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Diabetes Mellitus as a Cause of Osteoporosis: A Systematic Review

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ABSTRACT

Introduction: Osteoporosis is a metabolic bone condition characterized by decreased bone mineral density and deterioration of the microarchitecture of bone tissue, resulting in fragile bones susceptible to fractures. Diabetes mellitus (DM) is a chronic metabolic disease characterized by persistent hyperglycemia resulting from defects in insulin secretion or action.

Objective: To systematize and analyze the available evidence on the relationship between diabetes mellitus and osteoporosis, exploring the biological mechanisms, clinical impacts and possible management strategies.

Methods: This study constitutes a systematic review, classified as exploratory and descriptive. The research was developed through bibliographic research in electronic databases on methods associated with SLR (Systematic Literature Review) and SMARTER (*Simple Multi-Attribute Rating Technique using Exploiting Rankings*) applications.

Results: A comprehensive systematic search of the literature yielded a total of 4.490 articles on diabetes mellitus as a cause of osteoporosis, of which 36 articles were eligible to be included in this systematic review.

Conclusion: The challenges observed in the research, such as the difficulty in establishing causal relationships and the presence of confounding factors, indicate the need for more robust and diversified studies. Randomized clinical trials and longitudinal studies will be essential to better understand the relationship between diabetes and osteoporosis, especially with regard to the applicability of therapeutic interventions in different populations.

KEYWORDS: Diabetes Mellitus, Osteoporosis, Causes

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INTRODUCTION

Osteoporosis is a metabolic bone condition characterized by decreased bone mineral density and deterioration of the microarchitecture of bone tissue, resulting in fragile bones susceptible to fractures (ADEJUYIGBE et al., 2023; WAWRZYNIAK; BALAWENDER, 2022). This disease is a global public health problem, affecting millions of people, especially the elderly and postmenopausal women (LORENTZON et al., 2022; XIAO et al., 2022). However, in addition to traditional risk factors, chronic conditions such as diabetes mellitus (DM) have been recognized as significant contributors to osteoporosis (CHEN et al., 2022a; PRASAD et al., 2023; SCARPA et al., 2024).

Diabetes mellitus (DM) is a chronic metabolic disease characterized by persistent hyperglycemia, resulting from defects in insulin secretion or action (OJO et al., 2023). DM is mainly divided into two types: type 1, which is an autoimmune condition where the body does not produce insulin, and type 2, which is characterized by insulin resistance and/or relative insulin deficiency (DE CANDIA et al., 2019; LUCIER; DULEBOHN, 2024). Both types of diabetes have been associated with several long-term complications, including cardiovascular disease, neuropathy, nephropathy, and retinopathy (GOLDNEY; SARGEANT; DAVIES, 2023; NELLAIAPPAN et al., 2022). Recently, osteoporosis has also been recognized as a significant complication of DM (KUPAI et al., 2024).

The impact of diabetes mellitus on bone health is complex and involves a complex interaction of metabolic, hormonal and inflammatory factors (TANIOS et al., 2022). In type 1 diabetes, insulin deficiency and low levels of IGF-1 (insulin-like growth factor) impair bone formation (JADHAV; CHAKOLE, 2023). In type 2 diabetes, chronic hyperglycemia and insulin resistance lead to changes in bone remodeling, in addition to increasing the risk of falls due to neuromuscular complications associated with DM (RASMUSSEN; VESTERGAARD, 2022). These factors contribute to an increased risk of fractures in diabetic individuals, even when bone mineral density (BMD) may appear normal or even elevated. (LI et al., 2024; SCHWARTZ et al., 2022).

Epidemiological and experimental studies have demonstrated a clear link between diabetes mellitus and an increased risk of osteoporosis and fractures (CHEN et al., 2022a). Patients with type 1 diabetes have a two- to three-fold increased risk of fracture compared to the general population (LORENTZON et al., 2022). Patients with type 2 diabetes, despite often having normal or increased BMD, also have an elevated risk of fractures, possibly due to impaired bone quality and a higher incidence of falls (SHEU et al., 2023).

Understanding the underlying mechanisms by which diabetes mellitus contributes to osteoporosis is crucial for the development of effective therapeutic strategies (SONG et al., 2022). Factors such as strict glycemic control, vitamin D supplementation, regular exercise, and the use of specific bone-strengthening medications are potential interventions that can help mitigate the impact of diabetes on bone health (ÁLVAREZ-MERCADO; MESA; GIL, 2023). Future research should focus on elucidating these mechanisms and evaluating the efficacy of different therapeutic interventions in diabetic populations.

This systematic review aims to systematize and analyze the available evidence on the relationship between diabetes mellitus and osteoporosis, exploring the biological mechanisms, clinical impacts and possible management strategies. By bringing together data from epidemiological, clinical and experimental studies, we aim to provide a comprehensive and updated understanding of the role of diabetes mellitus as a cause of osteoporosis and offer recommendations for clinical practice and future research.

METHODS

This study is a systematic review, classified as exploratory and descriptive. The research was carried out through bibliographic research in electronic databases on methods associated with SLR (Systematic Literature Review) and applications of SMARTER (*Simple Multi-Attribute Rating Technique using Exploiting Rankings*). The work carried out is of a qualitative and quantitative nature. The qualitative analysis of the data was carried out intuitively and inductively during the survey of the theoretical framework. It is also quantitative by using the multicriteria method. In addition, there is also a numerical experimental study in order to simulate a situation of article selection based on the observed criteria.

The bibliographic research was carried out in the following databases: *Web of Science; Science Direct; Wiley ; Springer Link; Taylor and Francis and PubMed* . In addition, searches were carried out using bibliographic references of studies that addressed the topic in a relevant manner on the *Google Scholar* search platform .

The search in the databases was carried out using the terminologies registered in the Health Sciences Descriptors created by the Virtual Health Library developed from the *Medical Subject Headings of the US National Library of Medicine* , which allows the use of common terminology in Portuguese, English and Spanish. The present study sought to investigate the literature on diabetes mellitus as a cause of osteoporosis . For this purpose, the descriptors “diabetes mellitus”, “cause” and “osteoporosis” were used, initially in English, and complementary in Spanish and Portuguese.

As a tool to support decision-making in the selection and prioritization of articles, a set of criteria were considered essential to represent the state of the art of the research topic. This method has the following characteristics: (i) rigorous logic allows the method to be accepted as a decision-making support tool; (ii) simple to understand and apply with results that are easy to interpret.

References of selected papers were also searched for other documents of potential interest. Once qualified for full text in the evaluation, articles were included in the qualitative review if they met the following inclusion criteria: a) contained data on diabetes mellitus; b) contained data on the relationship of diabetes mellitus as a cause of osteoporosis. Articles were excluded if they were reports, banners or conference abstracts. There was no review of confidential health information and the study was not interventional. Therefore, ethics committee approval was not necessary. In the end, the result obtained totaled 36 articles that contemplated the desired characteristics for the study.

Four independent researchers extracted data from articles that met the inclusion criteria and recorded them in a “data extraction form” generated in Microsoft Excel on

diabetes mellitus as a cause of osteoporosis. From this form, the authors and year of publication, study abstract, study type, outcome measured, limitations and conclusions were included, which is demonstrated through Table 1.

RESULTS AND DISCUSSION

A comprehensive systematic literature search yielded a total of 4.490 articles on the incidence of overweight and obesity in adolescents. Of these, 1.225 studies were excluded due to data overlap. From this, the SMARTER (*Simple Multi-Attribute Rating Technique using Exploiting Rankings*) method was chosen and 98 articles that were suitable for full-text screening were selected, of which 54 articles were included for data extraction, of which 18 were excluded by the exclusion criteria, making 36 articles eligible for inclusion in the systematic review. In Figure 1, we describe the strategy for selecting articles on the topic in question.

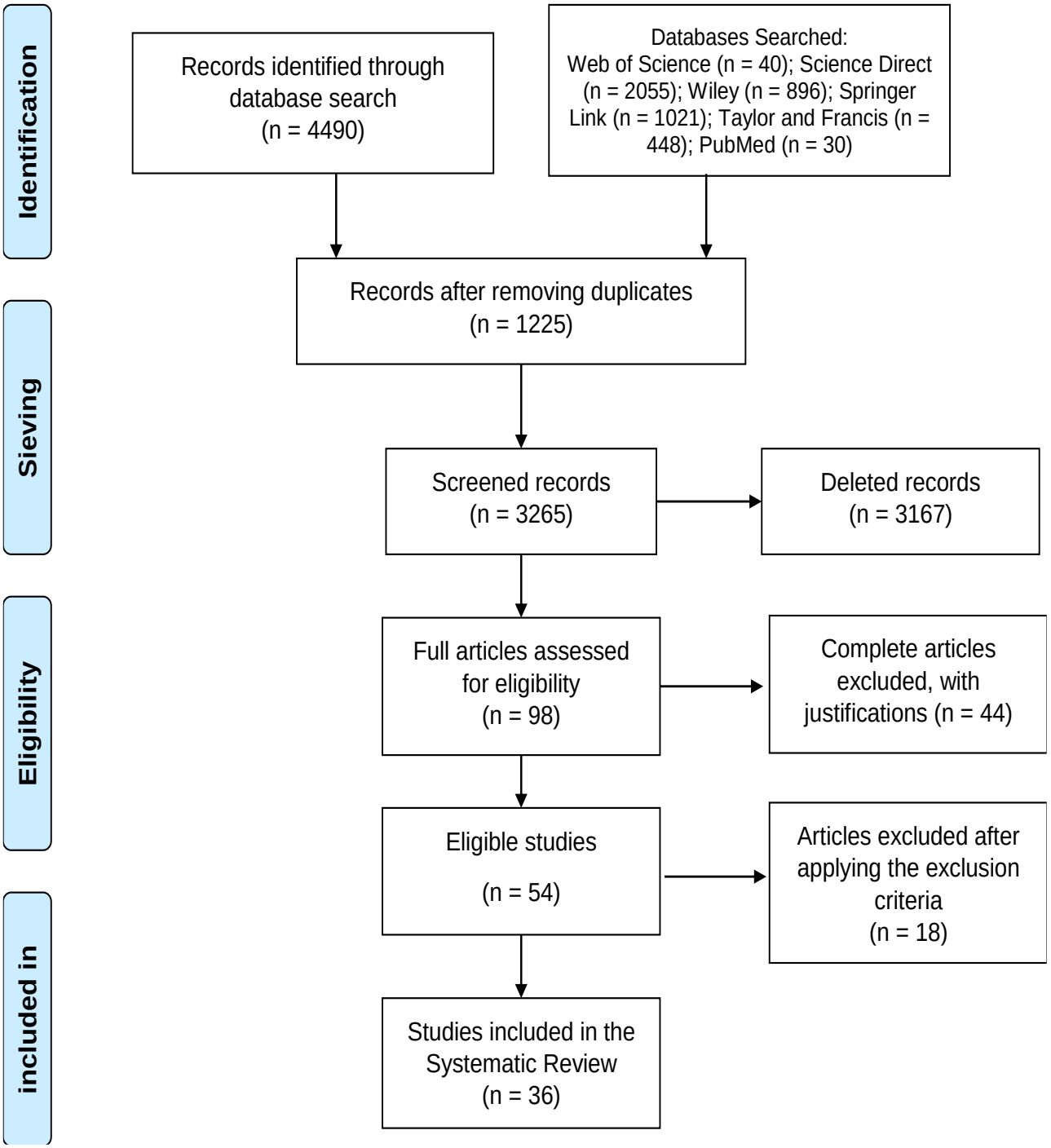

Figure 1. Article search strategy
Source: Authors (2024)

The association between diabetes mellitus (DM) and osteoporosis has been widely studied, with evidence pointing to both type 1 and type 2 DM as significant risk factors for bone health deterioration. Comparing the findings of different studies reveals a complex and varied picture of this relationship.

Recent epidemiological studies consistently demonstrate that individuals with type 1 DM have a significantly increased risk of fractures, with fracture rates two to three times higher compared to the general population (NASSER et al., 2023; RASMUSSEN et al., 2024). Studies have observed that bone mineral density (BMD) in patients with type 1 DM is often reduced, reflecting the deficiency in bone formation due to low levels of insulin and IGF-1 (HOFBAUER et al., 2022; LEUNGSUWAN; CHANDRAN, 2024; MEIER et al., 2023). These studies highlight the importance of insulin as a crucial anabolic hormone for bone health.

In contrast, patients with type 2 DM often have normal or even increased BMD, which initially seems contradictory to the increased risk of fractures (CHEN et al., 2022a) However, despite higher bone mineral density (BMD), bone quality in patients with type 2 diabetes is impaired, possibly due to advanced glycation of bone proteins and the direct effect of chronic hyperglycemia on bone cells (FORNER; SHEU, 2024).

The cohort study conducted by Lin et al. (2021) on the association between type 2 diabetes and osteoporosis risk demonstrated that type 2 DM was significantly associated with an increased risk of osteoporosis, especially in younger participants.

These findings suggest that BMD assessment alone may not be sufficient to predict fracture risk in individuals with type 2 DM, highlighting the need for more comprehensive bone quality assessment methods (CHEN et al., 2022a) .

Therapeutic interventions to reduce the impact of DM on bone health have also been widely studied (CHEN et al., 2022b; HOFBAUER et al., 2022; TANWAR; NAAGAR; MAITY, 2023). Strict glycemic control has shown benefits in preventing bone deterioration, especially in patients with type 1 DM. (SHEU; WHITE; CENTER, 2024). The study carried out by Schwartz et al. (2022), demonstrated that intensive glycemic control in patients with type 1 DM resulted in a lower incidence of fractures in the long term. In patients with type 2 DM, interventions such as vitamin D and calcium supplementation, regular physical exercise, and specific antidiabetic medications, such as GLP-1 receptor agonists, have shown promise in improving bone health (BAILEY, 2024; PRASATHKUMAR et al., 2022; SU et al., 2023).

Another line of evidence comes from studies examining the molecular mechanisms underlying osteoporosis in diabetes. In experimental models, hyperglycemia has been associated with increased oxidative stress and inflammation, both contributing to osteoblast and osteoclast dysfunction (CAVATI et al., 2023; SCARPA et al., 2024). Diabetic patients have elevated levels of inflammatory markers, such as TNF-α and IL-6, which are associated with increased bone resorption and reduced bone formation (TERKAWI et al., 2022).

However, some limitations are common to the reviewed studies. Most observational studies fail to establish a direct causal relationship due to the presence of potential confounding factors. In addition, many studies do not adequately differentiate between types of diabetes or do not fully adjust data for other comorbidities that may influence bone health, such as obesity and kidney disease.

To advance our understanding of the relationship between diabetes and osteoporosis, it is crucial to conduct longitudinal studies and randomized clinical trials that can elucidate causal mechanisms and evaluate the efficacy of different therapeutic interventions. Future studies should also focus on the diversity of study populations to ensure that recommendations are applicable to a broad range of patients with diabetes.

FINAL CONSIDERATIONS

An integrated approach to assessing bone health in patients with diabetes is of paramount importance. Although type 1 and type 2 DM affect bone mineral density (BMD) and bone quality differently, both represent significant risk factors for fractures. In type 1 DM, decreased BMD associated with insulin and IGF-1 deficiency contributes to increased bone vulnerability. In type 2 DM, despite a frequently preserved or increased BMD, impaired bone quality resulting from advanced glycation and chronic hyperglycemia increases the risk of fractures.

Therapeutic interventions, such as strict glycemic control, vitamin D and calcium supplementation, and the use of specific medications, show promise in reducing the negative impacts of DM on bone health. However, the complexity of the interactions between metabolic, molecular, and hormonal factors involved in diabetic osteoporosis requires further studies to identify the causal mechanisms and the most effective preventive strategies.

The challenges observed in research, such as the difficulty in establishing causal relationships and the presence of confounding factors, indicate the need for more robust and diversified studies. Randomized clinical trials and longitudinal studies will be essential to better understand the relationship between diabetes and osteoporosis, especially with regard to the applicability of therapeutic interventions in different populations.

Ultimately, improving our understanding of molecular mechanisms, such as the impact of inflammation and oxidative stress on osteoblast and osteoclast function, could open new avenues for more targeted treatments,

significantly benefiting the bone health of patients with diabetes and reducing the risk of long-term complications.

REFERENCES

I. ADEJUYIGBE, B.; KALLINI, J.; CHIOU, D.; KALLINI, JR Osteoporosis: Molecular Pathology, Diagnostics, and Therapeutics. International Journal of Molecular Sciences , vol. 24, no. 19, p. 14583, 26 September. 2023.

II. ÁLVAREZ-MERCADO, AI; MESA, MD; GIL, Á. Vitamin D: Role in chronic and acute diseases. In: Encyclopedia of Human Nutrition . [sl] Elsevier, 2023. p. 535–544.

III. BAILEY, CJ Future Drug Treatments for Type 2 Diabetes. In: Textbook of Diabetes . [sl: sn]. p. 1154–1166.

IV. CAVATI, G.; PIRROTTA, F.; MERLOTTI, D.; CECCARELLI, E.; CALABRESE, M.; GENNARI, L.; MINGIANO, C. Role of Advanced Glycation End-Products and Oxidative Stress in Type-2-Diabetes-Induced Bone Fragility and Implications on Fracture Risk Stratification. Antioxidants , vol. 12, no. 4, p. 928, 14 April. 2023.

V. CHEN, W.; MAO, M.; FANG, J.; Xie, Y.; RUI, Y. Fracture risk assessment in diabetes mellitus. Frontiers in Endocrinology , vol. 13, 2 Sep. 2022a.

VI. CHEN, Y.; ZHOU, Y.; LIN, J.; ZHANG, S. Challenges to Improve Bone Healing Under Diabetic Conditions. Frontiers in Endocrinology , vol. 13, 28 Mar. 2022b.

VII. DE CANDIA, P.; PRATTICHIZZO, F.; GARAVELLI, S.; DE ROSA, V.; GALGANI, M.; DI RELLA, F.; SPAGNUOLO, MI; COLAMATTEO, A.; FUSCO, C.; MICILLO, T.; BRUZZANITI, S.; CERIELLO, A.; PUCA, AA; MATARESE, G. Type 2 Diabetes: How Much of an Autoimmune Disease? Frontiers in Endocrinology , vol. 10, 4 Jul. 2019.

VIII. FORNER, P.; SHEU, A. Bone Health in Patients With Type 2 Diabetes. Journal of the Endocrine Society , vol. 8, no. 7, 23 May 2024.

IX. GOLDNEY, J.; SARGEANT, JA; DAVIES, MJ Incretins and microvascular complications of diabetes: neuropathy, nephropathy, retinopathy and microangiopathy. Diabetologia , v. 66, no. 10, p. 1832–1845, 19 Oct. 2023.

X. HOFBAUER, L. C.; BUSSE, B.; EASTELL, R.; FERRARI, S.; FROST, M.; MÜLLER, R.; BURDEN, AM; RIVADENEIRA, F.; NAPOLI, N.; RAUNER, M. Bone fragility in diabetes: novel concepts and clinical implications. The Lancet Diabetes & Endocrinology , vol. 10, no. 3, p. 207–220, 2022.

XI. JADHAV, I.; CHAKOLE, S. Effects of Type 1 Diabetes Mellitus on Linear Growth: A Comprehensive Review. Cureus , 17 September. 2023.

XII. KUPAI, K.; KANG, H.L.; PÓSA, A.; CSONKA, Á.; VÁRKONYI, T.; VALKUSZ, Z. Bone Loss in Diabetes Mellitus: Diaporosis. International Journal of Molecular Sciences , vol. 25, no. 13, p. 7269, 2 July. 2024.

XIII. LEUNGSUWAN, DS; CHANDRAN, M. Bone Fragility in Diabetes and its Management: A Narrative Review. Drugs , 2024.

XIV. LI, G.-F.; ZHAO, P.-P.; XIAO, W.-J.; KARASIK, D.; XU, Y.-J.; ZHENG, H.-F. The paradox of bone mineral density and fracture risk in type 2 diabetes. Endocrine , vol. 85, no. 3, p. 1100–1103, 26 June. 2024.

XV. LIN, H.-H.; HSU, H.-Y.; TSAI, M.-C.; HSU, L.-Y.; CHIEN, K.-L.; YEH, T.-L. Association between type 2 diabetes and osteoporosis risk: A representative cohort study in Taiwan. PLOS ONE , v. 16, no. 7, p. e0254451, 13 Jul. 2021.

XVI. LORENTZON, M.; JOHANSSON, H.; HARVEY, NC; LIU, E.; VANDENPUT, L.; MCCLOSKEY, EV; KANIS, JA Osteoporosis and fractures in women: the burden of disease. Climacteric , vol. 25, no. 1, p. 4–10, 2 Jan. 2022.

XVII. LUCIER, J.; DULEBOHN, SC Type 1 Diabetes . Treasure Island: StatPearls Publishing, 2024.

XVIII. MEIER, C.; EASTELL, R.; PIERROZ, DD; LANE, NE; AL-DAGHRI, N.; SUZUKI, A.; NAPOLI, N.; MITHAL, A.; CHAKHTOURA, M.; FULEIHAN, GE-H.; FERRARI, S. Biochemical Markers of Bone Fragility in Patients With Diabetes. The Journal of Clinical Endocrinology & Metabolism , vol. 108, no. 10, p. e923–e936, 18 Sept. 2023.

XIX. NASSER, MI; KVIST, AV; VESTERGAARD, P.; EASTELL, R.; BURDEN, AM; FROST, M. Sex - and Age Group - Specific Fracture Incidence Rates Trends for Type 1 and 2 Diabetes Mellitus. JBMR Plus , vol. 7, no. 11, 27 Nov. 2023.

XX. NELLAIAPPAN, K.; PREETI, K.; KHATRI, D.K.; SINGH, SB Diabetic Complications: An Update on Pathobiology and Therapeutic Strategies. Current Diabetes Reviews , vol. 18, no. 1, Jan. 2022.

XXI. OJO, OA; IBRAHIM, HS; ROTIMI, DE; OGUNLAKIN, AD; OJO, AB Diabetes mellitus: From molecular mechanism to pathophysiology and pharmacology. Medicine in Novel Technology and Devices , vol. 19, p. 100247, Sep. 2023.

XXII. PRASAD, TN; ARJUNAN, D.; PAL, R.;

BHADADA, SK Diabetes and Osteoporosis. Indian Journal of Orthopedics , vol. 57, no. S1, p. 209–217, 12 Dec. 2023.

XXIII. PRASATHKUMAR, M.; BECKY, R.; ANISHA, S.; DHRISYA, C.; SADHASIVAM, S. Evaluation of hypoglycemic therapeutics and nutritional supplementation for type 2 diabetes mellitus management: An insight into molecular approaches. Biotechnology Letters , vol. 44, no. 2, p. 203–238, 4 Feb. 2022.

XXIV. RASMUSSEN, NH; DRIESSEN, JHM; KVIST, AV; SOUVEREIN, PC; VAN DEN BERGH, J.; VESTERGAARD, P. Fracture patterns in adult onset type 1 diabetes and associated risk factors – A nationwide cohort study. Bone , vol. 179, p. 116977, Feb. 2024.

XXV. RASMUSSEN, NH; VESTERGAARD, P. Diabetes and osteoporosis – Treating two entities: A challenge or cause for concern? Best Practice & Research Clinical Rheumatology , vol. 36, no. 3, p. 101779, Sep. 2022.

XXVI. SCARPA, E.-S.; ANTONELLI, A.; BALERCIA, G.; SABATELLI, S.; MAGGI, F.; CAPRIOLI, G.; GIACCHETTI, G.; MICUCCI, M. Antioxidant, Anti-Inflammatory, Anti-Diabetic, and Pro-Osteogenic Activities of Polyphenols for the Treatment of Two Different Chronic Diseases: Type 2 Diabetes Mellitus and Osteoporosis. Biomolecules , vol. 14, no. 7, p. 836, 11 July. 2024.

XXVII. SCHWARTZ, A. V; BACKLUND, J.-YC; DE BOER, IH; RUBIN, MR; BARNIE, A.; FARRELL, K.; TRAPANI, VR; GREGORY, NS; WALLIA, A.; BEBU, I. Risk factors for lower bone mineral density in older adults with type 1 diabetes: a cross-sectional study. The Lancet Diabetes & Endocrinology , vol. 10, no. 7, p. 509–518, 2022.

XXVIII. SHEU, A.; GREENFIELD, JR; WHITE, CP; CENTER, JR Contributors to impaired bone health in type 2 diabetes. Trends in Endocrinology & Metabolism , vol. 34, no. 1, p. 34–48, 2023.

XXIX. SHEU, A.; WHITE, CP; CENTER, JR Bone metabolism in diabetes: a clinician's guide to understanding the bone–glucose interplay. Diabetologia , v. 67, no. 8, p. 1493–1506, 18 Aug. 2024.

XXX. SONG, S.; GUO, Y.; Yang, Y.; FU, D. Advances in pathogenesis and therapeutic strategies for osteoporosis. Pharmacology & Therapeutics , vol. 237, p. 108168, Sep. 2022.

XXXI. SU, J.; LUO, Y.; HU, S.; TANG, L.; OUYANG, S. Advances in Research on Type 2 Diabetes Mellitus Targets and Therapeutic Agents. International Journal of Molecular Sciences , vol. 24, no. 17, p. 13381, 29 Aug. 2023.

XXXII. TANIOS, M.; BRICKMAN, B.; CAGE, E.; ABBAS, K.; SMITH, C.; ATALLAH, M.; BAROI, S.; LECKA-CZERNIK, B. Diabetes and Impaired Fracture Healing: A Narrative Review of Recent Literature. Current Osteoporosis Reports , vol. 20, no. 5, p. 229–239, 12 Oct. 2022.

XXXIII. TANWAR, P.; NAAGAR, M.; MAITY, MK Relationship between Diabetes Mellitus and Bone Health–A Review. International Research Journal of Pharmacy and Medical Sciences (IRJPMS) , v. 6, no. 2, p. 46–58, 2023.

XXXIV. TERKAWI, MA; MATSUMAE, G.; SHIMIZU, T.; TAKAHASHI, D.; KADOYA, K.; IWASAKI, N. Interplay between Inflammation and Pathological Bone Resorption: Insights into Recent Mechanisms and Pathways in Related Diseases for Future Perspectives. International Journal of Molecular Sciences , vol. 23, no. 3, p. 1786, 4 Feb. 2022.

XXXV. WAWRZYNIAK, A.; BALAWENDER, K. Structural and Metabolic Changes in Bone. Animals , vol. 12, no. 15, p. 1946, 31 July. 2022.

XXXVI. XIAO, P.-L.; CUI, A.-Y.; HSU, C.-J.; PENG, R.; JIANG, N.; XU, X.-H.; MA, Y.-G.; LIU, D.; LU, H.-D. Global, regional prevalence, and risk factors of osteoporosis according to the World Health Organization diagnostic criteria: a systematic review and meta-analysis. Osteoporosis International , vol. 33, no. 10, p. 2137–2153, 10 Oct. 2022.