



QUALITY IN SPORT

eISSN 2450-3118 · Open Access · Peer-reviewed

apcz.umk.pl/QS

Nicolaus
University in Toruń

Copernicus



ŚCIBOR, Klaudia, WARDYN, Wiktor, SIKORSKA, Laura Magdalena, KUJAWA, Julia Anna, BONIECKA, Magdalena, OSSOWSKA, Dominika Adrianna, JANKOWSKA, Anna, KOSTAŃSKA, Aleksandra, and ŁASZCZYK, Michał. Exercise Joins the Prescription: Benefits and Risks of Pairing Physical Activity with Metformin for Body Weight Reduction. *Quality in Sport*. 2026;76:76013. <https://doi.org/10.12775/QS.2026.76.76013>

ARTICLE TIMELINE

Received: 11.09.2026. Revised: 12.09.2026. Accepted: 14.09.2026. Published: 27.09.2026.

The journal has been awarded 20 points in the parametric evaluation by the Polish Ministry of Higher Education and Science (Annex to the announcement of 05.01.2024, No. 32553). Unique Journal Identifier: 201398. Scientific disciplines assigned: Economics and Finance (Field of Social Sciences); Management and Quality Sciences (Field of Social Sciences).

Punkty Ministerialne z 2019 – aktualny rok 20 punktów. Załącznik do komunikatu Ministra Szkolnictwa Wyższego i Nauki z dnia 05.01.2024 Lp. 32553. Posiada Unikatowy Identyfikator Czasopisma: 201398. Przypisane dyscypliny naukowe: Ekonomia i finanse (Dziedzina nauk społecznych); Nauki o zarządzaniu i jakości (Dziedzina nauk społecznych). © The Authors 2026.

OPEN ACCESS · CC BY-NC-SA 4.0 This article is published with open access under the License Open Journal Systems of Nicolaus Copernicus University in Toruń, Poland, and is distributed under the terms of the Creative Commons Attribution Non-commercial Share Alike License (<http://creativecommons.org/licenses/by-nc-sa/4.0/>), which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the work is properly cited. The authors declare no conflict of interest regarding the publication of this paper.

Exercise Joins the Prescription: Benefits and Risks of Pairing Physical Activity with Metformin for Body Weight Reduction

Klaudia Ścibior¹

ORCID <https://orcid.org/0009-0008-9500-5109>

e-mail: scibior.klaudiaa@gmail.com

¹ Szpital Morski im. PCK, Gdynia, Poland

Wiktor Wardyn²

ORCID <https://orcid.org/0009-0002-6133-2220>

e-mail: wiktor12398@gmail.com

² Szpital Wojewódzki w Toruniu im. L. Rydygiera, Poland

Laura Magdalena Sikorska³

ORCID <https://orcid.org/0009-0009-5326-779X>

e-mail: laura666@onet.pl

³ St. Vincent de Paul Municipal Hospital in Gdynia, Poland

Julia Anna Kujawa⁴

ORCID <https://orcid.org/0009-0003-2502-8552>

e-mail: jxkujawa@gmail.com

⁴Szpital św. Wincentego a Paulo, Gdynia, Poland

Magdalena Aleksandra Boniecka⁵

ORCID <https://orcid.org/0009-0008-6941-1859>

e-mail: mboniecka98@gmail.com

⁵Szpital św. Wincentego a Paulo, Gdynia, Poland

Dominika Adrianna Ossowska⁶

ORCID <https://orcid.org/0009-0001-7196-1277>

e-mail: dominikado123@gmail.com

⁶Szpital im. dr Jadwigi Obodzińskiej-Król, Malbork, Poland

Anna Jankowska⁷

ORCID <https://orcid.org/0009-0001-2507-8694>

e-mail: jankowska.anna.97@gmail.com

⁷Szpital św. Wincentego a Paulo, Gdynia, Poland

Aleksandra Kostańska⁸

ORCID <https://orcid.org/0009-0006-4470-6277>

e-mail: olakostanska@gmail.com

⁸Samodzielny Publiczny Specjalistyczny Zakład Opieki Zdrowotnej w Lęborku, Poland

Michał Łaszczyk⁹

ORCID <https://orcid.org/0009-0002-7362-7595>

e-mail: michal.laszczyk1@gmail.com

⁹Szpital Specjalistyczny im. F. Ceynowy, Wejherowo, Pomorania, PL

Corresponding Author

Klaudia Ścibior, e-mail: scibior.klaudiaa@gmail.com

Abstract

The aim of this study was to analyze the current scientific evidence regarding the benefits and risks of pairing physical activity with metformin therapy for body weight reduction. The available evidence indicates that metformin exerts a modest effect on body weight reduction. Its beneficial effects may be attributed to improved insulin sensitivity, inhibition of hepatic gluconeogenesis, and modulation of appetite and satiety regulation. Regular physical activity plays a significant role in body weight reduction through improvements in energy balance and metabolic parameters. However, the available evidence is limited by the heterogeneity of the patient populations investigated across studies. Sources of heterogeneity included differences in age, degree of obesity, presence of metabolic comorbidities, and physical fitness, which complicated the interpretation and comparison of study findings. Further long-term studies are required to more conclusively establish the effects of metformin and physical activity in specific patient populations.

Keywords: metformin; physical activity; obesity; overweight; weight reduction

1. Introduction

[1] Obesity is an increasingly prevalent chronic metabolic disease with a multifactorial etiology. It represents one of the greatest challenges in contemporary medicine owing to its worldwide prevalence and its association with metabolic and cardiovascular complications. Effective obesity management primarily relies on lifestyle modification, regular physical activity, and, in selected clinical settings, appropriate pharmacotherapy.

[2] According to the World Health Organization (WHO), obesity is defined as abnormal or excessive fat accumulation and is diagnosed when the body mass index (BMI) exceeds 30 kg/m². In contrast, overweight is defined by a BMI ranging from 25.0 to 29.9 kg/m².

Obesity affects most organ systems and therefore constitutes a major threat to health. It is associated with increased healthcare costs and a substantial reduction in quality of life.

Obesity primarily results from a chronic positive energy balance, whereby caloric intake exceeds energy expenditure. Consequently, excess energy is stored primarily as fat in adipose tissue and ectopic depots throughout the body.

Individuals with overweight and obesity exhibit a chronic low-grade inflammatory state, as increased body weight promotes the synthesis of pro-inflammatory cytokines and adipokines. [3] Given its role in regulating metabolic and immune processes, adipose tissue is also recognized as an endocrine organ.

[4] The association between obesity and the development of insulin resistance is largely attributable to the chronic inflammatory state characteristic of obesity, which disrupts insulin signaling pathways via pro-inflammatory cytokine-mediated mechanisms.

[5] Given the strong association between central adiposity, insulin resistance, and metabolic dysfunction, waist circumference measurement is considered a useful tool for assessing the risk of metabolic syndrome and obesity-related metabolic disorders.

[6] Regular physical activity constitutes a cornerstone of the non-pharmacological management of obesity, as it improves energy balance and enhances tissue insulin sensitivity. [7] Consequently, it contributes to body weight reduction and a decrease in adipose tissue mass.

[8] Studies have demonstrated improvements in cardiorespiratory fitness and beneficial effects on glucose metabolism. Despite its favorable impact on body weight reduction, this approach appears to be insufficient in light of the continuing rise in obesity prevalence. Therefore, combined therapeutic approaches involving regular physical activity and pharmacotherapy are increasingly being incorporated into obesity management strategies.

The aim of this study was to analyze the current scientific evidence regarding the effects of metformin therapy and physical activity on body weight reduction, as well as to evaluate the potential clinical implications of combining these two therapeutic approaches.

2. Research materials and methods

A literature analysis was conducted as a narrative review using the PubMed database. The search strategy was designed to identify publications evaluating the effects of metformin and physical activity on body weight reduction. The following keyword combinations were used: “metformin,” “exercise,” “obesity,” “weight loss ratio,” and “biguanides.” Articles published between 2019 and 2026 were considered, with a particular focus on the most recent and relevant evidence. Additionally, selected older publications were included when they represented seminal contributions to the field.

Only articles published in peer-reviewed journals indexed in the PubMed database were considered eligible. The review primarily focused on human studies; however, experimental

studies investigating the mechanisms underlying body weight reduction were also included. Publication selection was based on the screening of titles and abstracts. Articles focusing exclusively on glycemic control in individuals with diabetes, as well as studies that did not meet predefined methodological quality criteria, were excluded. Case reports, conference abstracts, and non-peer-reviewed publications were also excluded.

Following the screening process, 17 articles met the inclusion criteria and were included in the final qualitative synthesis.

3. Biological Effects of Metformin and Physical Activity

[9] During physical activity, skeletal muscle contraction increases the energy demand of working muscles. Initially, intracellular stores of adenosine triphosphate (ATP) are utilized to meet this demand. Subsequently, ATP consumption leads to increased intracellular concentrations of adenosine diphosphate (ADP) and adenosine monophosphate (AMP), which activate AMP-activated protein kinase (AMPK). AMPK regulates numerous metabolic pathways, thereby adapting cellular metabolism to the increased energy demands associated with physical exercise. Consequently, this process induces a range of metabolic adaptations involving the regulation of carbohydrate and lipid metabolism. These changes result in improved insulin sensitivity and enhanced fatty acid oxidation, which may contribute to body weight reduction.

[10] It is important to note that the type of physical activity performed plays a significant role in body weight reduction. Evidence indicates that regular moderate- to high-intensity exercise has the greatest impact, as it contributes not only to reductions in body weight and body mass index (BMI) but also to a decrease in visceral adipose tissue accumulation. Furthermore, regular physical activity improves the metabolic profile by increasing energy expenditure, enhancing fatty acid oxidation, and reducing adipose tissue accumulation. In the analyzed studies, aerobic exercise (e.g., walking, running, and cycling), resistance training, and combined training programs were the most frequently implemented interventions. An important factor was the regularity of the exercise interventions, which typically involved several training sessions per week and contributed to the maintenance of beneficial effects.

[11,12] The mechanism of action of metformin is also based on the activation of AMP-activated protein kinase (AMPK), which leads to reduced hepatic glucose production, decreased intestinal glucose absorption, and inhibition of glucagon-mediated effects,

ultimately resulting in improved insulin sensitivity. Owing to these properties, metformin has been widely used for many years as a first-line antidiabetic agent.

Furthermore, metformin has been shown to reduce oxidative stress and limit the formation of advanced glycation end products. It also modulates glucose and lipid metabolism and exerts beneficial effects on the cardiovascular system. These effects may contribute to body weight reduction and a decrease in visceral adipose tissue, ultimately lowering the risk of cardiovascular complications.

Additionally, metformin exerts effects within the gastrointestinal tract, where it promotes the secretion of glucagon-like peptide-1 (GLP-1), resulting in enhanced postprandial insulin secretion.

Recent studies have also demonstrated that metformin influences the expression of growth differentiation factors, thereby suppressing appetite and facilitating body weight reduction through improvements in energy balance. Furthermore, it may exert beneficial effects on the gut microbiota.

[13] Metformin has also been observed to reduce food intake by influencing the secretion of satiety-related hormones, such as glucagon-like peptide-1 (GLP-1) and peptide YY (PYY).

[11,12] Beyond its antidiabetic effects, metformin is currently the subject of extensive research investigating its potential anticancer and neuroprotective properties. However, the precise mechanisms underlying these effects have not yet been fully elucidated.

However, metformin therapy is associated with several limitations. Gastrointestinal adverse effects are relatively common. Metformin may also reduce vitamin B12 levels, potentially contributing to the development of neuropathy. Furthermore, because it is excreted unchanged by the kidneys, its use is subject to limitations in patients with chronic kidney disease.

4. Clinical Effectiveness of Metformin and Physical Activity in Body Weight Reduction

[14] In a study comparing the effectiveness of beinaglutide and metformin for body weight reduction in patients with overweight or obesity, beinaglutide was shown to be more effective in reducing body weight than metformin. Nevertheless, the findings also indicated that metformin contributed to body weight reduction and improvements in metabolic parameters. Patients receiving metformin additionally exhibited a reduction in visceral adipose tissue. However, the study did not include a control group not receiving metformin. Therefore, the observed improvements may have been influenced by concomitant lifestyle interventions,

including dietary modification and 150 minutes of physical activity per week, making it difficult to determine the independent effect of metformin.

[15] Another study evaluated the effects of metformin and physical activity on glycated hemoglobin (HbA1c), lipid profile, body weight, quality of life, and physical fitness in individuals at increased risk of metabolic disorders. Because the participants were enrolled in a cardiovascular rehabilitation program, they were concurrently treated with multiple medications, including lipid-lowering agents, antihypertensive and antianginal drugs, and other antidiabetic therapies. Consequently, the specific contribution of metformin to the observed outcomes cannot be clearly established. The study demonstrated that the combination of exercise and metformin improved glycemic control and enhanced physical fitness. However, no significant differences in body weight reduction were observed between participants receiving metformin and those not treated with metformin.

[16] A recent study investigated the relationship between metformin use and specific types of physical activity with respect to insulin sensitivity and carbohydrate metabolism in individuals at risk of developing metabolic syndrome. The study was designed as a randomized, double-blind trial and included participants with a mean age of approximately 55 years and a mean body mass index (BMI) of approximately 34 kg/m². The participants were not receiving medications known to affect insulin sensitivity or vascular function. In addition, they had no history of cardiovascular disease, were non-smokers, and were not using hormonal contraception or hormone replacement therapy. In the intervention group, participants initiated treatment with metformin at a dose of 500 mg/day. The dosage was gradually increased to the target dose of 2,000 mg/day over a 4-week period, after which treatment was continued for the remaining 12 weeks of the study. Exercise intensity was determined on the basis of maximal oxygen uptake (VO₂max) assessed during treadmill testing. The exercise intervention was divided into two modalities: low-intensity training (55% of VO₂max) and high-intensity training (85% of VO₂max). The primary objective of the study was to evaluate changes in insulin sensitivity at the level of skeletal muscle, adipose tissue, and the liver using the hyperinsulinemic–euglycemic clamp technique and the Homeostatic Model Assessment of Insulin Resistance (HOMA-IR) index. Additionally, the effects of the intervention on body weight loss and associated metabolic changes were assessed, including alterations in glucose and lipid metabolism as well as adipokine concentrations. Following the 16-week intervention period, the results demonstrated that high-intensity exercise combined with placebo

significantly improved insulin sensitivity. In contrast, a similar effect was not observed in the group receiving metformin. The absence of a significant improvement in insulin sensitivity among participants receiving metformin may be attributable to the attenuation of exercise-induced metabolic adaptations by the drug. The authors suggested that metformin may impair mitochondrial function and reduce insulin-stimulated glucose utilization, resulting in a diminished improvement in insulin sensitivity despite participation in regular physical activity. Additionally, the reduction in body weight observed among participants receiving metformin was not accompanied by the expected improvements in metabolic parameters, suggesting a weakened relationship between weight loss and improvements in insulin sensitivity in this group.

[17] Another study investigated the effects of metformin on body weight reduction and appetite suppression through increased levels of the metabolite Lac-Phe (N-lactoyl-phenylalanine), which has been shown to suppress hunger. Previously, Lac-Phe was primarily associated with the physiological response to physical exercise.

The study employed a multi-stage design and was conducted across several experimental settings, including human participants (patients with type 2 diabetes and individuals enrolled in a large multiethnic population-based cohort study in the United States), animal models (C57BL/6J mice, including diet-induced obesity models), and in vitro experiments using cell lines and primary murine cells.

Blood samples were collected from participants receiving metformin to determine the concentrations of Lac-Phe and other metabolites. These findings were subsequently compared with data from large population-based studies, as well as with measurements of body weight and metabolic parameters.

In animal models, the effects of metformin on Lac-Phe levels, food intake, and body weight were evaluated, whereas in vitro studies investigated the biochemical mechanisms responsible for the formation of this metabolite. The integration of these approaches enabled the researchers to link the effects of metformin to appetite regulation mediated by Lac-Phe.

The authors demonstrated that metformin does not act solely through its classical mechanisms of improving glucose homeostasis but also influences signaling metabolites involved in appetite regulation. The findings indicate a novel and potentially important role of metformin in modulating Lac-Phe, which functions as an appetite-suppressing signal. Consistent results were observed across human studies, animal models, and in vitro experiments, thereby increasing confidence in the observed effect.

[18] The effectiveness of metformin therapy may also be influenced by the formulation and route of administration, which affect the bioavailability of the active substance. Conventional metformin therapy is associated with relatively limited bioavailability, estimated at approximately 40–60%, as well as adverse effects, particularly gastrointestinal disturbances, which may reduce treatment efficacy. In a study conducted in obese mice, the effectiveness of transdermal metformin delivery for body weight reduction was evaluated. The findings of this experimental study suggest that alternative drug delivery methods, including transdermal systems utilizing microneedles and iontophoresis, may enhance the therapeutic efficacy of metformin by enabling more targeted delivery of the drug to adipose tissue. However, despite these favorable findings, the observed reduction in body weight achieved with transdermal delivery systems was modest, resulting in approximately 9% greater weight loss compared with oral administration. Nevertheless, these findings require confirmation in clinical studies involving human participants before the clinical applicability of this approach can be established.

5. Safety and Limitations

Regular physical activity represents a safe and effective therapeutic strategy for body weight reduction. However, the effectiveness of this non-pharmacological intervention is influenced by factors such as exercise frequency, intensity, and individual patient characteristics. Consequently, clinical outcomes may vary according to age, health status, and baseline physical fitness.

[11,12] Metformin is generally considered to have a favorable safety profile; however, its use may be associated with several adverse effects in certain patient populations. These include gastrointestinal disturbances, such as nausea and diarrhea, as well as impaired vitamin B12 absorption.

[15] One of the main limitations of the study was that the participants were receiving multiple concomitant medications prescribed for conditions such as dyslipidemia and cardiovascular disorders. These therapies may also influence glucose metabolism and fatty acid oxidation, thereby complicating the interpretation of the independent effects of metformin and physical activity.

[14,15,16,17] Additional limitations of the reviewed studies included the relatively short follow-up periods, the use of fixed metformin doses, and the heterogeneity of exercise

interventions across studies. Furthermore, in several studies, the combined effects of metformin and physical activity were evaluated, making it difficult to distinguish the independent contribution of each intervention to the observed clinical outcomes. Another limitation was the lack of dietary standardization in some studies, which may have influenced the extent of body weight reduction and hindered comparisons between study findings.

6. Future Perspectives

Growing evidence suggests that metformin exerts a wide range of pleiotropic effects. Nevertheless, its clinical use remains subject to several limitations, primarily arising from the heterogeneity of study populations, differences in treatment protocols, and variations in lifestyle factors. To further elucidate the mechanisms through which metformin and physical activity contribute to body weight reduction, future studies should incorporate individual patient characteristics and provide a detailed characterization of physical activity, including its type, intensity, and frequency.

7. Conclusions

[12] Despite promising findings, metformin appears to exert only a modest effect on body weight reduction, and the observed outcomes are generally less pronounced than those reported for other pharmacological treatments for obesity, such as glucagon-like peptide-1 receptor agonists (GLP-1 RAs). [2,14] Current evidence suggests that lifestyle modifications, particularly regular physical activity, play a crucial role in body weight management.

[1,11,15] Nevertheless, available studies indicate that the combination of metformin therapy and regular physical activity may improve metabolic parameters, contribute to body weight reduction, and support long-term body weight control. Further long-term studies are needed to determine the effects of metformin and physical activity in specific patient populations and to identify the factors influencing treatment response.

Funding: This research received no external funding.

Conflict of interest: The authors declare that they have no conflict of interest.

References

- [1] Hjorth, Mads F., Alexandra S. Helbo, Arne Astrup. Prevention and Management of Obesity in a Lifetime Perspective. *Danish Medical Journal* 70, no. 7 (20 June 2023): A03230164. PMID: 37381866.
- [2] Lustig, Robert H., David Collier, Christopher Kassotis, et al. Obesity I: Overview and Molecular and Biochemical Mechanisms. *Biochemical Pharmacology* 199 (May 2022): 115012. <https://doi.org/10.1016/j.bcp.2022.115012>.
- [3] Kawai, Tatsuo, Michael V. Autieri, and Rosario Scalia. Adipose Tissue Inflammation and Metabolic Dysfunction in Obesity. *American Journal of Physiology-Cell Physiology* 320, no. 3 (2021): C375–91. <https://doi.org/10.1152/ajpcell.00379.2020>.
- [4] Janochova, Karolina, Michal Haluzik, and Marek Buzga. Visceral Fat and Insulin Resistance – What We Know? *Biomedical Papers* 163, no. 1 (2019): 19–27. <https://doi.org/10.5507/bp.2018.062>.
- [5] Patel, Pavankumar, and Nicola Abate. Body Fat Distribution and Insulin Resistance. *Nutrients* 5, no. 6 (2013): 2019–27. <https://doi.org/10.3390/nu5062019>.
- [6] Busebee, Bradley, Wissam Ghusn, Lizeth Cifuentes, and Andres Acosta. Obesity: A Review of Pathophysiology and Classification. *Mayo Clinic Proceedings* 98, no. 12 (2023): 1842–57. <https://doi.org/10.1016/j.mayocp.2023.05.026>.
- [7] Recchia, Francesco, Chit K. Leung, Angus P. Yu, et al. Dose–Response Effects of Exercise and Caloric Restriction on Visceral Adiposity in Overweight and Obese Adults: A Systematic Review and Meta-Analysis of Randomised Controlled Trials. *British Journal of Sports Medicine* 57, no. 16 (2023): 1035–41. <https://doi.org/10.1136/bjsports-2022-106304>.
- [8] Pojednic, Rachele, Emma D’Arpino, Ian Halliday, and Amy Bantham. The Benefits of Physical Activity for People with Obesity, Independent of Weight Loss: A Systematic Review. *International Journal of Environmental Research and Public Health* 19, no. 9 (2022): 4981. <https://doi.org/10.3390/ijerph19094981>.
- [9] Spaulding, Hannah R., and Zhen Yan. AMPK and the Adaptation to Exercise. *Annual Review of Physiology* 84, no. 1 (2022): 209–27. <https://doi.org/10.1146/annurev-physiol-060721-095517>.
- [10] Lee, Hyun Suk, and Junga Lee. Effects of Exercise Interventions on Weight, Body Mass Index, Lean Body Mass and Accumulated Visceral Fat in Overweight and Obese Individuals: A Systematic Review and Meta-Analysis of Randomized Controlled Trials.

- International Journal of Environmental Research and Public Health 18, no. 5 (2021): 2635. <https://doi.org/10.3390/ijerph18052635>.
- [11] Dutta, Siddhartha, Rima B. Shah, Shubha Singhal, et al. Metformin: A Review of Potential Mechanism and Therapeutic Utility Beyond Diabetes. *Drug Design, Development and Therapy* 17 (June 2023): 1907–32. <https://doi.org/10.2147/DDDT.S409373>.
- [12] Petrie, John R. Metformin beyond Type 2 Diabetes: Emerging and Potential New Indications. *Diabetes, Obesity and Metabolism* 26, no. S3 (2024): 31–41. <https://doi.org/10.1111/dom.15756>.
- [13] Yerevanian, Armen, and Alexander A. Soukas. Metformin: Mechanisms in Human Obesity and Weight Loss. *Current Obesity Reports* 8, no. 2 (2019): 156–64. <https://doi.org/10.1007/s13679-019-00335-3>.
- [14] Gao, Lijun, Hong Huang, Lu Zhang, et al. Comparison of Beinaglutide Versus Metformin for Weight Loss in Overweight and Obese Non-Diabetic Patients. *Experimental and Clinical Endocrinology & Diabetes* 130, no. 06 (2022): 358–67. <https://doi.org/10.1055/a-1608-0345>.
- [15] Eltonsy, Sherif, Monique Dufour Doiron, Patrice Simard, et al. Effects of the Combination of Metformin and Exercise on Glycated Hemoglobin, Functional Capacity, Lipid Profile, Quality of Life, and Body Weight. *Journal of International Medical Research* 47, no. 3 (2019): 1131–45. <https://doi.org/10.1177/0300060518817164>.
- [16] Malin, Steven K., Emily M. Heiston, Daniel J. Battillo, et al. Metformin Attenuates Metabolic Insulin Sensitivity and Insulin-Stimulated Carbohydrate Oxidation after High-Intensity Exercise Training in Adults at Risk for Metabolic Syndrome. *Diabetes, Obesity and Metabolism* 28, no. 4 (2026): 2941–52. <https://doi.org/10.1111/dom.70478>.
- [17] Xiao, Shuke, Veronica L. Li, Xuchao Lyu, et al. Lac-Phe Mediates the Effects of Metformin on Food Intake and Body Weight. *Nature Metabolism* 6, no. 4 (2024): 659–69. <https://doi.org/10.1038/s42255-024-00999-9>.
- [18] Abbasi, Mehrnaz, Zhaoyang Fan, John A. Dawson, and Shu Wang. Anti-Obesity and Metabolic Benefits of Metformin: Comparison of Different Delivery Routes. *Journal of Drug Delivery Science and Technology* 91 (January 2024): 105110. <https://doi.org/10.1016/j.jddst.2023.105110>.