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Visualizing Scientific Landscape of Physical Exercise Impact on Glucose Levels: A Bibliometric Approach

Rizaldo Septiano Robaeni [a,1,*], Lucki Hersya Rahman [a,2]

[a] Fakultas Pendidikan Olahraga dan Kesehatan, Universitas Pendidikan Indonesia, Indonesia
[1] Rizaldo.septiano@upi.edu *; [2] luckirachman@upi.edu
* corresponding author

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ABSTRACT

This study discusses the development of research on the relationship between physical exercise and glucose levels through bibliometric analysis using computational mapping with VOSviewer. The research data was obtained from the Google Scholar database via the Publish or Perish application. The titles and abstracts of the articles were used as keywords to target articles related to "Physical Exercise and Glucose." A total of 338 articles were identified as relevant to the searched keywords, covering a period of the last 10 years from 2015 to 2025, and originating from various journals and publications. A detailed examination based on the year of publication reveals the following distribution: 54 articles were published in 2015, 43 in 2016, 45 in 2017, 33 in 2018, 37 in 2019, 40 in 2020, 29 in 2021, 31 in 2022, 19 in 2023, 27 in 2024, and 12 articles in 2025. Based on the collected data, we observe a varied publication trend over time. The use of VOSviewer to represent this data is very important because the results from VOSviewer guide us specifically, highlighting frequently occurring terms such as "uptake," "activity," and others.

INTRODUCTION

In the realm of physical exercise, numerous supporting factors play a crucial role in helping individuals achieve their fitness goals. Each person engages in physical activity for different reasons some aim to become competitive athletes, while others exercise simply to maintain their physical health. Regardless of these varied motivations, one constant remains: the importance of sports science in making physical activity measurable, structured, and evidence-based. Scientific understanding allows for objective assessment and effective exercise planning, ensuring optimal health benefits. This is especially relevant given the growing body of evidence showing that even light-to-moderate physical activity is associated with a significantly lower risk of premature mortality, and that higher physical activity levels regardless of intensity contribute to better health outcomes in a dose-response manner (Ekelund et al., 2019)). Sports science is very important for coaches and sports enthusiasts to understand the best methods and goals to be achieved for their athletes (Rohendi & Rustiawan, 2020). Within sports science, several aspects are discussed, including human psychology, physiology, anatomy, tactics, and technique. In practice, we often see that only numbers and techniques are given by coaches to their athletes, whereas to reach peak athletic performance, the factors mentioned above are very important,

especially physiology, which is often overlooked. As researchers, this is an interesting topic to explore, as we can see the importance of physical exercise impacting an individual's physiology, either directly or indirectly.

Physiological aspects that can be directly observed from physical exercise typically include pulse rate, blood pressure, lung capacity, and changes in body mass index (BMI). However, one crucial indicator that is often overlooked is blood glucose level. While exercise is widely recognized for its cardiovascular and respiratory benefits, its role in modulating metabolic markers such as glucose regulation requires greater attention especially in the context of increasing metabolic disorders among youth. Recent studies, such as the one conducted by (Dwipa et al., 2025), provide compelling evidence that consistent aerobic activity like a 2.4 km run can significantly reduce blood glucose levels in athletes. Their experimental research on handball players demonstrated a measurable decrease in glucose levels following running interventions, emphasizing the importance of incorporating blood glucose monitoring into physical training programs, not only for athletes but also for broader public health initiatives. Research has shown that physical activity, particularly moderate to vigorous intensity, is associated with improvements in several cardiometabolic biomarkers, including glucose metabolism, in school age children and adolescents (Poitras et al., 2016). Indonesia itself is one of the countries with a high number of diabetes cases. According to the International Diabetes Federation, Indonesia had 20.4 million cases in 2024, and it is estimated to reach 28.6 million cases by 2050 (Ministry of Health, 2024). Blood glucose is the primary energy source for body cells derived from dietary carbohydrates, and its regulation is crucial to prevent metabolic diseases such as type 2 diabetes (Zheng et al., 2018)As blood glucose is one of the body's energy sources, physical exercise will directly affect blood glucose levels. Physical exercise improves blood glucose control in type 2 diabetes, regular exercise can maintain or slow the progression of type 2 diabetes, and it is estimated to have beneficial effects for type 1 diabetes patients as well (Colberg et al., 2016) In addition, physical exercise has also been shown to improve general physical fitness, as indicated by Body Mass Index (BMI) and cardiorespiratory endurance (Rido et al., 2025) which may indirectly influence glucose metabolism and diabetes risk.

There is an analytical technique that can be used to understand the development of research interest in sports, especially on the topic of physical exercise and blood glucose levels. This analysis is called bibliometric analysis. Bibliometrics is a method that uses quantitative data from scientific publications such as the number of articles, citations, and author collaborations to measure research productivity and impact. This approach is particularly useful in areas such as exercise science, where the role of physical activity as a therapeutic intervention in metabolic disorders, including type 2 diabetes, has been extensively studied and documented through a growing body of scientific literature (Pedersen & Saltin, 2015) Through this approach, we can identify trends in scientific development, collaboration patterns among researchers, and systematically map how a field of knowledge evolves over time using mathematical techniques and specialized software (Donthu et al., 2021) During the

preparation of this research, the author found several articles discussing bibliometric analysis in various fields. For example, (Putra & Sari, 2022) analyzed the development of research in sports instrumentation. Meanwhile, (Nurfauzan & Faizatunnisa, 2021) examined COVID19 research trends in Indonesia, particularly in business and management. (Supinah & Soebagyo, 2022)) highlighted the use of information and communication technology (ICT) in mathematics learning through bibliometric approaches. Additionally, (Gazali, 2023) analyzed research trends in curriculum and physical education. Equally important, (Farokhah et al., 2023) explored the development of literature on Self-Regulated Learning using bibliometric methods. More recently, (Zhannisa et al., 2025) conducted a study using the FITT (Frequency, Intensity, Time, Type) training project as an evidence-based approach in physical activity research, highlighting the importance of structured interventions in improving anaerobic endurance and physical learning outcomes. These findings provide a rich picture of how bibliometrics is used to understand research patterns and trends across various disciplines. Bibliometric analysis has proven to provide a comprehensive overview of the studied topic. Therefore, the author feels it is necessary to conduct this analysis as it offers significant benefits in understanding the field of physical exercise and its influence on blood glucose levels. The results of this analysis can map existing research and illustrate related research trends, which in the future can encourage the development of evidence-based practices in metabolic health and sports.

We observe that discussions on the effect of physical exercise on blood glucose levels have not been thoroughly studied. Therefore, a relevant literature-based review is needed to comprehensively address this topic. Moreover, there is a gap where research on the relationship between physical exercise and blood glucose control is still dominated by individual clinical studies without a comprehensive mapping of publication trends over time. Based on several articles found, there has been no in-depth bibliometric analysis on this topic, especially within the last ten years, from 2015 to 2025, using the VOSviewer application. Therefore, through this research, the author intends to conduct computational mapping using VOSviewer on data obtained from Google Scholar with the help of the Publish or Perish application, aiming that in the future academics and researchers can identify frequently studied themes and topics as well as those that are rarely explored, so other researchers can choose the right topics to develop in subsequent studies.

Physical exercise has now become an integral component in the management of metabolic conditions, particularly diabetes mellitus. Despite this, systematic implementation of structured exercise programs has not yet been fully integrated into standard protocols for blood glucose regulation—whether for healthy individuals, those with prediabetes, or patients diagnosed with diabetes. This gap is concerning given the substantial body of evidence indicating that physical activity significantly reduces blood glucose levels and enhances insulin sensitivity. As demonstrated by (Poitras et al., 2016) regular moderate-to-vigorous physical activity is associated with improved insulin dynamics and metabolic health outcomes in children and adolescents. Similarly, (Lavie et al., 2019) emphasize that

increased physical activity and improved cardiorespiratory fitness serve as powerful tools in preventing and managing chronic metabolic diseases, including type 2 diabetes mellitus.

In light of these findings, a growing number of academic studies have examined various types of physical exercise and their specific effects on blood glucose regulation. The diversity and volume of these studies provide a strong foundation for bibliometric analysis, a method used to map research trends by identifying frequently explored topics, key reference sources, and the most influential journals, institutions, and countries. Recognizing the critical role of blood glucose control in public health and chronic disease prevention, this study aims to address the information gap by conducting a bibliometric analysis on the relationship between physical exercise and glucose metabolism. The insights gained are expected to assist health practitioners, fitness professionals, and academics in understanding current research directions and applying evidence-based strategies to improve population health outcomes.

The urgency of this research is to inform coaches, health practitioners, and academics that extensive research on the relationship between physical exercise and blood glucose has been conducted. This can increase confidence that physical exercise interventions are essential in blood glucose management, and academics can identify major topics that have rapidly developed in this field. It is hoped that this will inspire other researchers to continue developing related research, especially in the context of physical exercise interventions to effectively and sustainably control blood glucose levels.

METHOD

The data used in this study were collected from scientific articles published online and accessible through Google Scholar. The choice of Google Scholar as the primary source was based on its open access nature, allowing unrestricted access to a wide range of scholarly publications. This platform is widely recognized and commonly used among researchers and academics, especially in Indonesia, due to its convenience and comprehensiveness in retrieving relevant literature. One of the key advantages of Google Scholar lies in its user-friendly interface and ability to locate recent scientific articles, research findings, and other relevant references efficiently. Furthermore, Google Scholar provides interlinked citation data, enabling researchers to trace related works with ease, ultimately saving time and effort in the literature review process. Its extensive database coverage, without subscription fees, adds significant value for researchers seeking high quality academic resources. Additionally, the platform offers citation metrics, which are beneficial for evaluating the impact and credibility of scholarly articles, thereby enhancing the overall quality of research and publication outputs.

To support the data retrieval process, this study also utilized the Publish or Perish application, which allows for efficient extraction and analysis of article metadata. Publish or Perish is specifically designed for academic use, helping individual researchers locate and evaluate scholarly literature based

on a range of bibliometric indicators (Aulianto et al., 2019) This tool streamlines the selection of articles from online databases by providing detailed information such as citation counts, author names, article titles, publication years, publishers, and DOIs. As a result, the data obtained are both comprehensive and suitable for further analysis.

Research Subject

The subjects in this study are not human participants, but rather scientific publication documents discussing the relationship between physical exercise and blood glucose levels. The population in this context includes all scholarly articles available online and accessible through the Google Scholar database during the period from 2015 to 2025.

A total of 370 scientific articles were selected as the sample using a combination of keywords in both Indonesian and English, including: “physical exercise”, “glucose level”, “blood sugar”, and “exercise and glucose metabolism.” The selection of articles for this study was guided by several inclusion criteria to ensure relevance and analytical suitability. First, the articles had to be scientific journal publications that specifically addressed the relationship between physical exercise and its impact on blood glucose regulation. This thematic focus was essential to maintain the integrity and precision of the analysis. Second, each article was required to include complete metadata such as title, author, year of publication, number of citations, and the journal source so that the data could be processed effectively using bibliometric tools like *Publish or Perish* and *VOSviewer*. Additionally, only articles published within the ten year range from 2015 to 2025 were considered, to ensure the inclusion of up to date and relevant research findings. Finally, the articles had to be written in either English or Indonesian to align with the linguistic capabilities available for analysis.The characteristics of the analyzed articles vary in terms of research type (experimental studies, longitudinal studies, metaanalyses, systematic reviews), target population (adults, individuals with diabetes, obese individuals), and the type of exercise intervention examined (aerobic, resistance, or combined exercises). Thus, the unit of analysis in this study is scientific documents that reflect the development of scholarly knowledge in the field of the relationship between physical exercise and blood glucose levels.

Research Procedure

This study employed a bibliometric method to analyze scientific publications related to physical exercise and blood glucose levels within the time frame of 2015 to 2025. The research procedure was conducted through four main stages:

Data collection using the Publish or Perish application.

For researchers who have not yet installed this application, it can be downloaded and installed on a computer or laptop. Once installed, the application is ready for immediate use. The use of Publish

or Perish in bibliometric research has been documented in various studies, including the work of (Al Husaeni & Nandiyanto, 2021) In this study, the author conducted searches using several keywords: "physical exercise", "glucose levels", "physical exercise", "glucose level", "blood sugar", and "exercise and glucose metabolism", targeting journal articles published between 2015 and 2025.

Data processing using Microsoft Excel.

The data obtained through Publish or Perish were saved in Excel format. In Microsoft Excel, the data were organized and refined to ensure that the selected publications from the last ten years were relevant and clearly visible for further analysis.

Data analysis using VOSviewer.

The next step involved the use of VOSviewer, a software tool designed to process bibliometric data from the previously collected articles. VOSviewer enables researchers to build and visualize connections between publications and to represent specific information through bibliometric mapping (van Eck & Waltman, 2010) The application procedure for VOSviewer has been demonstrated in studies such as that by (Utami & Karlina, 2022)

Interpretation of the analysis results from VOSviewer.

The final step involved discussing the analytical results generated by VOSviewer. These results are displayed in three types of visualizations: network visualization, overlay visualization, and density visualization, each of which can be selected based on the researcher's needs. In addition to displaying visual results, VOSviewer also identifies clusters and shows which keywords belong to which cluster. This feature greatly facilitates the interpretation and presentation of bibliometric findings.

RESULTS AND DISCUSSION

Based on the data search results using the Publish or Perish application from the Google Scholar database, various research titles relevant to the keywords determined by the author were obtained. From these search results, a total of 370 articles in the form of metadata were collected and then described in detail using Microsoft Excel. The composition of this data includes information such as: number of citations, author names, article titles, publication year, journal source, publisher name, article link, citation link, Google Scholar ranking (GSRank), search date, document type, DOI, ISSN, citation link, volume, issue, starting page, ending page, citations per year, citations per author, number of authors, article age, abstract, full text link, and other related links. The author presents a table detailing the articles obtained through the aforementioned application. Table 1 contains several example articles that will be analyzed using the VOSviewer application, where the author selects the top 20 articles with the highest number of citations within the period from 2015 to 2025 that are truly relevant to the topic of physical exercise and glucose levels.

Tabel 1. Data on Physical Exercise and Glucose Level Articles

Data on Physical Exercise and Glucose Level Articles				
Authors	**Title**	**Year**	**Citation**	**Reference**
SR Colberg, RJ Sigal, JE Yardley, MC Riddell…	Physical activity/exercise and diabetes: a position statement of the American Diabetes Association	2016	3607	pmc.ncbi.nlm.nih.gov
M Hargreaves, LL Spriet	Skeletal muscle energy metabolism during exercise	2020	1174	nature.com
MA Nystoriak, A Bhatnagar	Cardiovascular effects and benefits of exercise	2018	1062	frontiersin.org
BH Goodpaster, LM Sparks	Metabolic flexibility in health and disease	2017	982	cell.com
MC Riddell, IW Gallen, CE Smart, CE Taplin…	Exercise management in type 1 diabetes: a consensus statement	2017	980	thelancet.com
BK Pedersen	Anti-inflammatory effects of exercise: role in diabetes and cardiovascular disease	2017	807	Wiley Online Library
I SanMillán, GA Brooks	Reexamining cancer metabolism: lactate production for carcinogenesis could be the purpose and explanation of the Warburg Effect	2017	726	academic.oup.com
J Kim, AS Campbell, J Wang	Wearable noninvasive epidermal glucose sensors: A review	2018	623	Elsevier
MM AdevaAndany, M GonzálezLucán…	Glycogen metabolism in humans	2016	610	Elsevier
JP Kirwan, J Sacks…	The essential role of exercise in the management of type 2 diabetes	2017	602	pmc.ncbi.nlm.nih.gov
GD Cartee, RT Hepple, MM Bamman, JR Zierath	Exercise promotes healthy aging of skeletal muscle	2016	572	cell.com
L Sylow, M Kleinert, EA Richter…	Exercisestimulated glucose uptake—regulation and implications for glycaemic control	2017	560	nature.com
H Yanai, H Yoshida	Beneficial effects of adiponectin on glucose and lipid metabolism and atherosclerotic progression: mechanisms and perspectives	2019	518	mdpi.com
J Peake, P Della Gatta, K Suzuki…	Cytokine expression and secretion by skeletal muscle cells: regulatory mechanisms and exercise effects	2015	507	eprints.qut.edu.au
K Pinckard, KK Baskin, KI Stanford	Effects of exercise to improve cardiovascular health	2019	487	frontiersin.org
R Kjøbsted, JR Hingst, J Fentz, M Foretz…	AMPK in skeletal muscle function and metabolism	2018	484	pmc.ncbi.nlm.nih.gov
MM AdevaAndany, N PérezFelpete…	Liver glucose metabolism in humans	2016	483	portlandpress.com
M Evans, KE Cogan, B Egan	Metabolism of ketone bodies during exercise and training: physiological basis for exogenous supplementation	2017	480	Wiley Online Library

O Varlamov, CL Bethea, CT Roberts Jr	Sexspecific differences in lipid and glucose metabolism	2015	476	frontiersin.org
JP Thyfault, A Bergouignan	Exercise and metabolic health: beyond skeletal muscle	2020	471	Springer

Next, Figure 1 presents information on the development of research in the field of physical exercise, specifically focusing on the relationship between physical exercise and blood glucose levels, published between 2015 and 2025 and sourced from Google Scholar.

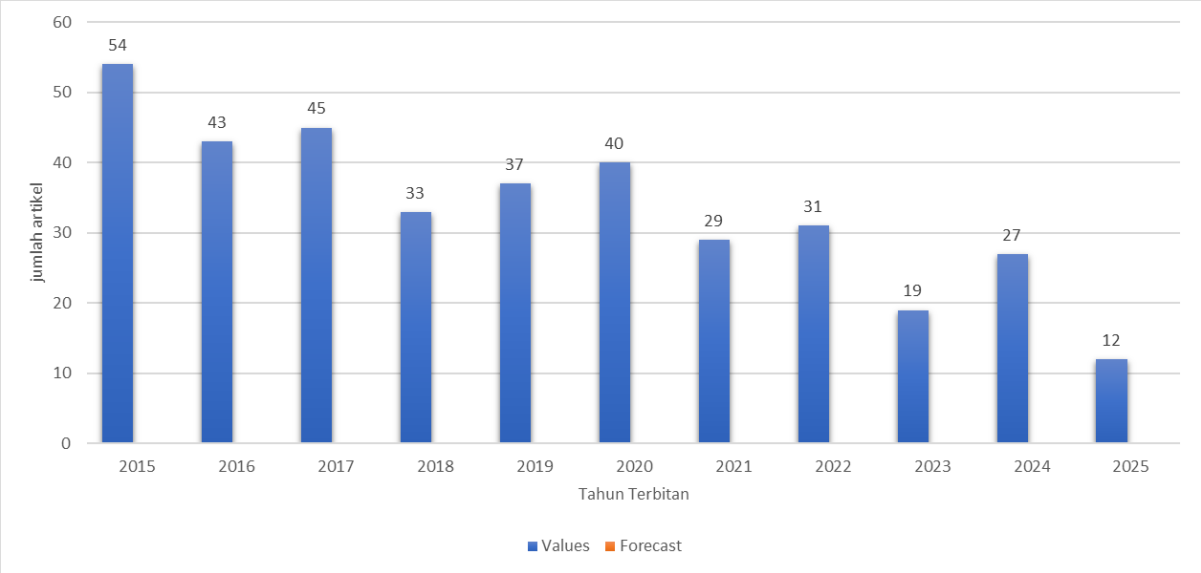

Figure 1. Trends in Scientific Research on Physical Exercise and Blood Sugar Levels

Figure 1 illustrates the diverse development of research in the field of physical exercise and its relationship with blood glucose levels. Over the past ten years, a total of 370 journal articles have been published in various academic journals and by a range of publishers, with an average of 27 articles per year. Examples of journals include the Journal of Physical Exercise and Blood Glucose, Journal of Exercise Physiology, Journal of Clinical Exercise Science, Journal of Metabolic Science, and the International Journal of Exercise and Metabolism. Notable publishers include Taylor & Francis, Journals.humankinetics.com, Cambridge.org, Springer, NCBI (PubMed), and ResearchGate, among others.

In 2015, the number of publications peaked at 54 articles, indicating a strong interest in exploring the impact of physical exercise on blood glucose levels during that period. However, after 2015, there was a gradual decline in publication numbers, despite slight increases in certain years such as 2017 (45 articles) and 2020 (40 articles). Overall, the trend shows a significant decrease, particularly in the most recent years. For instance, 2018 and 2021 saw sharp drops to 33 and 29 articles, respectively. The most dramatic decline occurred in 2023, with only 19 articles published. In 2025, only 12 articles were recorded so far, although this number may increase as the year has not yet ended.

These fluctuations may reflect shifts in research focus, funding availability, or changing priorities within the field of physical exercise and blood glucose management. The noticeable decline in publication numbers in recent years could also signal the need to revitalize interest and support for research in this domain. Overall, the data suggest that while there was significant interest at the beginning of the period, attention to research on physical exercise and blood glucose has declined, indicating the need for strategic efforts to boost publication rates and advance research development in the future.

Discussion

After the data were extracted and saved from Publish or Perish, the dataset was imported into VOSviewer to facilitate bibliometric analysis and computational mapping. VOSviewer was employed to generate a visual representation of keyword co-occurrence networks, enabling the identification of prevailing themes and conceptual linkages within the literature. The initial mapping process yielded a total of 323 unique keywords. To refine the analysis and enhance thematic relevance, a systematic selection process was undertaken, during which 113 keywords were retained based on their direct association with the primary focus of the study—namely, the relationship between physical exercise and blood glucose regulation. This selection process involved iterative screening and expert judgment to exclude general, redundant, or peripheral terms, thereby ensuring that the resulting map accurately reflected the conceptual structure of the field. The curated set of keywords formed the basis for subsequent cluster analysis, allowing for the identification of major research domains and emerging patterns relevant to exercise physiology and metabolic health.

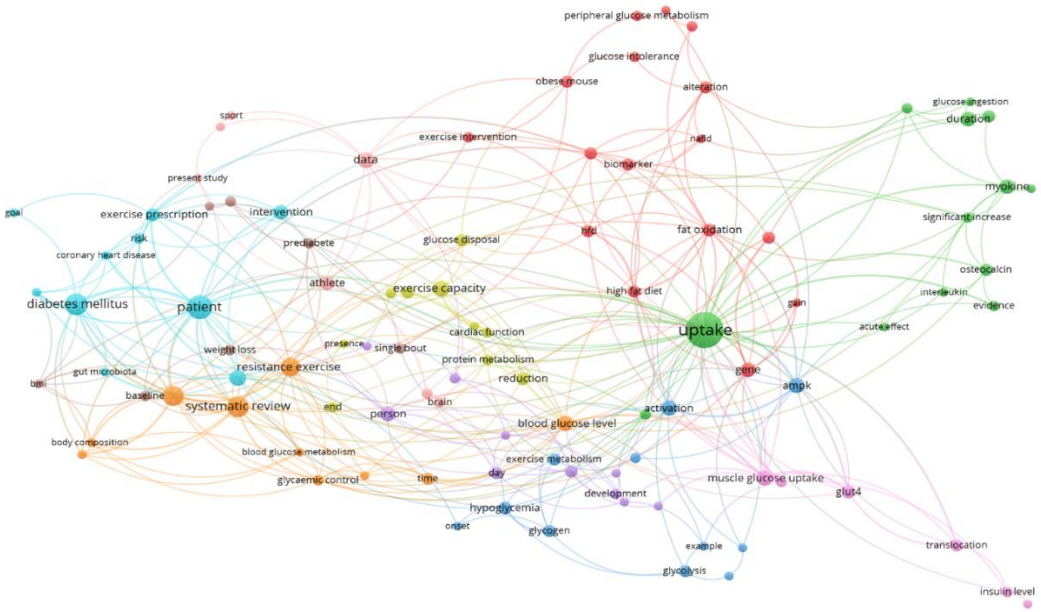

Figure 2. Visualization of Keyword Relationships in Physical Exercise and Glucose Studies

Visualization of Computational Mapping Results Reveals Nine Main Clusters Identified by Different Colors. The cluster analysis reveals nine distinct thematic areas, each highlighting unique

aspects of the relationship between physical exercise and glucose metabolism. Cluster 1 (Dark Green) focuses on the *molecular and biochemical mechanisms of physical exercise*, incorporating keywords such as uptake, activation, gene, myokine, osteocalcin, interleukin, and glucose ingestion. This cluster underscores how exercise activates molecular pathways that promote glucose uptake in muscle tissues, driven by the release of myokines and hormones like osteocalcin and interleukin. These processes involve gene expression changes associated with energy metabolism and insulin sensitivity, emphasizing how exercise intensity and duration influence biological effects on blood glucose regulation. Cluster 2 (Red) centers on *peripheral glucose metabolism and dietary influence*. It includes terms like glucose tolerance, obesity, fat oxidation, and exercise intervention, highlighting how physical activity affects glucose metabolism in peripheral tissues such as muscle and fat. This cluster also addresses the role of exercise in improving glucose tolerance in individuals with obesity or metabolic disorders, examining how exercise induced fat oxidation and metabolic biomarkers contribute to better glucose control.

Cluster 3 (Light Blue) is oriented toward the *clinical aspects and interventions for patients*, with main keywords such as diabetes mellitus, exercise prescription, coronary heart disease, and prediabetes. This cluster explores the therapeutic use of exercise in clinical populations, assessing its role in managing diabetes, reducing complications from cardiovascular disease, and enhancing glycemic control. These studies help inform personalized exercise prescriptions and rehabilitation strategies tailored to individual health conditions. Cluster 4 (Orange) highlights the *effects of resistance training and systematic reviews*. Key terms like resistance exercise, body composition, glycemic control, and systematic review reflect a focus on evaluating how resistance training influences muscle mass, basal metabolism, and insulin sensitivity. This cluster also investigates how resistance exercise affects gut microbiota, linking these changes to improved glucose metabolism.

Cluster 5 (Yellow) deals with *exercise capacity and organ function*, particularly examining how exercise influences glucose disposal and cardiac performance. With keywords such as exercise capacity, glucose disposal, and cardiac function, this cluster demonstrates that enhanced physical capacity contributes to better heart health and supports effective glucose regulation through improved protein and metabolic functioning. Cluster 6 (Dark Blue) explores *energy metabolism and hypoglycemia*, with a focus on glycogen storage and glycolysis. Keywords like hypoglycemia, glycogen, and glycolysis point to the mechanisms by which energy is produced during exercise and the risk of low blood sugar levels when energy demands outpace glucose availability. Cluster 7 (Brown) centers on *glucose transport mechanisms and insulin's role*, featuring terms like muscle glucose uptake, GLUT4, and insulin level. This cluster delves into how exercise promotes GLUT4 transporter activity in muscle cells, enhancing insulin sensitivity and supporting glucose regulation in both healthy and diabetic individuals. Cluster 8 (Light Purple) examines *blood glucose changes and systemic effects*, with keywords including blood glucose level, exercise metabolism, and brain. The studies in this cluster

investigate how exercise induced changes in glucose levels affect broader physiological systems, including brain function and cognitive performance, offering insights into systemic energy balance. Finally, Cluster 9 (Light Yellow) reinforces the *synergy between exercise capacity and metabolism*. Keywords such as exercise capacity, protein metabolism, and cardiac function illustrate the interconnected roles of physical performance, protein processing, and cardiovascular health in maintaining blood glucose balance and overall metabolic wellbeing.

"Collectively, these thematic clusters offer a nuanced and integrative understanding of the multifactorial role that physical activity plays in glucose regulation and overall metabolic health. At the molecular level, exercise has been shown to modulate key intracellular signaling pathways, including AMPK and Akt, which contribute to enhanced glucose uptake and improved insulin sensitivity. These molecular responses are further supported by physiological adaptations, such as increased mitochondrial biogenesis, improved capillary density, and greater muscle glucose transporter (GLUT4) expression, particularly in skeletal muscle. Beyond the cellular and tissue levels, the clusters also emphasize the translational and clinical implications of these findings, highlighting the efficacy of structured exercise programs as non-pharmacological interventions for the prevention and management of metabolic disorders, notably type 2 diabetes mellitus and insulin resistance. Altogether, this body of evidence reinforces the essential role of physical activity as a cornerstone in maintaining glucose homeostasis, reducing metabolic risk, and supporting long-term human health and physiological resilience."

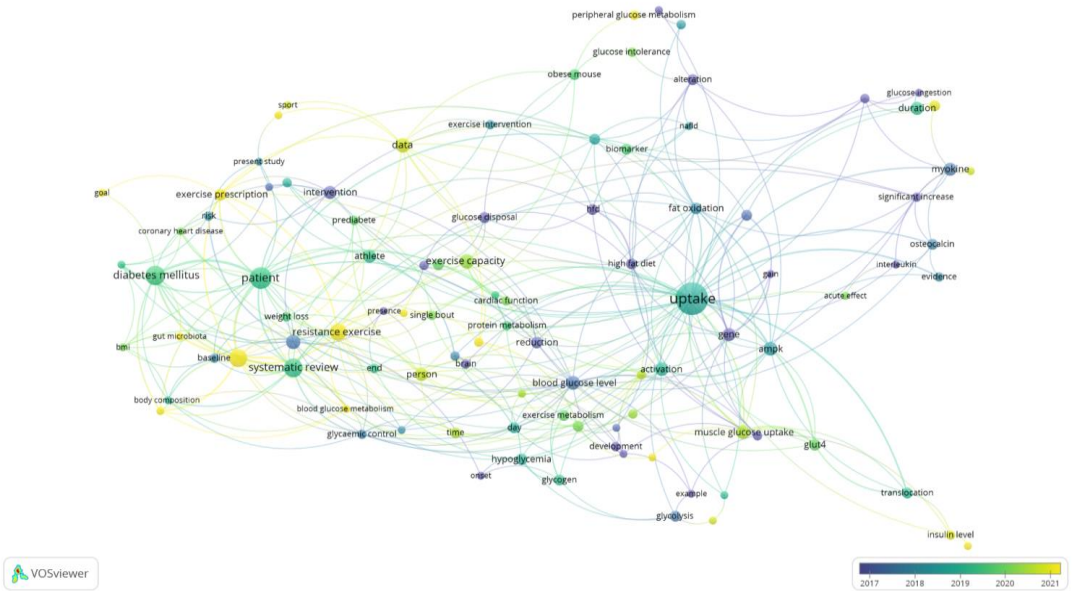

Figure 3. Visualization of Keyword Relationships in Physical Exercise and Blood Glucose Research by Year

This network visualization illustrates the rich and diverse trajectory of research in the field of

glucose metabolism and physical activity. At the center of the image, the word "uptake" stands out as a focal point, highlighting the critical role of glucose uptake in various studies. The varying sizes of the nodes naturally reflect the level of attention each term has received larger nodes indicate key focal areas in the body of research. Each node's color represents a time gradient from 2017 to 2021, showcasing how research themes have evolved over the years.

Shades of blue and purple reflect keywords that have been central since the early stages of the research period, serving as the foundational concepts. As time progresses, green tones emerge around 2019–2020, signaling a growing interest in certain topics. Bright yellow hues mark the most recent and trending research themes, particularly from 2020 to 2021. Within this context, terms like "systematic review" and "patient" appearing in green indicate that clinical aspects of physical exercise and glucose regulation have gained substantial attention in recent years. Meanwhile, the emergence of terms such as "glucose ingestion," "duration," and "significant increase" in bright yellow suggests an increasing focus on specific variables and novel findings being actively explored by the research community.

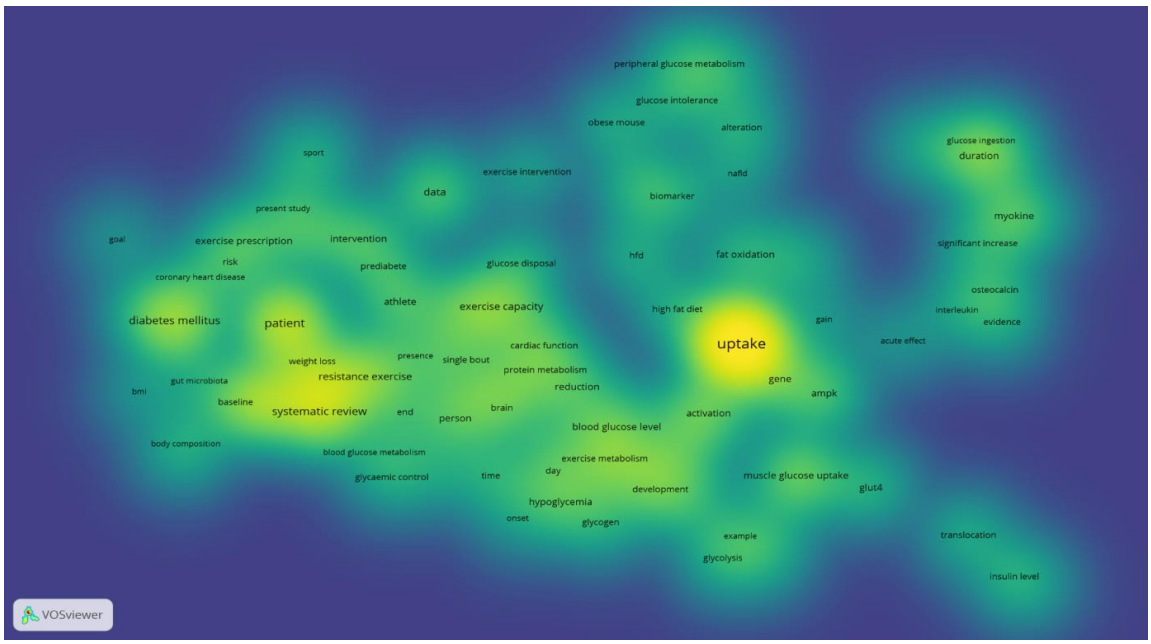

Figure 4. Density Visualization of Keywords in Studies on Physical Exercise and Blood Glucose

In this image, each frequently occurring keyword within the body of scientific publications related to "uptake" is visualized based on its frequency and its connection to other keywords. The brightest areas (yellow) indicate regions with the highest keyword density, meaning these terms appear very frequently and are highly interconnected with other terms. The keyword "uptake" serves as the central node, surrounded by other important terms such as "patient," "systematic review," "resistance exercise," "diabetes mellitus," and "exercise capacity." As the color shifts toward green and blue, the keyword density decreases, indicating terms that appear less frequently or are less connected.

Additionally, several groups of keywords form clusters, such as the group related to "myokine,"

"duration," "osteocalcin," and "insulin level," which are located at the periphery of the map—indicating the emergence of more specialized research topics. This visualization helps identify central themes and recent research trends in the analyzed field, while also revealing the relationships between the main concepts within the literature.

CONLCUSION

This bibliometric analysis reveals a comprehensive and evolving landscape of scientific research examining the relationship between physical exercise and blood glucose regulation. Through computational mapping using VOSviewer, a total of nine distinct clusters were identified, each representing specific thematic areas ranging from molecular mechanisms and clinical interventions to systemic metabolic effects and emerging niche topics. At the core of the network lies the concept of "uptake," which consistently appears as a central keyword, indicating its fundamental role in glucose metabolism studies. Supporting terms such as "exercise capacity," "diabetes mellitus," and "insulin level" reflect the interdisciplinary nature of the field, combining insights from physiology, endocrinology, clinical medicine, and sports science. The temporal visualization highlights a dynamic shift in research trends. Foundational keywords from 2017–2018 (e.g., "activation," "GLUT4") gave way to a growing focus on clinical applications and systematic reviews in 2019–2020, while emerging variables like "glucose ingestion" and "duration" gained prominence in 2020–2021. This trend suggests an increasing interest in individualized and evidencebased exercise interventions aimed at improving glycemic outcomes. The keyword density mapping further emphasizes the thematic dominance of clinical and physiological mechanisms, while also identifying specialized areas such as myokine signaling, osteocalcin release, and gut microbiota interactions as promising frontiers for future exploration.In conclusion, the bibliometric mapping provides not only a structured overview of past and current research priorities but also offers strategic direction for future investigations. As the global burden of diabetes continues to rise, interdisciplinary and evidencebased approaches involving physical activity are increasingly vital in both preventive and therapeutic contexts.

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