Journal of Autonomous Intelligence (2023) Volume 6 Issue 3
doi: 10.32629/jai.v6i3.995

ORIGINAL RESEARCH ARTICLE

A keyword network analysis of research trends on metabolic syndrome

Eun Sil Her[1], Yun Kyoung Oh[2,*]

[1] *Department of Food and Nutrition, Changshin University, Changwon-si 51352, Korea*

[2] *Department of Cosmetology, Changshin University, Changwon-si 51352, Korea*

*** Corresponding author:** Yun Kyoung Oh, yk212@cs.ac.kr

ABSTRACT

Recently, the prevalence and mortality of metabolic syndrome has been increasing worldwide. Accordingly, interest in metabolic syndrome and scientific and clinical studies are increasing. Through keyword analysis of articles related to metabolic syndrome published in Korea Citation Index (KCI) journals for the past 10 years, this study identified key research issues, structural characteristics, and relationships between keywords. The research methodology included data collection, cleaning, visualization, and analysis. Keyword frequency analysis revealed obesity (129 times) was the highest, followed with Health > Exercise > Risk factor > Women > Elderly > Physical activity at more than 50 times. In the structural form of the network, the density was 0.415; average connection strength was 22.821; average connection distance was 1.586; diameter was 3; component was 1; and network centrality was 58.8%. In the structural characteristics of the network, the keyword "obesity" was the highest in both connection and mediation centrality. This study suggests a combination of specific research topics and directions for future metabolic syndrome-related research.

Keywords: metabolic syndrome; keyword; network analysis; Korea Citation Index

ARTICLE INFO

Received: 18 July 2023
Accepted: 14 August 2023
Available online: 25 September 2023

1. Introduction

The term "metabolic syndrome" has been widely used since its inception in 2001 by the NCEP: ATPIII[1] and includes the clustering of insulin resistance, abdominal obesity, elevated blood pressure, and dyslipidemia[2].

According to the results of the KNHAENS (Korea National Health and Nutrition Examination Survey), the prevalence of metabolic syndrome in Korea increased 1.5 times over 20 years from 20.0% in 1998 to 31.9% in 2017[3]. Additionally, in 2021, the 10 major causes of death in Korea were cancer, heart disease, pneumonia, cerebrovascular disease[4], suicide, diabetes mellitus, Alzheimer's disease, liver disease[5], sepsis, and hypertensive diseases[6]. Furthermore, the mortality rate of diseases caused by risk factors of metabolic syndrome is high[7]. Metabolic syndrome is caused by complex influences such as genetic, metabolic, and environmental factors[8], but the mechanism of its occurrence has not yet been clearly identified[9].

Since metabolic syndrome was defined by the National Cholesterol Education Program's Adult Treatment Panel III (NCEP: ATPIII) in May 2001, more than 86,743 articles have appeared on the PubMed site as of 2022. Searching for metabolic syndrome through

the Korea Citation Index (KCI) site reveals 1494 articles were published from 2002 to 2022. Other endocrine syndromes we are familiar with, such as Cushing's syndrome, had 52 cases during the same period. Of course, scientific value cannot be discussed in the number of publications on metabolic syndrome or related citations; nevertheless, it is clear that there is growing interest in metabolic syndrome and research on its scientific and clinical significance.

A keyword network is constructed by extracting keywords from the literature of a particular subject area, calculating the co-existence frequency of each keyword pair, and calculating the similarity between keywords from this frequency. Keyword network analysis is an effective way to analyze research trends in a particular field by measuring the intensity of associations between keywords in literature published in a particular field of study[10]. The number of research trend articles related to diseases on the KCI site were cancer (113), suicide (56), obesity (55), diabetes mellitus (17), Alzheimer's disease (11), hypertensive diseases (10), and heart disease (7). Studies on various factors affecting metabolic syndrome are being conducted. However, no research trend analysis study investigated the network using metabolic syndrome as a keyword. The purpose of this study is to provide basic data on research trends in metabolic syndrome and to suggest implications for future research directions.

This study investigates the research questions:

- RQ1: What are the research issues related to "metabolic syndrome" published in KCI journals from 2013 to 2022?
- RQ2: What are the structural characteristics and relationships between keywords related to metabolic syndrome?

2. Literature review

Several simultaneous definitions have evolved because metabolic syndrome refers to clusters of conditions other than one disease. The prevalence of metabolic syndrome is increasing at a rate that is prevalent not only in Korea but also around the world[11]. The definition of metabolic syndrome in Korea is based on the revised NCEP-ATP II[12], but the Obesity Society defined waist circumference[13]. A person may be diagnosed with metabolic syndrome if they have three or more of the following criteria: 1) triglycerides ≥150 mg/dL or medication use; 2) waist circumference >90 cm in men and >85 cm in women; 3) blood pressure ≥130/85 mmHg or antihypertensive medication use; 4) HDL cholesterol <40 mg/dL in men and <50 mg/dL in women or medication use; 5) Fasting glucose ≥100 mg/dL or medication use (insulin or oral agents). Most studies indicate that the metabolic syndrome is associated with a 5-fold increased risk for type 2 diabetes mellitus[14] approximately a doubling increased risk of cardiovascular disease[15], 2.6 to 4-fold increased risk of death from cardiovascular disease, and a 2-fold increased risk of death from other causes[16]. Therefore, lifestyle modification and weight loss should be at the core to treat or prevent metabolic syndrome and its components. As such, metabolic syndrome has a significant influence on the morbidity and mortality of representative chronic diseases; accordingly, interest in the occurrence, prevention, management, and treatment of the metabolic syndrome is increasing, and research is steadily progressing.

Network text analysis is used to investigate the relationship between languages constituting a text and enables the extraction of a network of connections among language concepts included in a text[10]. Semantic network analysis, language network analysis, keyword network analysis, and so on are forms of text network analysis, which has recently emerged as a new research methodology. Keyword network analysis can visually confirm keywords that appear simultaneously with specific keywords, and by analyzing keywords that play a central role, it is possible to identify core research topics in the academic area and confirm the intellectual structure of the discipline[17]. Existing research trend analysis mainly uses the content analysis method, but this may lack objectivity in the process of organizing and categorizing the content. On the other

hand, keyword network analysis using unstructured data has the advantage of being able to secure the objectivity of research and grasp the underlying meaning through the relationship between keywords, which is difficult to ascertain in the literature analysis method[18].

Among the network analysis indicators, the most frequently used centrality indicator is one that expresses the degree to which a node (keyword) is located at the center of the entire network. Through centrality analysis, it is possible to identify keywords that play an important role in the entire network. Connection and mediation centrality are used as centrality indicators. Link centrality is an index that measures how many other nodes a node is connected to, and the larger the number of links, the more influential it can be because it can easily spread to nearby words. Betweenness centrality is an indicator of how many mediators are in the relationship between nodes, and the higher the value, the higher the control over the flow of information in the network[10].

3. Research methodology

3.1. Data collection

As part of the data collection phase, we collected articles from the KCI database on 17 January 2023, with the keyword for metabolic syndrome. A restriction was applied on the publishing year. The collection period was limited to articles published in registered journals for the last 10 years (search period: 1.1.2013-12.31.2022). A total of 678 articles were collected in the first round, and 665 were selected for the final analysis, excluding missing abstracts or duplicate searches.

3.2. Data cleaning

The second phase involves data cleaning. First, keywords were extracted from the collected 665 articles. A total of 1129 keywords were extracted, including duplicates, and data were refined to improve the accuracy of keyword network analysis and to clearly interpret the results. Text mining was conducted using Textom for the collected keywords, and the Espresso K method was adopted, which reflects complex and proper nouns in the result value as they are[18]. “Metabolic Syndrome”, “MetS”, and “Metabolic Syndrome X”, which were used as search terms in the extracted keywords, are keywords commonly included in all data; hence, it was removed because it was difficult to give meaning to the analysis of the structural characteristics and centrality of the network. Synonyms (e.g., “older”, “aged” → “elderly”) or abbreviations (e.g., HDL, HDL-C → HDL cholesterol) were unified into one keyword. In addition, “Physical activity” and “Body composition” were unified by removing spaces. Examples of refinement standards for collected data are presented in **Table 1**.

Table 1. Keywords in every network map cluster.

Division	Method	Example
Delete	Search word	Metabolic syndrome (MetS, Metabolic syndrome X)
Integrated	Similar concept	Older, aged → Elderly Danger factor, risk factor → Risk factor Adolescent, youth → Adolescent Consumption, intake → Intake HDL, HDL-C→HDL cholesterol Serum triglyceride, TG → Triglyceride
Absorption	Unity of spacing	Physical activity → Physicalactivity Body composition → Bodycomposition Health behavior → Healthbehavior

3.3. Data analysis

Textom was used for data purification and frequency analysis of the collected data, and UCINET6 and NetDraw were used for keyword network analysis between keywords. Based on the refined data, a frequency analysis of keywords related to metabolic syndrome was performed, and a 100 × 100 1-mode matrix dataset was generated. The keyword network analysis procedure performed in this study is as follows. First, authors investigated the number of nodes, density, average connection strength, average connection distance, number of components, diameter, and network concentration to determine the structural characteristics among keywords related to metabolic syndrome. Second, a single sample mean difference test with bootstrap was performed to statistically test that the estimated density of the keyword network was not accidental. Third, authors analyzed connection and mediation centrality to find out how keyword centrality appears in the keyword network.

4. Result and discussion

4.1. Recent research trends on metabolic syndrome

The Top 20 rankings of journals with the most publications related to metabolic syndrome over the past 10 years are presented in **Table 2**. The Korean Society of Sports Science (54 articles) had the largest number of published papers, followed by the Journal of Korea Academia-Industrial Cooperation Society (27 articles), Korean Journal of Health Promotion (24 articles), Journal of Obesity & Metabolic Syndrome (22 articles), and Korean Journal of Community Nutrition (19 articles), and Journal of Nutrition and Health (19 articles) (**Table 2**). In the Top 20, exercise-related journals (Rank 1, 9, 14, 16) accounted for the most with four, and there were three food and nutrition-related journals (Rank 5, 6, 19).

The research trends by year of publication of articles related to metabolic syndrome selected for analysis are illustrated in **Figure 1**. Over the past 10 years, more than 45 papers related to metabolic syndrome have been published each year, with 77 papers in 2016 and 2019, and the lowest in 2021, with 46 papers. Over the past 10 years, metabolic syndrome studies published in Korea have been steadily conducted and published every year and have become a continuing area of interest for researchers in a situation where the prevalence of metabolic syndrome is increasing[8].

Table 2. List of journals and number of published articles.

Rank	Journal name	N[1)]	Rank	Journal name	N
1	The Korean Society of Sports Science	54	11	Journal of Digital Convergence	15
2	Journal of Korea Academia-Industrial Cooperation Society	27	12	The Korean Journal of Growth and Development	14
3	Korean Journal of Health Promotion	24	13	Korean Journal of Clinical Laboratory Science	13
4	Journal of Obesity & Metabolic syndrome	22	14	Journal of Sport and Leisure Studies	12
5	Korean Journal of Community Nutrition	19	15	The Journal of the Korea Contents Association	11
6	Journal of Nutrition and Health	19	16	Exercise Science	11
7	Journal of the Korea Convergence Society	18	17	The Korean Journal of Food and Nutrition	10
8	Journal of Wellness	18	18	Journal of Korean Biological Nursing Science	10
9	The Korean Journal of Sport	17	19	Journal of Life Science	10
10	The Korean Society of Living Environmental System	16	20	Korean Journal of Occupational Health Nursing	9

[1)] Number.

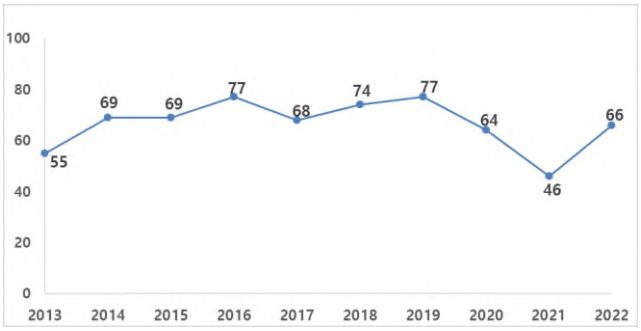

Figure 1. Number of documents per year.

4.2. Wordcloud

Keywords related to metabolic syndrome were collected and refined using the KCI journal database provided by the NRF (National Research Foundation) in Korea; among them, the top 56 keywords (frequency of occurrence of 11 or more) were selected as the subject of final network analysis. A visualization of the top 30 keywords using Wordcloud is presented in **Figure 2**.

Figure 2. Wordcloud for metabolic syndrome related keywords.

4.3. Keyword frequency analysis

As a result of frequency analysis on the extracted keywords, “Obesity” (129 times) was the only keyword that showed a frequency of more than 100 times, “Health” (92 times), “Exercise” (87 times), “Risk factor” (77 times), “Women” (77 times), “Elderly” (66 times), and “Physical activity” (58 times) showed a frequency of more than 50 times (**Table 3**). Looking at this, metabolic syndrome research is mainly conducted with keywords such as “Obesity”, “Health”, “Risk factor”, “Exercise”, and “Physical activity” targeting “Women” and “Elderly”. In addition, the frequencies of “Women” and “Menopause” were high in relation to gender in the study subjects. Although the prevalence of metabolic syndrome is higher in men than women in Korea, this indicates a 4.88-fold increase in the probability of suffering from postmenopausal metabolic syndrome[19,20]. The frequency of age-related keywords appeared in the order of “Elderly,” “Adult”, “Middle-aged”, and “Adolescent”. This seems to reflect the fact that the prevalence of metabolic syndrome increases with age according to the National Health Examination Statistical Yearbook[20]. Studies on metabolic syndrome influencing factors were also active. As related keywords, “Exercise” and “Physical activity” related to activity and “Intake”. “Dietary” and “Nutrient” related to nutrition were ranked high. In fact, to prevent and manage metabolic syndrome, it is recommended to practice healthy lifestyles such as diet, physical activity, smoking, drinking, and stress, and to maintain a healthy weight[21]. The frequency of “Obesity” and “BMI” related to metabolic syndrome was also high. In Kim et al.’s[22] analysis of research trends on obesity, BMI was the most used obesity index in clinical studies, and observational studies reported that there were 28 studies on the relationship with other diseases related to obesity, such as diabetes

and hyperlipidemia. "KNHANES", which is widely used as a research database, also appeared as a top keyword. KNHANES, which was first started in 1998, provides raw data for free every year by dividing it into sophistication of sampling, large number of samples, and examination, health, and nutrition surveys. For this reason, it is thought to be the result of being used as secondary data for various studies[23].

Table 3. Frequency analysis of keywords related to metabolic syndrome.

Rank	Keyword	F[1)]	Rank	Keyword	F	Rank	Keyword	F	Rank	Keyword	F
1	Obesity	129	15	Korean	28	29	hs-CRP	18	41	Body	14
2	Health	92	16	Health behavior	27	29	Sleep	18	44	Strength	13
3	Exercise	87	17	BMI[2)]	25	31	Liver	17	44	Worker	13
4	Risk factor	77	17	Dietary	25	31	Hypertension	17	44	Student	13
4	Women	77	19	Nutrient	23	33	Diabetes	16	44	Program	13
6	Elderly	66	19	Adolescent	23	33	Smoking	16	48	Aerobic	12
7	Physical activity	58	21	Lifestyle	21	33	Cardiovascular disease	16	48	Qualitylife	12
8	KNHANES	49	21	Menopause	21	33	Combine Exercise	16	48	Status	12
9	Intake	41	21	Prevalence	21	33	Training	16	48	Abdominal	12
10	Disease	39	24	HDL cholesterol	20	33	Depression	16	48	Bloodlipid	12
10	Adult	39	24	Physical fitness	20	33	Fat	16	48	Triglyceride	12
12	Middle-aged	35	26	Function	19	40	Walking	15	54	Diet	11
13	Body composition	34	26	Insulin resistance	19	41	Age	14	54	Muscle	11
14	Fitness	33	26	Stress	19	41	Metabolic syndrome component	14	54	Weight	11

[1)] F: Frequency;
[2)] BMI: Body Mass Index.

Relatively recent research trends are compared with previous research trends in **Table 4** by dividing the last 10 years into 5-year periods, 1st period (2013–2017) and 2nd period (2018–2022). As a result of examining the Top 10 keywords according to the survey period, in the first period, "Obesity" (63 times) appeared the most, followed by "Exercise" (47 times), "Risk factor" (42 times), "Health" (42 times), "Elderly" (31 times), "Women" (31 times), "Physical activity" (29 times), "Intake" (23 times), "Disease" (21 times), "Fitness" (20 times) in order. In phase 2, "Obesity" (66 times) had the highest frequency of occurrence, followed by "Health" (50 times), "Women" (46 times), "Exercise" (40 times), "Elderly" (35 times), "Risk factor" (35 times), "KNHANES" (30 times), "Physical activity" (18 times), "Health behavior" (20 times), and "Adult" (20 times). The fact that "Obesity" ranked first in the frequency of appearance in both phases 1 and 2 seems to reflect the steadily increasing obesity rate[15], similar to metabolic syndrome. In addition, the keywords "Exercise", "Risk factor", "Health", "Elderly" and "Women" were all in the Top 5, although there was a slight change in ranking. Keywords that appeared only in the first period included "Korean", "Adolescent", "BMI", "Fat", "Lifestyle", "Menopause", and "Worker". During this period, studies on BMI, Fat, and Lifestyle were mainly conducted for adolescents, postmenopausal women, and workers. In particular, "Adolescent" (14 times) was not included in the top link in the second period, and this result does not seem to reflect the recent increase in the prevalence of metabolic syndrome among adolescents[24]. On the other hand, the keywords "Stress", "Hypertension", "Function", "Strength", "Health behavior", "HDL cholesterol", and "Physical fitness", which were not in the first period, newly appeared in the second period, indicating that research topics are being further subdivided. The frequency of appearance of "KNHANES" increased more in the second period (30 times) than in the first period (19 times), indicating that the use of KNHANES increased.

Table 4. Frequency analysis of keywords related to metabolic syndrome.

1 period (2013–2017)						2 period (2018–2022)					
Rank	**Keyword**	**F[1)]**	**Rank**	**Keyword**	**F**	**Rank**	**Keyword**	**F**	**Rank**	**Keyword**	**F**
1	Obesity	63	11	Adult	19	1	Obesity	66	12	Intake	18
2	Exercise	47	14	Body composition	17	2	Health	50	14	Body composition	17
3	Risk factor	42	15	Middle-aged	16	3	Women	46	15	Stress	14
3	Health	42	16	BMI	15	4	Exercise	40	16	Hypertension	13
5	Elderly	31	17	Adolescent	14	5	Elderly	35	16	Fitness	13
5	Women	31	18	Dietary	13	5	Risk factor	35	18	Dietary	12
7	Physical activity	29	18	Fat	13	7	KNHANES	30	19	Nutrient	11
8	Intake	23	20	Nutrient	12	8	Physical activity	29	19	Function	11
9	Disease	21	20	Lifestyle	12	9	Health behavior	20	19	Strength	11
10	Fitness	20	20	Menopause	12	9	Adult	20	19	Prevalence	11
11	KNHANES	19	23	Prevalence	10	11	Middle-aged	19	19	HDL cholesterol	11
11	Korean	19	24	Worker	10	12	Disease	18	19	Physical fitness	11

[1)] F: Frequency.

4.4. Keyword network analysis

4.4.1. The structural form of the network

Figure 3 shows the results of analyzing the properties of the network structure, focusing on the top 56 keywords for frequency analysis. There were 56 nodes, 0.415 densities, 22.821 average connectivity, 1.586 average connectivity, 3 diameters, 1 component, and 58.8% network centrality. This result means that one keyword is associated with an average of 1.58 different keywords, and all keywords are associated with up to three keywords. Testing the statistical significance of the entire network for metabolic syndrome using bootstrap techniques showed that the mean of the sampling distribution of the network data was 1.1545, and the standard error (SE) was 0.165, Z = 6.2824. The probability that the test statistics were observed to be higher than the absolute value of the Z-score was 0.0002, and the relationship between the data in the network was found to be statistically significant at the 5% level.

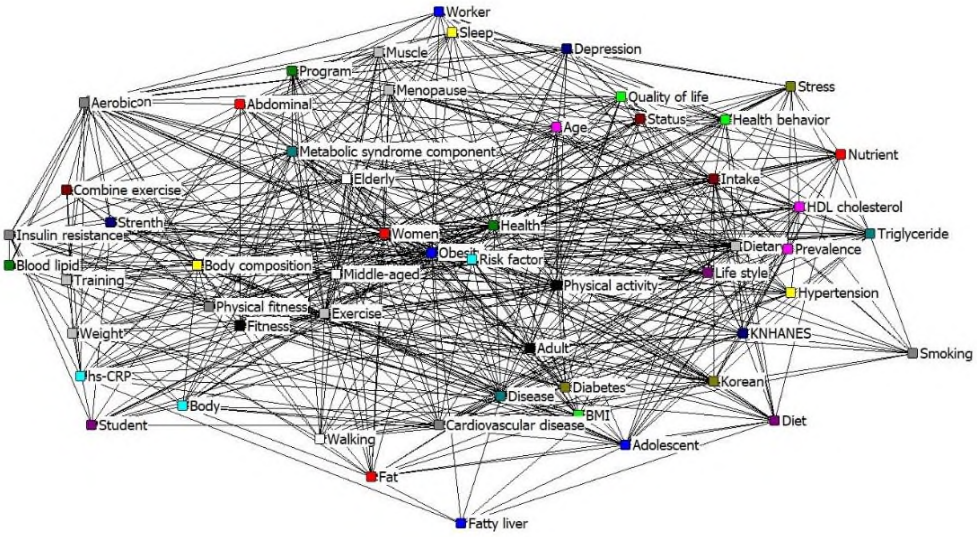

Figure 3. The overall network of metabolic syndrome keywords.

4.4.2. The structural characteristics of network

A centrality analysis was conducted to examine the influence of major keywords on the network (**Table 5**). Degree centrality analysis is used to measure the size of the influence of one keyword on other keywords, and high degree centrality means that the keyword is most connected with other keywords[25]. As a result, Obesity > Health > Exercise > Risk factor = Women > Elderly, which was in the top 5 of the frequency of occurrence, exhibited a small change in the ranking in degree centrality, but most (Elderly ranked 6th) were in the Top 5 (Obesity > Women > Exercise > Health > Risk factor). In particular, the connection centrality of 'Obesity' (0.173) and 'Women' (0.153) was high, which means that research on metabolic syndrome is being actively conducted in the obesity-related area, especially for women. On the other hand, the fact that 'Disease' has a high frequency of appearance but low link centrality indicates that the 'Disease'-related metabolic syndrome research is likely to be conducted by a small number of scholars.

Keywords with high betweenness centrality mean that they play a mediating role between different sub-topics and are expanding to other topics[25]. The Top 5 keywords with high mediation centrality (**Table 6**) are 'Obesity' (8.350) > 'Health' (4.434) > 'Women' (4.125) > 'Exercise' (4.082) > 'Risk factor' (3.662) > 'Physical activity' (2.887) had a small change in the order of occurrence frequency, but most were the same keyword. In other words, 'Obesity' and 'Health', the keywords with the highest mediation centrality, are expandable topics that connect and mediate detailed research topics in the field of metabolic syndrome in Korea. In particular, 'Middle-aged', 'Body composition', 'Metabolic syndrome component', 'Adolescent', 'Prevalence', 'Cardiovascular disease' and 'Physical fitness' are keywords that have risen above the frequency ranking, and in particular, 'Metabolic syndrome component' moved 31 places (41st → 10th rank) and 'Cardiovascular disease' 15 places (33rd → 18th rank). As a result, the 'Metabolic syndrome component' or 'Cardiovascular disease', which rose significantly in the ranking of mediation centrality rather than the frequency of occurrence, could be a suitable topic when trying to converge with other research topics in the study of metabolic syndrome. On the other hand, 'KNHANES', 'Intake', and 'Dietary' ranked lower than the frequency of occurrence.

Table 5. Centrality for keywords related to metabolic syndrome.

Degree centrality						**Betweenness centrality**					
Rank	**Keyword**	**Centrality**	**Rank**	**Keyword**	**Centrality**	**Rank**	**Keyword**	**Centrality**	**Rank**	**Keyword**	**Centrality**
1	Obesity	0.173	11	Intake	0.052	1	Obesity	8.350	11	Disease	1.412
2	Women	0.153	12	Adult	0.05	2	Health	4.434	12	Adolescent	1.183
3	Exercise	0.129	13	Body composition	0.044	3	Women	4.125	13	Fitness	1.154
4	Health	0.123	14	Disease	0.04	4	Exercise	4.082	14	KNHANES	1.056
5	Risk factor	0.109	15	Korean	0.039	5	Risk factor	3.662	15	Intake	0.989
6	Elderly	0.102	16	Physical fitness	0.034	6	Physical activity	2.887	16	Dietary	0.977
7	Physical activity	0.077	17	Dietary	0.034	7	Elderly	2.752	17	Prevalence	0.965
8	Middle-aged	0.074	18	Nutrient	0.034	8	Middle-aged	2.097	18	Cardiovascular disease	0.956
9	KNHANES	0.056	19	Menopause	0.034	9	Body composition	1.636	19	Physical fitness	0.812
10	Fitness	0.053	20	Adolescent	0.031	10	MetS component	1.491	20	Lifestyle	0.782

5. Conclusion and future work

The current research revealed that many studies on metabolic syndrome in Korea were conducted mainly in relation to obesity, and the connection centrality and mediation centrality with obesity were also the highest. By life cycle, research on the elderly > middle-aged > adults is active, but adolescents exhibiting an increase in the prevalence of metabolic syndrome have received little academic interest in the past five

years. Regarding the influencing factors of metabolic syndrome, studies on physical activity related to exercise, physical activity, and physical fitness keywords, nutritional factors related to intake, dietary, and nutrient keywords, and stress were active, but other factors (e.g., smoking, drinking, demographic factors, etc.) have received little attention.

This study has limitations in generalizing the research results owing to the following points. First, it is possible that unpublished dissertations or dissertations that deviate from the search terms were omitted by analyzing only thesis keywords in KCL-listed journals from a network perspective. Second, in the process of refining words, there is a possibility that the researcher's subjectivity was involved in the decision-making of similar and negative words. Nevertheless, through keyword network analysis of metabolic syndrome-related studies over the past 10 years, the process of change in research was identified and structural relationships between keywords explored. There is a difference from previous research trend studies that identified quantitative trends in the categories set by the researcher or those that conducted network analysis with words that appeared in bibliographies (titles). This study suggests a combination of directions and specific research topics for future research. In the future, it will be necessary to classify papers related to metabolic syndrome into subcategories such as research topics and subjects, analyze the contents, and grasp the relevance between keywords in various ways through topic modeling.

Acknowledgments

This work was supported by Changshin University Research Fund of 2022-081.

Author contributions

Conceptualization, ESH and YKO; methodology, YKO; investigation, ESH; formal analysis, ESH and YKO; data curation, YKO; writing—original draft preparation, ESH and YKO; writing—original draft, ESH and YKO; review and editing, ESH and YKO; visualization, ESH and YKO. All authors have read and agreed to the published version of the manuscript.

Conflict of interest

The authors declare no conflict of interest.

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