2019 in the city of Wuhan (China), a new outbreak of coronavirus was reported. The World Health Organization (WHO) named this new disease as coronavirus 2019 (COVID-19), which is an infectious disease caused by the SARS-CoV-2 virus (World Health Organization, 2023); SARS-CoV-2 is a single-stranded RNA virus capable of infecting humans and other mammals, which has an interaction of the viral capsid protein S and human receptor proteins, mainly angiotensin-converting enzyme 2 (ACE-2) and transmembrane protease, serine 2 (TMPRSS2) that allow entry of the virus into host cells (V'kovski et al. , 2021), causing symptoms of fever, dry cough, dyspnoea and pneumonia in its severe form that can lead to death (Thompson, 2020). In addition, it has a severe reduction in serum T-cells, CD4⁺ T-cells, CD8⁺ T-cells and β -cells. Previous studies found that total T cells, CD4⁺ T cells or CD8⁺ T cells are lower than 800, 400 or 300/ μ l, respectively, and are inversely correlated with patient survival rate (Diao et al., 2020; XU et al., 2020). In itself, COVID-19 spread rapidly globally, becoming pandemic in March 2020 and eventually producing several variants.

Long-COVID, also called post-acute COVID-19 syndrome (PACS), is a complex secondary multisystemic condition comprising often severe symptoms following SARS-CoV-2 infection (Greenhalgh et al., 2020). It is defined by WHO as the development of new symptoms 3 months after the initial SARS-CoV-2 infection, with a duration of these symptoms of at least 2 months without other explanation (World Health Organization, 2022). PACS can be subdivided into two categories: 1) subacute or ongoing symptomatic COVID-19, including symptoms and abnormalities present 4-12 weeks after acute COVID-19; and 2) chronic or post-COVID-19 syndrome, which includes symptoms and abnormalities persisting or present beyond 12 weeks from the onset of acute COVID-19 (Nalbandian et al., 2021).

The five most common symptoms are: fatigue (58%), headache (44%), attention disorder (27%), hair loss (25%) and dyspnoea (24%) (Cares-Marambio et al., 2021; FAIR Health Releases Study on Post-COVID Conditions | FAIR Health, n.d.; Shah et al., 2021), but there are a variety of other less typical symptoms

reported including: cough, myalgia, chest and joint pain, mobility problems, cognitive and mental disorders ("cerebral fog", memory loss), olfactory and gustatory dysfunction, sleep disorders, depression, anxiety, post-traumatic stress disorder, gastrointestinal distress, wheezing, rhinorrhoea, sputum, skin rashes and palpitations (Ayoubkhani et al., 2022; Davis et al., 2022; Davis et al., 2022), 2022; Davis et al., 2021, 2023; Xie et al., 2022). Less common symptoms of pernio, chills, flushing, ear pain and visual impairment have also been documented (McMahon et al., 2021; Stavem et al., 2021; Xiong et al., 2021).

One of the distinguishing features in subjects who develop severe manifestations of long-COVID is not the extent of viral damage, but immune damage mediated by exaggerated inflammation created by the "cytokine storm" (Coperchini et al., 2021; Fajgenbaum & June, 2020; Sheth et al., 2020). This inflammation is advocated as one of the main factors associated with muscle catabolism in patients with long-COVID (Akbarialiabad et al., 2021; Raveendran et al., 2021). Furthermore, it has been shown to have a negative impact on several organs and body systems, including skeletal muscle (Piotrowicz et al., 2021; Yong, 2021). In fact, more than 60% of people with long-COVID reported fatigue, reduced mobility and muscle weakness (Huang et al., 2021; Karaarslan et al., 2022). For example, Paneroni et al. (Paneroni et al., 2021) reported muscle strength and physical performance outcomes in patients who recovered from COVID-19 pneumonia without any previous musculoskeletal problems. They found weakness in the biceps (73 %) and quadriceps (86 %) muscles. The maximum voluntary contraction for quadriceps was 54% and for biceps 69% of the expected normal value. Similarly, another study (Andrade-Junior et al., 2021) investigated muscle mass and muscle strength in patients with COVID-19 after ICU admission. It showed a significant decrease in rectus femoris cross-sectional area (30.1 %), quadriceps muscle anterior compartment thickness (18.6 %) and grip strength (22.3 %) during the first 10 days.

In people with long-COVID, a continued decrease in lymphocytes and significant elevation of neutrophils and inflammatory markers, including C-reactive protein (CRP), IP-10, monocyte chemotactic protein 1 (MCP1), macrophage inflammatory protein-1 alpha



(MIP1 α), tumour necrosis factor alpha (TNF- α), interleukin (IL)-1 β , IL-2, IL-6, IL-8, IL-10 and IL-17, and ferritin (Evcik, 2023; Grifoni et al., 2020; Liu et al., 2020; Malik et al., 2022; Mendoza, 2020; Ueland et al., 2020; Ye et al., 2020). These proinflammatory cytokines are known for their ability to negatively affect muscle protein metabolism through activation of catabolic pathways and suppression of anabolism (Webster et al., 2020, 2020) and, over time, these proinflammatory cytokines will lead to muscle fibre proteolysis, decreased protein synthesis and decreased ability of satellite cells to proliferate and differentiate, and ultimately fibrosis (Disser et al., 2020; Silva et al., 2022; Wang et al., 2022).

The aim of this study was to carry out a bibliometric analysis of articles related to long-COVID and its implication for muscle strength linked to physical activity.

MEANS AND METHODS

A bibliometric review was carried out using the databases of PubMed, Scopus, Dialnet and SportDiscus, as they are databases of indexed articles specialised in the biomedical area at an international level and are mainly in English. They were managed with the bibliographic manager Mendeley Reference Manager. For the search, the following keywords and Boolean operators were used:

((long covid) OR (permanent covid) OR (post covid) OR (Post-COVID Conditions) OR (long-haul COVID) OR (post-acute COVID-19) OR (post-acute sequelae of SARS CoV-2 infection) OR (long-term effects of COVID) OR (chronic COVID)) AND (muscle strength) AND (exercise) AND (performance)

Only original peer-reviewed full-text articles were considered. To select studies for inclusion, a review of titles and abstracts was conducted prior to examining the full text versions.

Inclusion criteria

The articles included were all those that met the following parameters: 1) Articles, systematic and/or bibliometric reviews; 2) Papers that refer to

pathologies or rehabilitation of muscular, functional strength or strength training in post-COVID patients; and 3) That the COVID sequelae were: fatigue associated with cardiorespiratory endurance, sarcopenia.

Exclusion criteria

All articles that did not meet the following parameters were excluded: 1) No reference to post COVID or long-COVID; and 2) Letter to editors.

Data extraction

Afterwards, a data collection process was carried out in Microsoft Excel for further statistical analysis, where the following questions were answered:

Q1: What was the year, volume and number of publication?

Q2: In which journal is it published?

Q3: What is the title of the article?

Q4: What is the quartile, impact factor and indexation of the article?

Q5: What type of document is it?

Q6: What language is it published in?

Q7: What is the gender and country of affiliation of the first author?

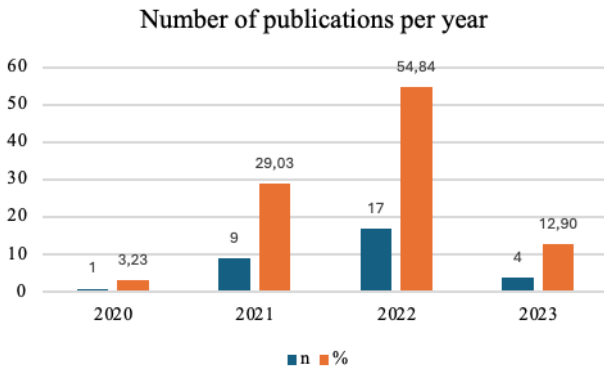
RESULTS

Based on the descriptor used as a search string in the different databases, of the 88 documents linked to the long-COVID and after filtering with the elements of inclusion and exclusion in this analysis, 31 articles related to the long-COVID and muscle strength were finally identified. Given that the subject studied is quite current, the search in the different databases used was not limited in time. It is evident that the highest number of papers were produced in the hardest years after the SARS-CoV2 pandemic, in the year 2021 with 9 published papers and 2022 with 17 papers (29.03% and 54.84% respectively). In the year when the WHO declared the COVID-19 virus a global pandemic, only one paper was produced (3.23%) while in the current year 4 papers have been produced, constituting 12.90%



of the total production of published long-COVID and muscle strength papers (Figure 1).

Figure 1
Distribution of publications per year



In reference to the quartiles in which these documents have been published, there is a predominance of Q1 JCR quartiles over the rest, with 51.61%, followed by documents published in Q2 JCR journals, with 29.03% of the total number of documents analysed (Table 1).

Table 1
Distribution of papers by JCR quartiles and year

Years	Q1		Q2		Q3		Q4		Other	
	n	%	n	%	n	%	n	%	n	%
2020	1	3.23								
2021	4	12.90	2	6.45	2	6.45			1	3.23
2022	8	25.81	6	19.35	2	6.45	1	3.23		
2023	3	9.68	1	3.23						

Note. n = frequency by year and quartile.

It should be noted that the journal in which most publications were produced was the International Journal of Environmental Research and Public Health, an Open Access journal of the MDPI publishing group, with a total of 5 publications in the years under analysis, accounting for 16.13% of the production in this analysis.

In terms of the origin of the countries in which the research was produced, documents were published in 13 different countries, with Italy, Spain and Brazil standing out, producing 16.13% of the documents published in each of these countries (Table 2). A very

high percentage of the documents, 96.77%, are published in English. Only one document was published in a different language, in Japanese.

Table 2
Distribution of the documents by research country and year

Country	2020	2021	2022	2023
Italy (n)	1	2	2	
Italy (%)	3.23	6.45	6.45	
France (n)			2	
France (%)			6.45	
Portugal (n)		1		1
Portugal (%)		3.23		3.23
United Kingdom (n)		2		
United Kingdom (%)		6.45		
Turkey (n)		2	1	
Turkey (%)		6.45	3.23	
Spain (n)			3	2
Spain (%)			9.68	6.45
Japan (n)			1	1
Japan (%)			3.23	3.23
Singapore (n)		1		
Singapore (%)		3.23		
Brazil (n)			4	1
Brazil (%)			12.9	3.23
China (n)			1	
China (%)			3.23	
South Korea (n)			1	
South Korea (%)			3.23	
Egypt (n)			1	
Egypt (%)			3.23	
Mexico (n)			1	
Mexico (%)			3.23	

Note. n = frequency of documents per year.

As shown in Table 3, the selected papers were analysed according to the type of paper or research being described. Three types of scientific papers were distinguished according to the inclusion and exclusion elements of this analysis, differentiating between intervention research, systematic reviews and other types of research. Papers published with



intervention research occupy the highest percentage in all the years analysed.

Table 3
Distribution by document type and year

Years	Intervention (n)	%	Systematic review (n)	%	Other type (n)	%
2020	1	3.23				
2021	5	16.13			4	12.90
2022	9	29.03	2	6.45	6	19.35
2023	3	9.68			1	3.23

Note. n = frequency by year and type of document.

With reference to the number of authors who sign the documents, it should be noted that none of the documents under analysis have a single authorship, being all the production in co-authorship or collaboration. The average number of authors per document ranges from 4.47 in 2022 to 8 in 2020. Year by year, the number of authors signing the documents has grown (8 authors in 2020, 56 authors in 2021 and 76 authors in 2022), with the current year 2023 having a total of 23 authors participating before the end of the year. Table 4 also shows the percentage of collaboration by year.

Table 4
Distribution by authorship and year

Year	Single author	% Single author	Collaborative papers	% in collaboration	M collaborative authors
2020			1	3.23	8.00
2021			9	29.03	6.22
2022			17	54.84	4.47
2023			4	12.90	5.75

Note. M = average number of authors.

In relation to the authorship and co-authorship of the documents analysed, it is worth noting that 64.52% of the authors participating in the different documents are women compared to 35.48% men. However, only one woman appears among the most productive authors with authorship and/or co-authorship of the 31 documents analysed. Once again, the years 2021 and 2022 are the years with the highest percentage of female authorship, with 12.90% and 38.71% respectively, compared to an average of 16.13% for men, and with a clear predominance of the University

of Murcia as the institution with the highest number of affiliations. Table 5 shows the authors who have participated most in the authorship of the documents, their affiliation and their country.

Table 5
Authors with the highest production of documents, their affiliation and country

Autor	n	Filiación	País
Amaya Jimeno-Almazán	3	University of Murcia	Spain
Jesús G. Pallarés	3	University of Murcia	Spain
Alejandro Martínez-Cava	3	University of Murcia	Spain
Ángel Buendía-Romero	3	University of Murcia	Spain
Bernardino J. Sánchez-Alcaraz Martínez	3	University of Murcia	Spain
Francisco Franco-López	3	University of Murcia	Spain
Javier Courel-Ibáñez	3	University of Murcia	Spain
José Antonio Sánchez-Agar	2	University of Murcia	Spain
Mehmet Kaan Kırılı	2	Kartal Koşuyolu Yüksek İhtisas Eğitim ve Araştırma Hastanesi	Turkey
Stefania Costi	2	University of Modena and Reggio Emilia	Italy

Note. n = frequency of authored or co-authored projects.

DISCUSSION

The aim of this work was to perform a bibliometric analysis of the scientific production related to long-COVID and its implication for muscle strength linked to physical activity.

Since the emergence of COVID-19, numerous scientific papers related to COVID-19, post-COVID-19 syndrome and physical activity have been published, including meta-analyses and systematic or literature reviews. However, there have been no bibliometric analyses specifically addressing long-COVID and the implication it has had on muscle strength in people who were infected with COVID-19.

Zhang's research (Zhang et al., 2022) incorporated a bibliometric review in the Web of Science and Science Citation Index Expanded (SCI-Expanded) databases, setting a publication period from 1 January 2020 to 14 February 2022. It included 1331 of articles and reviews, showing that the number of



published studies had increased from 334 in 2020 to 932 in 2021; furthermore, of these publications, 8548 authors published on COVID-19 and physical activity. Another review (Wattanapisit et al., 2022) searched the PubMed database from the start of the COVID-19 pandemic until 26 February 2022. They included 1125 articles, showing that the majority of articles ($n = 709$, 63.02%) were published in 2021, while the remaining articles were published in 2020 ($n = 341$, 30.31%) and 2022 ($n = 75$, 6.67%). The most frequent type of publication was original or research articles ($n = 678$, 60.27%) and the least frequent was systematic reviews ($n = 21$, representing 1.87%). Similarly, the study by Ciuldim and colleagues (2022) searched the SCOPUS and Web of Science databases in the years 2020 and 2021, without language restriction. For the final analysis they included 2023 articles, of which 382 were published in 2020 and 1641 in 2021, representing an annual growth rate of 330%. Likewise, the review by Zhang et al. (2022) focused on searching the Web of Science Core Collection database with cohort dates between 1 January 2020 and 9 April 2022, where they selected the 50 most cited articles on physical activity and COVID-19, this study had no restrictions in terms of population, study type or language.

Regarding the journals with the most publications, the study by Zhang, Y., et al. (2022) commented that, of the top 10 journals that published research articles related to COVID-19 and physical activity, MDPI's International Journal of Environmental Research and Public Health was the most productive with 179 publications; it was also the journal with the highest impact factor (IF) (IF = 3.39). In Ciuldim's (2022) review, the most published scientific journal was also the International Journal of Environmental Research and Public Health, obtaining the highest number of publications, citations and H-index. From Zhang's (2022) study, the 50 most cited articles were published in 34 journals with an IF ranging from 1.76 to 13.80; in addition, the International Journal of Environmental Research and Public Health was the journal with the most cited articles ($n = 10$). It is worth noting that this same journal is the one with the highest scientific production according to this bibliometric review, with a total of 5 publications accounting for 16.13% of the publications included.

With regard to the distribution of countries that have published the most articles, out of the total of 110 countries in Zhang's (2022) study, the top five countries with the most articles were the USA ($n=344$), followed by the UK ($n=168$), Italy ($n=137$), China ($n=130$) and Spain ($n=117$). Similarly, Wattanapisit's (2022) review showed that the top five countries include the USA as the first country ($n=176$, with 15.64%), the UK ($n=98$, with 8.71%), Italy ($n=93$, with 8.27%), Brazil ($n=84$, with 7.47%) and finally Spain ($n=81$, with 7.20%). In Ciuldim's (2022) analysis, the country with the most research on physical activity and COVID-19 was the USA ($n=832$), followed by Spain ($n=604$), Italy ($n=519$), the UK ($n=473$) and China ($n=458$). Finally, with respect to the study by Zhang, F. (2022), the 50 most cited articles were published by authors from 34 countries, with the USA contributing the highest number of articles (14), followed by Italy (11), England (9), Canada (8) and Spain (8). This is in complete contrast to our review, where the top countries were Italy, Spain and Brazil, producing 16.13% each. It is true that this bibliometric review focuses exclusively on muscular strength, a term that is not specified in the other reviews, where only physical activity is mentioned.

On the other hand, in relation to the institutions of affiliation, Zhang (2022) points out that the institution with the most publications was Harvard Medical School, USA (21). It is worth noting that in this bibliometric review he identified a similar number of scientific papers produced by the University of Murcia, Spain (21) with 67.74 %. In Ciuldim's review (2022), the most productive institutions were located in Brazil ($n=7$), Canada ($n=2$), United Kingdom ($n=2$), Vietnam ($n=2$), Austria ($n=1$), Italy ($n=1$) and Taiwan ($n=1$).

Regarding authorship, Ciuldim (2022) showed that Deborah Carvalho Malta (Federal University of Minas Gerais, Brazil) was the most productive researcher, co-authoring 16 studies. André de Oliveira Werneck (University of São Paulo, Brazil) and Lee Smith (Anglia Ruskin University, UK) shared second place, with a total of 15 studies each. A result that clarifies a point previously addressed in our review, where 64.52% of the authors participating in the different papers we included were women, compared to 35.48% men.



CONCLUSION

We conclude from this bibliometric review that more scientific research is needed to specifically address the implications of long-COVID in patients who have suffered from the disease in relation to muscle strength.

AUTHOR CONTRIBUTIONS

Conceptualization, O.R.Á., E.E.R.A., C.A.T.,A.F.J.O., S.J.L.M.,S.C.P., C.A.Z.H. and V.A.G.; methodology, O.R.Á.; software, O.R.Á.; validation, O.R.Á., E.E.R.A., C.A.T.,A.F.J.O., S.J.L.M.,S.C.P., C.A.Z.H. and V.A.G.; formal analysis, O.R.Á.; writing—original draft preparation, O.R.Á., E.E.R.A., C.A.T.,A.F.J.O., S.J.L.M.,S.C.P., C.A.Z.H. and V.A.G.; writing—review and editing, O.R.Á., E.E.R.A., C.A.T.,A.F.J.O., S.J.L.M.,S.C.P., C.A.Z.H. and V.A.G.; visualization, O.R.Á.; supervision, O.R.Á.; project administration, O.R.Á. All authors have read and agreed to the published version of the manuscript.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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