World Academy of Science, Engineering and Technology
International Journal of Medical and Health Sciences
Vol:19, No:02, 2025

Identifying Biomarker Response Patterns to Vitamin D Supplementation in Type 2 Diabetes Using K-means Clustering: A Meta-Analytic Approach to Glycemic and Lipid Profile Modulation

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Abstract : Background and Aims: This meta-analysis aimed to evaluate the effect of vitamin D supplementation on key metabolic and cardiovascular parameters, such as glycated hemoglobin (HbA1C), fasting blood sugar (FBS), low-density lipoprotein (LDL), high-density lipoprotein (HDL), systolic blood pressure (SBP), and total vitamin D levels in patients with Type 2 diabetes mellitus (T2DM). Methods: A systematic search was performed across databases, including PubMed, Scopus, Embase, Web of Science, Cochrane Library, and ClinicalTrials.gov, from January 1990 to January 2024. A total of 4,177 relevant studies were initially identified. Using an unsupervised K-means clustering algorithm, publications were grouped based on common text features. Maximum entropy classification was then applied to filter studies that matched a pre-identified training set of 139 potentially relevant articles. These selected studies were manually screened for relevance. A parallel manual selection of all initially searched studies was conducted for validation. The final inclusion of studies was based on full-text evaluation, quality assessment, and meta-regression models using random effects. Sensitivity analysis and publication bias assessments were also performed to ensure robustness. Results: The unsupervised K-means clustering algorithm grouped the patients based on their responses to vitamin D supplementation, using key biomarkers such as HbA1C, FBS, LDL, HDL, SBP, and total vitamin D levels. Two primary clusters emerged: one representing patients who experienced significant improvements in these markers and another showing minimal or no change. Patients in the cluster associated with significant improvement exhibited lower HbA1C, FBS, and LDL levels after vitamin D supplementation, while HDL and total vitamin D levels increased. The analysis showed that vitamin D supplementation was particularly effective in reducing HbA1C, FBS, and LDL within this cluster. Furthermore, BMI, weight gain, and disease duration were identified as factors that influenced cluster assignment, with patients having lower BMI and shorter disease duration being more likely to belong to the improvement cluster. Conclusion: The findings of this machine learning-assisted meta-analysis confirm that vitamin D supplementation can significantly improve glycemic control and reduce the risk of cardiovascular complications in T2DM patients. The use of automated screening techniques streamlined the process, ensuring the comprehensive evaluation of a large body of evidence while maintaining the validity of traditional manual review processes.

Keywords : HbA1C, T2DM, SBP, FBS
Conference Title : ICDM 2025 : International Conference on Diabetes and Metabolism
Conference Location : Washington, United States
Conference Dates : February 24-25, 2025