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RESEARCH ARTICLE

A Clinical Evaluation Framework for Metabolic Equivalent (MET)-Guided Individualized Exercise Prescription in Optimizing Glycaemic Control in Type 2 Diabetes Mellitus

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Abstract

Type 2 Diabetes Mellitus (T2DM) is a multifactorial metabolic disorder characterized by progressive insulin resistance and impaired glycaemic regulation, necessitating integrated pharmacological and lifestyle interventions. Among non-pharmacological strategies, structured physical activity remains a cornerstone; however, conventional exercise prescriptions often lack precision, personalization, and metabolic calibration. This study proposes a clinical evaluation framework based on Metabolic Equivalent of Task (MET)-guided individualized exercise prescription to optimize glycaemic control in T2DM patients. The framework integrates physiological intensity quantification, patient-specific metabolic profiling, and adaptive exercise dosing to enhance glycaemic outcomes and reduce HbA1c variability.

The proposed model synthesizes evidence from clinical trials, systematic reviews, and digital health innovations to construct a structured, scalable, and clinically implementable approach. Prior research highlights the superiority of resistance-based and structured exercise interventions over generalized aerobic activity in improving glycaemic outcomes (Kobayashi et al., 2023). Additionally, advancements in digital monitoring, reinforcement learning systems, and wearable biosensing technologies support the feasibility of real-time metabolic optimization (Forman et al., 2019; Saab et al., 2024). Emerging bio-integrated sensing frameworks further reinforce the role of continuous metabolic feedback systems in personalized healthcare delivery (Kaushik et al., 2020).

The study emphasizes the integration of MET-based stratification with clinical decision support systems, enabling precision-guided exercise dosing tailored to individual metabolic responses. Findings suggest that structured MET-guided interventions may significantly improve glycaemic stability, enhance insulin sensitivity, and reduce long-term diabetes-related complications. However, challenges such as adherence variability, infrastructural limitations, and inter-individual metabolic heterogeneity remain critical barriers to implementation.

This framework contributes to the advancement of precision exercise medicine and provides a scalable model for integrating metabolic analytics into routine diabetes management.

KEYWORDS

Type 2 Diabetes Mellitus; Metabolic Equivalent (MET); Individualized Exercise Prescription; Glycaemic Control; Precision Medicine; Physical Activity Optimization; HbA1c; Digital Health; Clinical Framework; Insulin Resistance.

INTRODUCTION

Type 2 Diabetes Mellitus (T2DM) represents one of the most significant global public health challenges, characterized by chronic hyperglycaemia resulting from insulin resistance and progressive β-cell dysfunction. The increasing prevalence of T2DM has been strongly associated with sedentary lifestyles, obesity, and metabolic imbalance, necessitating multidimensional intervention strategies that extend beyond pharmacological management.

Exercise therapy is universally recognized as a fundamental component of diabetes management due to its ability to enhance glucose uptake, improve insulin sensitivity, and regulate body composition. However, conventional exercise prescriptions often rely on generalized intensity recommendations that fail to account for individual metabolic variability. This limitation results in inconsistent therapeutic outcomes and suboptimal glycaemic control.

Recent clinical evidence demonstrates that structured and resistance-based exercise interventions are more effective than unstructured aerobic activity in improving glycaemic markers and body composition in T2DM patients (Kobayashi et al., 2023). Furthermore, long-term physical activity patterns have been shown to significantly influence cardiovascular and metabolic risk profiles (Florido et al., 2018). Despite these findings, a standardized, quantifiable, and individualized exercise prescription model remains underdeveloped.

The concept of Metabolic Equivalent of Task (MET) provides a scientifically grounded framework for quantifying physical activity intensity in a standardized manner. MET-based evaluation enables clinicians to classify exercise intensity levels and align them with patient-specific metabolic capacities. However, its integration into personalized clinical decision-making systems is still limited.

Parallel advancements in artificial intelligence and digital health systems have introduced new opportunities for optimizing metabolic interventions. Reinforcement learning-based models have demonstrated potential in dynamically adjusting treatment strategies based on continuously monitored physiological data (Forman et al., 2019). Similarly, large-scale AI systems in medicine highlight the feasibility of integrating computational intelligence into clinical decision-making (Saab et al., 2024).

In addition, innovations in biosensing technologies, such as wearable and biofuel cell-based systems, have enabled real-time physiological monitoring, supporting closed-loop healthcare systems (Kaushik et al., 2020; Wu et al., 2021). These developments provide a technological foundation for integrating MET-guided exercise prescriptions into adaptive clinical frameworks.

Research Problem

Despite advancements in exercise science and digital health, there remains a lack of clinically validated frameworks that integrate MET-based quantification with individualized exercise prescription for optimized glycaemic control in T2DM patients.

Objectives

1. To develop a MET-guided clinical evaluation framework for individualized exercise prescription.
2. To assess its theoretical effectiveness in optimizing glycaemic control in T2DM.
3. To integrate digital health and biosensing technologies into exercise prescription systems.
4. To evaluate the clinical implications and limitations of MET-based personalization.

Scope and Significance

This research is significant in advancing precision exercise medicine by bridging the gap between metabolic quantification and individualized clinical intervention. It contributes to the development of adaptive, scalable, and data-driven diabetes management systems that can be integrated into primary care and digital health ecosystems.

LITERATURE REVIEW

The literature on T2DM management highlights a strong consensus on the role of physical activity in glycaemic regulation. However, variability in exercise response among individuals necessitates more refined and personalized approaches.

Kobayashi et al. (2023) demonstrated that resistance training significantly improves glycaemic control and body composition compared to aerobic exercise alone, indicating the importance of exercise modality specificity. Similarly, Svensson et al. (2017) emphasized that different exercise intensities yield varied impacts on health-related quality of life in obese populations, reinforcing the need for intensity calibration.

Florido et al. (2018) further established that long-term changes in physical activity levels are strongly associated with cardiovascular outcomes, including heart failure risk, underscoring the systemic impact of exercise behavior modification.

From a pharmacological perspective, Gu et al. (2022) provided a comparative evaluation of glucose-lowering agents, highlighting that pharmacotherapy alone may not fully address glycaemic instability, thereby reinforcing the need for integrated lifestyle interventions. Additionally, Kim et al. (2019) demonstrated that treatment intensification alone yields variable HbA1c outcomes, further supporting adjunctive exercise-based strategies.

Digital transformation in healthcare has introduced computational models capable of optimizing treatment pathways. Forman et al. (2019) illustrated how reinforcement learning algorithms can utilize continuously monitored data to optimize weight loss interventions, suggesting applicability to diabetes exercise prescriptions. Similarly, Saab et al. (2024) discussed the capabilities of advanced AI models in medicine, reinforcing the potential for intelligent clinical decision support systems.

Technological innovations in biosensing further strengthen the feasibility of real-time metabolic monitoring. Wearable biofuel cells and biosensing devices have been identified as emerging tools for continuous physiological tracking, enabling adaptive feedback systems in clinical care (Kaushik et al., 2020; Wu et al., 2021). These systems provide a foundation for integrating MET-based exercise prescription into dynamic, data-driven healthcare models.

Economic and systemic factors also influence diabetes care delivery. Moreno et al. (2020) and Stegbauer et al. (2020) highlight significant cost drivers in T2DM management across healthcare systems, emphasizing the importance of scalable and cost-effective interventions such as structured exercise frameworks.

Despite these advancements, a critical research gap exists in integrating MET-based quantification with AI-driven personalization and real-time biosensing into a unified clinical framework. Current models remain fragmented, lacking interoperability between physiological measurement, clinical decision-making, and behavioral intervention systems.

METHODOLOGY

3.1 Study Design

This research proposes a conceptual clinical evaluation framework based on MET-guided individualized exercise prescription for T2DM management. The design integrates evidence synthesis, physiological modeling, and digital health architecture to construct a precision-based intervention system.

3.2 Framework Architecture

The proposed framework consists of four integrated layers:

1. Patient Stratification Layer: Classification based on baseline HbA1c, BMI, comorbidities, and physical activity history.
2. MET Quantification Layer: Standardization of exercise intensity using MET values to categorize low, moderate, and high-intensity activity.
3. Personalization Engine: Algorithmic mapping of patient metabolic capacity to optimal exercise dose-response curves.
4. Feedback and Monitoring Layer: Integration of wearable biosensors and digital tracking systems for continuous adaptation.

The integration of biosensing technologies is conceptually supported by emerging biofuel cell-based wearable systems, which enable continuous metabolic monitoring and energy-efficient data capture (Kaushik et al., 2020).

3.3 MET-Based Exercise Quantification Model

Metabolic Equivalent of Task (MET) is used as a standardized physiological unit to quantify energy expenditure during physical activity. In this framework, MET serves as the central calibration variable for exercise prescription in Type 2 Diabetes Mellitus (T2DM) patients. One MET represents resting metabolic rate, while increasing MET values correspond to proportional increases in energy expenditure.

The proposed model categorizes exercise intensity into three metabolic zones:

- Low intensity (1.5–3 METs): Walking, light household activities

- Moderate intensity (3–6 METs): Brisk walking, cycling
- High intensity (>6 METs): Resistance training, interval-based exercise

The framework operationalizes MET not merely as a descriptive metric but as a dynamic clinical dosing parameter. This aligns with evidence suggesting that structured resistance training produces superior glycaemic improvements compared to aerobic-only interventions (Kobayashi et al., 2023).

Importantly, the model integrates dose–response principles, where glycaemic improvement is proportional to cumulative MET-minutes per week. This approach ensures quantifiable progression in exercise prescriptions tailored to individual metabolic tolerance.

3.4 Individualized Prescription Algorithm

The personalization engine is designed as a rule-based adaptive algorithm that integrates metabolic biomarkers and physical capacity indicators. The algorithm considers:

- Baseline HbA1c levels
- Body mass index (BMI)
- Insulin resistance index
- Cardiovascular risk profile
- Physical activity history

The output is a personalized MET target range (PMTR), which dynamically adjusts exercise prescriptions over time.

For example:

- A high-risk patient (HbA1c > 8.5%) is assigned a moderate but progressive MET load to minimize metabolic shock.
- A controlled patient (HbA1c < 7%) receives maintenance-level MET prescriptions with variability for prevention.

This adaptive mechanism reflects principles similar to reinforcement learning systems in healthcare, where treatment strategies evolve based on continuous feedback loops (Forman et al., 2019).

3.5 Digital Integration and Monitoring System

The framework incorporates digital health infrastructure using wearable biosensors and real-time monitoring systems. These devices continuously track:

- Heart rate variability
- Energy expenditure
- Activity duration
- Glucose fluctuations (when integrated with CGM systems)

Advances in wearable biofuel cell technology provide the technical feasibility for sustained physiological monitoring with minimal energy constraints (Kaushik et al., 2020; Wu et al., 2021).

Additionally, AI-enabled analytical models, including large-scale medical intelligence systems, can process real-time patient data to refine exercise prescriptions dynamically (Saab et al., 2024).

3.6 Clinical Evaluation Metrics

The effectiveness of the framework is evaluated using the following outcomes:

- Reduction in HbA1c levels
- Improvement in insulin sensitivity
- Variability in fasting blood glucose
- MET adherence index (MAI)
- Quality of life (QoL) scores

Secondary outcomes include cardiovascular risk reduction and body composition improvement.

RESULTS

The conceptual evaluation of the MET-guided individualized exercise prescription framework suggests several clinically relevant outcomes based on synthesized evidence.

First, structured MET-based exercise dosing demonstrates a consistent relationship with improved glycaemic control. Studies indicate that higher cumulative MET exposure correlates with significant reductions in HbA1c and improved insulin sensitivity. This supports the hypothesis that quantifiable energy expenditure is a stronger predictor of metabolic improvement than generic exercise recommendations.

Second, individualized MET calibration reduces inter-patient variability in glycaemic response. Patients with higher baseline metabolic dysfunction benefit from gradual MET escalation, minimizing adverse metabolic fluctuations. This finding aligns with comparative pharmacological studies showing heterogeneous responses to glucose-lowering therapies (Gu et al., 2022; Kim et al., 2019).

Third, integration of digital monitoring systems enhances adherence and enables continuous feedback. Wearable biosensors and AI-driven analytics allow real-time adjustment of exercise intensity, improving compliance and reducing dropout rates. This is consistent with reinforcement learning-based healthcare optimization models that dynamically adjust interventions based on behavioral and physiological feedback (Forman et al., 2019).

Fourth, resistance-based exercise incorporated into MET-guided frameworks yields superior metabolic outcomes compared to aerobic-only prescriptions. This reinforces prior randomized clinical trial evidence demonstrating improved glycaemic control with structured strength training protocols (Kobayashi et al., 2023).

Fifth, socio-economic disparities significantly influence the effectiveness of exercise-based interventions. Patients from lower socioeconomic backgrounds show reduced adherence, indicating that clinical frameworks must incorporate accessibility considerations to ensure equitable implementation (Flores-Hernández et al., 2025).

Finally, the integration of biosensing technologies enhances real-time metabolic tracking, enabling predictive adjustments in exercise dosing. This creates a closed-loop system where physiological data continuously informs clinical decision-making, improving long-term metabolic stability.

DISCUSSION

The findings of this study highlight the clinical relevance of MET-guided individualized exercise prescription as a precision medicine approach for T2DM management. Unlike conventional exercise guidelines, which are often generalized and non-dynamic, the proposed framework introduces a quantifiable and adaptive metabolic dosing system.

A key theoretical implication is the reframing of exercise as a metabolically dosed therapeutic intervention rather than a lifestyle recommendation. This aligns with emerging precision health paradigms that emphasize individualized physiological calibration.

The integration of digital health technologies significantly enhances the feasibility of this model. Wearable biosensors, as described in emerging biomedical engineering research, enable continuous physiological monitoring that supports adaptive intervention strategies (Kaushik et al., 2020). Furthermore, AI systems capable of analyzing real-time health data provide a scalable infrastructure for personalized care delivery (Saab et al., 2024).

However, several limitations must be acknowledged. First, the framework remains largely conceptual and requires large-scale clinical validation. Second, variability in patient adherence may reduce real-world effectiveness. Third, technological accessibility remains uneven, particularly in low-resource healthcare settings. Fourth, MET-based estimation may not fully capture individual metabolic heterogeneity, particularly in patients with comorbid cardiovascular or musculoskeletal conditions.

Despite these limitations, the proposed framework offers a significant advancement in integrating exercise physiology, digital health, and clinical diabetes management. It also supports the broader transition toward data-driven, precision-based therapeutic models.

CONCLUSION

This study presents a comprehensive MET-guided individualized exercise prescription framework for optimizing glycaemic control in Type 2 Diabetes Mellitus. By integrating metabolic quantification, personalized algorithmic modeling, and digital health monitoring systems, the framework offers a scalable and adaptive approach to exercise-based diabetes management.

The findings suggest that structured MET-based prescriptions can significantly improve glycaemic outcomes, enhance insulin sensitivity, and reduce metabolic variability. Additionally, the incorporation of AI-driven and biosensor-based technologies strengthens the feasibility of real-time adaptive intervention systems.

Future research should focus on clinical validation through randomized controlled trials and integration with national diabetes management programs. Expanding accessibility and ensuring equitable implementation will be critical for translating this framework into real-world healthcare systems.

Overall, this study contributes to the advancement of precision exercise medicine and provides a novel pathway for integrating metabolic analytics into chronic disease management.

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