

Assessment of Blood Glucose measurement using New Non-Invasive Technology: Protocol & Methodology

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Table of Contents

Original Manuscript..... 5

Supplementary Files..... 28

 Figures 29

 Figure 1..... 30



Assessment of Blood Glucose measurement using New Non-Invasive Technology: Protocol & Methodology

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Abstract

Background: Diabetes Mellitus is a major non-communicable disease with significant increase in prevalence, especially in low and middle-income countries. The latest IDF Diabetes Atlas (2025) reports that 11.1%, or about 1 in 9, of the adult population (20-79 years old) is living with diabetes, with over 4 in 10 unaware that they have the condition. This Prevalence is expected to increase to 1 in 8 adults by the year 2050.

Early diagnosis and treatment of Diabetes reduces the risk and slows the progression of debilitating complications such as amputation, vision loss, and renal failure, cardiovascular disease, dementia, some cancers, and infections such as tuberculosis and severe COVID-19.

Current screening methods for diabetes are invasive and costly. This has limited its more widespread utilisation especially in a high-density population, middle-low income country such as Indonesia. Blood Glucose Evaluation and Monitoring (BGEM) is a machine learning (ML) algorithm developed by Actxa to analyze Photoplethysmography (PPG) data from wearable devices for diabetic risk assessment. Its non-invasive and user-friendly nature makes it a strong candidate for fulfilling the need for a diabetes screening tool.

Objective: The Aim of this study is to enhance BGEM's performance on a large and diverse data set with an emphasis on the detailed blood sugar fluctuation, also known as glycaemic variability, under semi-controlled conditions in an Indonesian population.

Methods: Adult subjects aged 18 years old and above, either with a diabetic or non-diabetic history that resides in Greater Jakarta Area, Indonesia were recruited. The study will explore BGEM blood glucose prediction capabilities compared to laboratory blood analysis from capillary or plasma samples at after fasting, 1 hour, 2 hour and 3 hours after meal. In addition to PPG and blood data collection, anthropological measurement, a standardize questionnaire on activity, demographic information

and diabetic status were also conducted to provide a more complete dataset.

Results: A total of 885 subjects were included into the study from June to October 2024, 473 were diabetic subjects and 412 were non-diabetic subjects. The blood sugar profiles of the subjects will be studied and analysed. BGEM's performance will be assessed on this Indonesian dataset on glycaemic variability.

Conclusions: This protocol paper outlines the methodology designed for subject's blood sugar profiles especially on glycaemic variability in order to evaluate BGEM, a PPG-based AI model designed to estimate blood glucose levels and diabetic risk. The clinical trial was conducted on both diabetic (DM) and non-diabetic (non-DM) Indonesian subjects, while considering various influencing factors. The results will provide objective evidence on the validity and use of a non-invasive technique for the measurement of blood sugar levels using wearables. Clinical Trial: Clinical trial registration NCT06642467

Institutional Review Board of Ukrida faculty of medicine & health sciences ethical committee 1779/SLKE/IM/UKKW /FKIK/KEPK /VII/2024

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Original Manuscript

Assessment of Blood Glucose measurement using New Non-Invasive Technology; Protocol & Methodology

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Abstract

Background

Diabetes Mellitus is a major non-communicable disease with significant increase in prevalence, especially in low and middle-income countries. The latest IDF Diabetes Atlas (2025) reports that 11,1%, or about 1 in 9, of the adult population (20-79 years old) is living with diabetes, with over 4 in 10 unaware that they have the condition. This Prevalence is expected to increase to 1 in 8 adults by the year 2050.

Early diagnosis and treatment of Diabetes reduces the risk and slows the progression of debilitating complications such as amputation, vision loss, and renal failure, cardiovascular disease, dementia, some cancers, and infections such as tuberculosis and severe COVID-19.

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Objective:

The Aim of this study is to enhance BGEM's performance on a large and diverse data set with an emphasis on the detailed blood sugar fluctuation, also known as glycaemic variability, under semi-controlled conditions in an Indonesian population.

Method:

Adult subjects aged 18 years old and above, either with a diabetic or non-diabetic history that resides in Greater Jakarta Area, Indonesia were recruited. The study will explore BGEM blood glucose prediction capabilities compared to laboratory blood analysis from capillary or plasma samples at after fasting, 1 hour, 2 hour and 3 hours after meal. In addition to PPG and blood data collection, anthropological measurement, a standardize questionnaire on activity, demographic information and diabetic status were also conducted to provide a more complete dataset.

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Trial Registrations:

Clinical trial registration NCT06642467

Institutional Review Board of Ukrida faculty of medicine & health sciences ethical committee 1779/SLKE/IM/UKKW /FKIK/KEPK /VII/2024

Keywords: Diabetes Mellitus; Non-Invasive; Blood Glucose; Screening; Machine Learning; Photoplethysmography; Artificial Intelligence; Wearables; BGEM; Indonesia;

Introduction

Diabetes Mellitus (DM) is a major non-communicable disease which affected around 500 million people worldwide and continue to rise up to 700 million people globally in 2045[1]. Other non-communicable diseases death risk decreased by 20% since turn of the century, DM in contrast, has increased by 3% worldwide. The latest IDF Diabetes Atlas (2025) reports that 11.1% , or about 1 in 9, of the adult population (20-79 years) is living with diabetes, with over 4 in 10 unaware that they have the condition. This prevalence is expected to increase to 1 in 8 adults by the year 2050[2].

Several reports have projected that about 1 in 2 adult diabetic patients are unaware of their diagnosis[1–3]. Undiagnosed DM has resulted in increase of cases with complications and elevated the burden of disease, as younger undiagnosed DM cases have more rapid progress of complications and lower respond to general DM treatment. This has been shown to be higher in low-middle income countries where 80% of DM population lived, thus reflect the enormous burden of the disease[4][5]. While, early diagnosis and treatment of DM reduces the risk and slows the progression of debilitating complications such as amputation, vision loss, renal failures, cardiovascular disease, dementia, some cancers, infections including tuberculosis and severe COVID-19[6]. All those which calls for screening strategies that is both effective and cost efficient.

Current available method to detect DM are Haemoglobin A1c (HbA1c) level, fasting plasma glucose, 2 hours glucose tolerance test and random plasma glucose test. All these methods are invasive, needed trained professionals and laboratory equipment to be done correctly. American Diabetic Association has recommended DM screening starting at 35 years old and every 3 years after, especially for people with obesity, overweight and one risk factor [7]. In low-middle income countries, this is even harder to implement due to cost and scarce resources of such screening methods [5,6,8].

Glycaemic variability which refers to a fluctuations blood glucose concentration that happens in a day or similar timeframes on different days, has been shown to results in microvascular and macrovascular damage in DM patients[9]. Glycaemic variability has been proposed in multiple study for DM management, however difficulties in measurement and consensus on its optimal value even with recent more widespread use of continuous glucose monitoring has limited its use in general population[9,10], despite its general acceptance that it is a very potential indicator for DM control.

Indonesia, a middle-income country with 283 million population thus faces a big

challenge in DM management. It was estimated that DM prevalence was 9.49% (2024) and will increase to 16.09% (2045) without any major effective intervention[11]. As in any other low-middle income country the cost and availability of DM testing has prohibited Indonesia to enact an effective prevention or screening program, therefore an affordable, effective and simple screening method for DM will be a boon in the national health program.

Photoplethysmography (PPG) is a non-invasive optical technology that measures light absorbance to assess blood volume changes. It has been widely integrated into wearable devices, such as smartwatches, to monitor heart rate and other related physiological parameters[12]. Emerging research suggests that PPG data may also be valuable for detecting DM and estimating glucose levels[13–15]. The non-invasive nature, affordability, and convenience of PPG make it a promising tool for early detection and preventive screening of DM, especially in large and diverse populations such as Indonesia. Improving the reliability (accuracy and stability) of PPG-based technology in wearable devices for blood glucose monitoring and DM risk prediction remains a critical challenge in achieving this goal [8].

Blood Glucose Evaluation and Monitoring (BGEM) a machine learning (ML) algorithm developed by Actxa to analyse PPG data for assessing diabetic risk. It is one of the first ML models deployed in commercial wearable devices. BGEM was trained using data collected from a registered clinical trial (NCT05504096) conducted at KK Women's and Children's Hospital in Singapore, involving 500 Singaporean participants. The reported accuracy of BGEM is 84.7%[14]. The model's performance is sensitive to demographic features, with the inclusion of demographic data significantly enhancing its accuracy[15]. BGEM would benefit from a larger and more diverse training dataset, as the current training data consists primarily of Singaporean participants, predominantly healthy females.

Here, we present the protocol for a registered clinical trial (NCT06642467) designed to collect a larger and more robust training dataset to enhance BGEM's performance. The study aims to comprehensively collect PPG data using two different types of wearable devices at multiple time points before and after a breakfast meal. Both capillary and plasma blood samples were collected and subjected to thorough laboratory analysis. More than 800 participants from Indonesia were recruited, ensuring a balanced

representation in terms of diabetic status (diabetic/ non-diabetic) and gender. Additionally, a comprehensive questionnaire was used to gather essential information, capitalizing on the diversity of the training data, including factors such as hypertension, skin type, and other relevant variables.

Methods

Subject recruitment

Subjects with the total of 885 people from adults aged 18 years old and above, that resides in Greater Jakarta Area, Indonesia were recruited, from diabetic exercise group, staff & family member of Krida Wacana Christian University (Ukrida) with its affiliated organizations using an online registration provided by the research team. Exclusion criteria was BMI $>37 \text{ kg/m}^2$, diastolic blood pressure $\geq 120 \text{ mmHg}$ and systolic blood pressure $\geq 180 \text{ mmHg}$, wearing a pacemaker, having fever or any other acute critical illness during the data collection and pregnant female subjects are also excluded from this study. All subjects before admission to study received explanation on the study purpose, protocol and risk, also signed the informed consent.

Study design

This study utilises a cross-sectional design with short-term prospective measurements of blood glucose profiles, with data collection conducted between July – October 2024 at the Ukrida Hospital, Jakarta, Indonesia. The study will explore BGEM blood glucose prediction capabilities compared to laboratory blood analysis from capillary or plasma blood samples with the study workflow summarized in Figure 1. The subjects were given explanation on the study, asked for informed consent, and given a numeric identity tag to ensure anonymity of the data set after undergoing minimum 8 hours of fasting before admittance to the study. Subjects undertook weight, height, waist circumference, blood pressure measurement using GEA ZT120 body scales, tape measure roll, and Beurer BM26 sphygmomanometer consecutively. Body Mass Index (BMI) scores are calculated from weight and height of subjects to evaluate obesity or metabolic condition of subjects.

Subsequently, each participant's PPG data at the fasting time point (the 1st time point) were collected using both a smart ring (JC Smart Health Ring 2301B) and a smartwatch (Actxa Spark+ Series 2), both provided by Actxa Pte Ltd. Simultaneously, blood samples were obtained from two sources: capillary blood for glucose concentration measurement using Accu-Chek (Roche) and plasma blood from the cubital

vein for laboratory analysis, as described in a later section.

Participants then consumed a 552 kcal meal set with 79.8 gr of carbohydrate content prepared by Ukrida Hospital. This meal was chosen to ensure adequate sustenance and satiety after overnight fasting, as sugary drinks alone may not sufficiently fulfil. The nutritional composition of the meal is detailed in Table 1 and Table S1.

Participants then underwent measurements at the second time point (1 hour postprandial), third time point (2 hours postprandial), and fourth time point (3 hours postprandial). PPG data collection followed the same procedure as the first time point, using both the smartphone and the smart ring. For blood sample collection and testing, the third time point followed the same procedure as the first time point, with both capillary and plasma blood samples collected and analysed. At the second and fourth time points, plasma blood collection was omitted, and only capillary blood samples were obtained and tested. Further details are provided in Table 2.

During the one-hour intervals at the last three time points, while waiting between data and sample collection, participants were asked to complete the International Physical Activity Questionnaire (IPAQ) long form, along with other questionnaires related to DM and its risk factors (Table 3).

All protocol was performed under hospital's medical staff supervision at all times. Ethics approval for the study has been obtained from the Ukrida Faculty of Medicine & Health Sciences ethical committee (1779/SLKE/IM/UKKW /FKIK/KEPK /VII/2024).

Blood sample analysis

All capillary blood samples were analysed using the Accu-Chek Guide glucometer. Cubital plasma blood samples were analysed for full blood count using the Sysmex XN-550, plasma blood glucose using the Cobas C111 Analyzer, and HbA1c levels using the FineCare FIA Meter III Plus. These instruments were available at the Ukrida Hospital clinical laboratory. All hospital equipment was routinely calibrated according to the provider's manual.

PPG data collection

In this study, two wearable devices were utilized: the Actxa Spark+ Series 2 smartwatch and the JC Smart Health Ring 2301B. Both devices are equipped with a

green light PPG sensor that captures PPG signals at 50 Hz, ensuring adequate signal quality for heart rate analysis.

During data collection, the smartwatch was worn on the participant's non-dominant wrist, positioned at least two finger widths away from the wrist bone. The smart ring, selected based on appropriate sizing, was worn at the base of the index finger on the same hand. To ensure optimal signal acquisition, the ring's PPG sensor was positioned facing the inner side of the finger. Each PPG recording session lasted for five minutes. Participants were instructed to remain seated, maintain a relaxed posture, and minimize movement, with their non-dominant hand resting on a table to reduce motion artifacts.

PPG data were collected by the wearable devices and transmitted via Bluetooth to a smartphone. The smartphone then relayed the data via the internet to Actxa's company server for storage and further analysis.

Statistical analysis

Demographic data for continuous variables will be presented as mean $\pm$ standard deviation, and categorical variables will be presented as count (percentage). Univariate analyses will be performed using t-test for independent groups for continuous variables and chi-square tests for categorical variables. Discriminations are assessed by plotting the receiver operating characteristic (ROC) curve and calculating the area under the ROC curve (AUC) or C-statistic. Accuracy of the prediction model will be analysed using Parkes error Grid. Sensitivity, specificity, F1 of BGEM model will also be evaluated and presented to give a clear description of its strength & weakness.

The blood sugar profiles of subjects with varying demographic characteristics will be analysed and compared statistically to quantify the similarities and differences between individuals. Profile analysis, correlation and regression techniques will be utilised for the comparison of the blood sugar profiles, taking into consideration the correlation between the repeated measurements within each individual.

The data will be analysed using statistical package Stata Version 19 and machine learning packages R and Python. P-values less than 0.05 will be considered as statistically significant.

Discussion

Overview

This study will provide a significant amount of data on 3 main areas. First it will provide much data to further empower the BGEM artificial intelligence model that has been developed since 2022[14]. The PPG features data from 885 subjects and 4 timeline extractions will enable BGEM to increase its predictive strength and accuracy.

Inclusion of additional clinical data such as anthropological measurement, HbA1c, haematocrit and other blood parameters performed in this study will give more expansive view on factors that may influence PPG blood glucose predictive ability[16]. Analysis of the factors will provide insight whether any of them influence BGEM accuracy or can be used as additional data to improve its performance[17].

This study is the first to report performance of PPG based artificial intelligence model use in Indonesian population. Population-wide DM screening in Indonesia posed a problem to any health intervention program due to the challenging geography and population spread across multiple islands, and diverse ethnicity of Indonesian people[18,19]. Therefore, this study can become a foundation of BGEM use in DM management, prevention and/or screening in Indonesia.

DM with its huge disease burden and increasing number of afflicted populations, needs new, innovative and effective means to control and minimize its impact[20,21]. This protocol paper hope to provide a base method in developing a non-invasive PPG based AI model to predict blood glucose level and evaluating DM status of the subject.

Comparison with previous work

BGEM use in a relatively large Indonesian population is a unique point that will become an important stepping stone on developing a non-invasive model that is effective in blood glucose screening, monitoring and DM management. The previous study of BGEM was performed in a female dominant and mainly non-DM population[15], thus this study with a different gender make-up and large DM population will strengthen the model and give a good contrast for comparison between population of differing characteristic[14,16].

The study has a comprehensive four time points of data collection which is more extensive[22,23], and will provide a more complete view of how PPG data fluctuates between different state of food intake, The additional 1 hour and 3 hours after meal may give a clearer view of blood glucose level changes compared to the standardize fasting and 2 hours post meal that already widely accepted. The use of AI in detection of

glycaemic variability is very limited[24] and to our knowledge no AI using PPG based sensors has been reported despite its strong potential use for DM management, therefore this study will be giving new and novel insight on the topic.

Study limitation

This protocol has certain limitations. We prioritized achieving a balanced distribution of gender and diabetic/non-diabetic participants. With this focus, efforts were made to increase the overall number of participants. As the sample size grew, a broader range of demographic characteristics was naturally captured, reflecting the inherent diversity of the larger Indonesian population. However, no deliberate strategies were employed to design or randomize demographic features; the observed diversity emerged organically from the expanded participant pool. Several demographic features, such as participants aged over 60, are underrepresented. Although the study includes a diverse range of ethnicities, the overall ethnic composition does not reflect the general proportions of the Indonesian population. This limits the extent to which certain inferences can be drawn from the final data analysis.

Conclusion

This protocol paper outlines the methodology designed for evaluating BGEM, a PPG-based AI model designed to estimate blood glucose levels and diabetic risk. The clinical trial was conducted on both DM and non-DM Indonesian subjects, while considering various influencing factors. The protocol is distinctive as it aims to generate high-quality training data for the AI model, ensuring balanced data structure, sufficient data quantity, diversity, and comprehensive relevant information including unique data on glycaemic variability using wearables for downstream analysis and future research.

Acknowledgement

This research was sponsored by Actxa Pte Ltd, and data collection was performed at

UKRIDA hospital in Jakarta, Indonesia.

Conflict of Interests

DSS is clinical research advisor of Actxa Pte Ltd and SBA is a medical advisor of Actxa Pte Ltd, LA, ZE, and LFZ are employee of Actxa Pte Ltd. Other authors have no competing interest.

Abbreviations

AI: Artificial Intelligence

AUC: Area Under the Curve

AUROC: Area-Under the ROC Curve

BMI: Body Mass Index

BGEM: Blood Glucose Evaluation and Monitoring

BP: Blood Pressure

COVID-19: Coronavirus Disease 2019

C-Statistic: Concordance Statistic

DM: Diabetes Mellitus

HbA1c: Haemoglobin A1c

IDF: International Diabetes Federation

IPAQ: International Physical Activity Questionnaire

ML: Machine Learning

NCT: National Clinical Trial (Registration Number)

Non-DM: Non-Diabetic Mellitus

PPG: Photoplethysmography

ROC: Receiver Operating Characteristic

SD: Standard Deviation

SPSS/Stata: Statistical Analysis Software

Ukrida: Krida Wacana Christian University

References

1. Saeedi P, Petersohn I, Salpea P, Malanda B, Karuranga S, Unwin N, Colagiuri S, Guariguata L, Motala AA, Ogurtsova K, Shaw JE, Bright D, Williams R. Global and regional diabetes prevalence estimates for 2019 and projections for 2030 and 2045: Results from the International Diabetes Federation Diabetes Atlas, 9th edition. *Diabetes Res Clin Pract* 2019;157. doi: 10.1016/j.diabres.2019.107843 [CrossRef]
2. International Diabetes Federation. IDF Diabetes Atlas 11th Edition. 2025. https://diabetesatlas.org/media/uploads/sites/3/2025/04/IDF_Atlas_11th_Edition_2025.pdf
3. Ogurtsova K, da Rocha Fernandes JD, Huang Y, Linnenkamp U, Guariguata L, Cho NH, Cavan D, Shaw JE, Makaroff LE. IDF Diabetes Atlas: Global estimates for the prevalence of diabetes for 2015 and 2040. *Diabetes Res Clin Pract* 2017;128. doi: 10.1016/j.diabres.2017.03.024 [CrossRef]
4. The Lancet Diabetes & Endocrinology. Undiagnosed type 2 diabetes: an invisible risk factor. *Lancet Diabetes Endocrinol*. 2024. doi: 10.1016/S2213-8587(24)00072-X [CrossRef]
5. Manne-Goehler J, Geldsetzer P, Agoudavi K, Andall-Brereton G, Aryal KK, Bicaba BW, Bovet P, Brian G, Dorobantu M, Gathecha G, Gurung MS, Guwatudde D, Msaidie M, Houehanou C, Houinato D, Adelin Jorgensen JM, Kagaruki GB, Karki KB, Labadarios D, Martins JS, Mayige MT, McClure RW, Mwalim O, Mwangi JK, Norov B, Quesnel-Crooks S, Silver BK, Sturua L, Tsabedze L, Wesseh CS, Stokes A, Marcus M, Ebert C, Davies JJ, Vollmer S, Atun R, Bärnighausen TW, Jaacks LM. Health system performance for people with diabetes in 28 low-and middle-income countries: A cross-sectional study of nationally representative surveys. *PLoS Med* 2019;16(3). doi: 10.1371/journal.pmed.1002751 [CrossRef]
6. Zhou B, Rayner AW, Gregg EW, Sheffer KE, Carrillo-Larco RM, Bennett JE, Shaw JE, Paciorek CJ, Singleton RK, Barradas Pires A, Stevens GA, Danaei G, Lhoste VP, Phelps NH, Heap RA, Jain L, D'Ailhaud De Brisis Y, Galeazzi A, Kengne AP, Mishra A, Ikeda N, Lin H-H, Aguilar-Salinas CA, Anjana RM, Ben Romdhane H, Davletov K, Ganapathy S, Heidemann C, Khader YS, Khang Y-H, Laxmaiah A, Mbanya JCN, Mohan V, Narayan KV, Pavkov ME, Sobngwi E, Wade AN, Younger-Coleman NO, Zdrojewski T, Abarca-Gómez L, Abbasi-Kangevari M, Abdul Rahim HF, Abu-Rmeileh NM, Adambekov S, Adams RJ, Aekplakorn W, Afzal S, Agdeppa IA, Aghazadeh-Attari J, Agyemang C, Ahmad NA, Ahmadi A, Ahmadi N, Ahmadi N, Ahmed SH, Ahrens W, Ajlouni K, Al-Hamli SF, Al-Hinai H, Al-Lawati JA, Al Asfoor D, Alarouj M, AlBuhairan F, AlDhukair S, Ali MM,

Ali MK, Alieva A V, Alinezhad F, Alkandari A, Alkerwi A, Aly E, Amarapurkar DN, Andersen LB, Anderssen SA, Andrade DS, Ansari-Moghaddam A, Aounallah-Skhiri H, Araújo J, Aris T, Arku RE, Arlappa N, Aryal KK, Aspelund T, Assah FK, Assembekov B, Au Yeung SL, Auvinen J, Avdičová M, Azad K, Azevedo A, Azimi-Nezhad M, Azizi F, Bacopoulou F, Balakrishna N, Balanova Y, Bamoshmoosh M, Banach M, Bandosz P, Banegas JR, Barbagallo CM, Barcelo A, Baretić M, Barrera L, Barreto M, Basit A, Batieha AM, Batista AP, Baur LA, Belavendra A, Benedek T, Benet M, Benzeval M, Berkinbayev S, Bernabe-Ortiz A, Berrios Carrasola X, Bettiol H, Beybey AF, Bhargava SK, Bi Y, Bika Lele EC, Bikbov MM, Bista B, Bjerregaard P, Bjertness E, Bjertness MB, Björkelund C, Bloch K V, Blokstra A, Bobak M, Boehm BO, Boggia JG, Boissonnet CP, Bojesen SE, Bonaccio M, Bonilla-Vargas A, Borghs H, Botomba S, Bovet P, Brajkovich I, Brenner H, Brewster LM, Brian GR, Briceño Y, Brito M, Bueno G, Bugge A, Buntinx F, Cabrera de León A, Caixeta RB, Can G, Cândido APC, Capanzana M V, Čapková N, Capuano E, Capuano R, Capuano V, Cardoso VC, Carlsson AC, Casanueva FF, Censi L, Cervantes-Loaiza M, Chadji Georgiou CA, Chamnan P, Chamukuttan S, Chan Q, Charchar FJ, Chaturvedi N, Chen C-J, Chen H, Chen L-S, Cheng C-Y, Cheraghian B, Chetrit A, Chiou S-T, Chirlaque M-D, Chudek J, Cifkova R, Cirillo M, Claessens F, Clarke J, Cohen E, Concin H, Cooper C, Cosmin CR, Costanzo S, Cowan MJ, Cowell C, Crampin AC, Crujeiras AB, Cruz JJ, Cureau F V, Cuschieri S, D'Arrigo G, d'Orsi E, da Silva-Ferreira H, Dallongeville J, Damasceno A, Dankner R, Dastgiri S, Dauchet L, De Curtis A, de Gaetano G, De Henauw S, De Ridder D, Deepa M, DeGennaro VJ, Demarest S, Dennison E, Deschamps V, Dhimal M, Dika Z, Djalalinia S, Donfrancesco C, Dorobantu M, Dragano N, Drygas W, Du S, Du Y, Duante CA, Duboz P, Duda RB, Dushpanova A, Dzerve V, Dziankowska-Zaborszczyk E, Ebrahimi N, Eddie R, Eftekhari E, Efthymiou V, Egbagbe EE, Eggertsen R, Egtesad S, Ejembi CL, El-Khateeb M, El Ati J, Eldemire-Shearer D, Elosua R, Enang O, Erasmus RT, Erem C, Ergor G, Eriksen L, Eriksson JG, Esmaeili A, Evans RG, Fagherazzi G, Fahimfar N, Fakhradiyev I, Fakhretdinova AA, Fall CH, Faramarzi E, Farjam M, Farzadfar F, Farzi Y, Fattahi MR, Fawwad A, Felix-Redondo FJ, Ferguson TS, Fernández-Bergés D, Fernando DR, Ferrao T, Ferrari M, Ferrario MM, Ferreccio C, Ferrer E, Feskens EJ, Fink G, Flood D, Forsner M, Fosse-Edorh S, Fottrell EF, Fouad HM, Francis DK, Frontera G, Fujiati II, Fumihiko M, Furusawa T, Gaciong Z, Galvano F, Garnett SP, Gaspoz J-M, Gasull M, Gazzinelli A, Gehring U, Ghaderi E, Ghamari S-H, Ghanbari A, Ghasemi E, Gheorghe-Fronea O-F, Ghimire A, Gialluisi A, Giampaoli S, Gianfagna F, Gill TK, Giovannelli J, Gironella G, Giwerzman A, Goldberg M, Goltzman D, Gomula A, Gonçalves H, Gonçalves M, Gonzalez-Chica DA, Gonzalez-Gross M, González-Rivas JP, Gonzalez AR, Goto A, Gottrand F, Grafnetter D, Grammatikopoulou MG, Grant A, Grimsgaard AS, Grodzicki T, Grøntved A, Grosso G, Gu D, Gudnason V, Guerrero R, Guessous I, Gujral UP, Gupta R, Gutierrez L, Gwee X, Ha S, Haghsheenas R, Hakimi H, Hambleton IR, Hamzeh B, Hange D, Hantunen S, Hao J, Harooni J, Hashemi-Shahri SM, Hata J, Hayes AJ, He J, Henrique R dos S, Henriques A, Herrala S, Herzig K-H, Heshmat R, Hill AG, Ho SY, Holdsworth M, Homayounfar R, Hopman WM, Horimoto AR, Hormiga C, Horta BL, Houti L, Howitt C, Htay TT, Htet AS, Htike MMT, Huerta JM, Huhtaniemi IT, Huiart L, Huisman M, Hunsberger M, Hussein A, Huybrechts I, Iacoviello L, Iakupova EM, Iannone AG, Ibrahim Wong N, Ijoma C, Irazola VE, Ishida T, Islam SMS, Islek D, Ittermann T, Iwasaki M, Jääskeläinen T, Jacobs JM, Jaddou HY, Jadoul M, Jallow B, James K, Jamil KM, Janus E, Jarvelin M-R, Jasienska G, Jelaković A, Jelaković B, Jennings G, Jha AK, Jibo A, Jimenez RO, Jöckel K-H, Jokelainen JJ, Jonas JB, Josipović J, Joukar F, Jóźwiak J, Kafatos A, Kajantie EO, Kalamatayeva Z, Kalter-Leibovici O, Karakosta A, Karki KB, Katibeh M, Katulanda P, Kauhanen J, Kazakbaeva GM, Kaze FF, Ke C, Keinänen-Kiukaanniemi S, Kelishadi R, Keramati M, Kersting M, Khalagi K, Khaledifar A, Khalili D, Kheiri B, Kheradmand M, Khosravi Farsani A, Kiechl-Kohlendorfer U, Kiechl SJ, Kiechl S, Kim HC, Kingston A, Klakk H, Klanova J, Knoflach M, Kolsteren P, König J, Korpelainen R, Korrovits P, Kos J, Koskinen S, Kowlessur S, Koziel S, Kratzer W, Kriemler S, Kristensen PL, Krokstad S, Kromhout D, Kubinova R, Kujala UM, Kulimbet M, Kulothungan V, Kumari M, Kutsenko V, Kyobutungi C, La QN, Laatikainen T, Labadarios D, Lachat

C, Laid Y, Lall L, Langsted A, Lankila T, Lanska V, Lappas G, Larijani B, Latt TS, Laurenzi M, Le Coroller G, Lee J, Lehtimäki T, Lemogoum D, Leung GM, Lim C, Lim W-Y, Lima-Costa MF, Lin Y-J, Lind L, Lissner L, Liu L, Liu X, Lo W-C, Loit H-M, Lopez-Garcia E, Lopez T, Lozano JE, Luksiene D, Lundqvist A, Lunet N, Lung T, Lustigová M, Ma G, Machado-Coelho GL, Machado-Rodrigues AM, Macia E, Macieira LM, Madar AA, Maestre GE, Maggi S, Magliano DJ, Magriplis E, Mahasampath G, Maire B, Makdisse M, Makrilakis K, Malekpour M-R, Malekzadeh F, Malekzadeh R, Malyutina S, Maniego L V, Manios Y, Mansour-Ghanaei F, Manzato E, Mapatano MA, Marcil A, Mardones F, Margozzini P, Marques-Vidal P, Marques LP, Martorell R, Mascarenhas LP, Masimango Imani M, Masinaei M, Masoodi SR, Mathiesen EB, Mathur P, Matsha TE, McDonald Posso AJ, McFarlane SR, McGarvey ST, McLean SB, McNulty BA, Mediene Benchechor S, Mehlig K, Mehrparvar AH, Melgarejo JD, Méndez F, Menezes AMB, Mereke A, Meshram II, Meto DT, Michels N, Minderico CS, Mini G, Miquel JF, Miranda JJ, Mirjalili MR, Mirkopoulou D, Modesti PA, Moghaddam SS, Mohammad K, Mohammadi MR, Mohammadi Z, Mohammadifard N, Mohammadpourhodki R, Mohd Yusoff MF, Mohebbi I, Møller NC, Molnár D, Momenan A, Montenegro Mendoza RA, Moosazadeh M, Moradpour F, Morejon A, Moreno LA, Morgan K, Morin SN, Moschonis G, Moslem A, Mosquera M, Mossakowska M, Mostafa A, Mostafavi S-A, Mota E, Mota J, Mota M, Motlagh ME, Motta J, Msyamboza KP, Mu TT, Muiesan ML, Munroe PB, Mursu J, Musa KI, Mustafa N, Muyer MTM, Nabipour I, Nagel G, Naidu BM, Najafi F, Námesná J, Nang EEK, Nangia VB, Naseri T, Navarro-Ramírez AJ, Neelapaichit N, Nejatizadeh A, Nenko I, Nervi F, Ng TP, Nguyen CT, Nguyen ND, Nguyen QN, Ni MY, Nie P, Nieto-Martínez RE, Ning G, Ninomiya T, Nishi N, Noale M, Noboa OA, Noda M, Nordestgaard BG, Noto D, Nsour M Al, Nuhoğlu I, Nyirenda M, O'Neill TW, Oh K, Ohtsuka R, Omar MA, Onat A, Ong SK, Onodugo O, Ordunez P, Ornelas R, Ortiz PJ, Osmond C, Ostovar A, Otero JA, Ottendahl CB, Otu A, Owusu-Dabo E, Pahomova E, Palmieri L, Pan W-H, Panagiotakos D, Panda-Jonas S, Pang Z, Panza F, Paoli M, Park S, Parsaeian M, Patalen CF, Patel ND, Pechlaner R, Pećin I, Pedro JM, Peixoto SV, Peltonen M, Pereira AC, Pessôa dos Prazeres TM, Peykari N, Phall MC, Pham ST, Pichardo RN, Pigeot I, Pikhart H, Pilav A, Piler P, Pitakaka F, Piwonska A, Pizarro AN, Plans-Rubió P, Plata S, Popkin BM, Porta M, Poudyal A, Pourfarzi F, Pourshams A, Poustchi H, Prabhakaran D, Pradeepa R, Price AJ, Price JF, Providencia R, Puder JJ, Puhakka S, Punab M, Qiao Q, Qorbani M, Quintana HK, Quoc Bao T, Radisauskas R, Rahimikazerooni S, Raitakari O, Ramachandran A, Ramirez-Zea M, Ramke J, Ramos E, Ramos R, Rampal L, Rampal S, Ramsay SE, Rangel Reina DA, Rannan-Eliya RP, Rashidi M-M, Redon J, Renner JD, Reuter CP, Revilla L, Rezaei N, Rezaianzadeh A, Rho Y, Rigo F, Riley LM, Risérus U, Roa RG, Robinson L, Rodríguez-Anderson WE, Rodríguez-Artalejo F, Rodríguez-Perez M del C, Rodríguez-Villamizar LA, Rodríguez AY, Roggenbuck U, Rohloff P, Rojas-Martinez R, Romeo EL, Rosengren A, Roy JG, Rubinstein A, Ruiz-Castell M, Russo P, Rust P, Rutkowski M, Sabanayagam C, Sabbaghi H, Sachdev HS, Sadjadi A, Safarpour AR, Safi S, Safiri S, Saghi MH, Saidi O, Sakata S, Saki N, Šalaj S, Salanave B, Salonen JT, Salvetti M, Sánchez-Abanto J, Santos DA, Santos LC, Santos MP, Santos R, Santos TR, Saramies JL, Sardinha LB, Sarrafzadegan N, Sato Y, Saum K-U, Savin S, Sawada N, Sbaraini M, Sczufca M, Schaan BD, Schargrodsky H, Scheidt-Nave C, Schipf S, Schmidt AF, Schmidt B, Schmidt CO, Schnohr P, Schooling CM, Schöttker B, Schramm S, Seibert S, Sedaghattalab M, Sein AA, Sen A, Sepanlou SG, Servais J, Sewpaul R, Shalnova S, Shamshirgaran SM, Shanthirani CS, Sharafkhah M, Sharma SK, Sharman A, Shayanrad A, Shayesteh AA, Shibuya K, Shimizu-Furusawa H, Shiri R, Shoranov M, Shrestha N, Si-Ramlee K, Siani A, Siedner MJ, Silva DAS, Sim X, Simon M, Simons J, Simons LA, Sjöström M, Slowikowska-Hilczek J, Slusarczyk P, Smeeth L, Söderberg S, Soemantri A, Solfrizzi V, Somi MH, Soumaré A, Sousa-Poza A, Sousa-Uva M, Sparrenberger K, Staessen JA, Stang A, Stavreski B, Steene-Johannessen J, Stehle P, Stein AD, Stessman J, Stokwiszewski J, Stronks K, Suarez-Ortegón MF, Suebsamran P, Suka M, Sun C-A, Sun J, Sundström J, Suriyawongpaisal P, Sylva RC, Tai ES, Takuro F, Tamosiunas A, Tan EJ, Tanabayev B, Tandon N, Tarawneh MR, Tarqui-Mamani CB, Taylor A, Tello T, Tham YC, Thankappan K, Theobald H, Theodoridis X, Thomas N, Thrift AG,

Timmermans EJ, Tolonen HK, Tolstrup JS, Tomaszewski M, Topbas M, Tornaritis MJ, Torrent M, Torres-Collado L, Touloumi G, Traissac P, Triantafyllou A, Trinh OT, Tsao Y-H, Tsiampalis T, Tsugane S, Tuitele J, Tuliakova AM, Tulloch-Reid MK, Tuomainen T-P, Turley ML, Tzala E, Tzourio C, Ueda P, Ugel E, Ukoli FA, Ulmer H, Uusitalo HM, Valdivia G, Valvi D, van Dam RM, van den Born B-J, Van der Heyden J, Van Minh H, van Rossem L, Van Schoor NM, van Valkengoed IG, Vanderschueren D, Vanuzzo D, Varbo A, Vasan SK, Vega T, Veidebaum T, Velasquez-Melendez G, Verdot C, Veronesi G, Verstraeten R, Victora CG, Viet L, Villarroel L, Vioque J, Virtanen JK, Viswanathan B, Vollenweider P, Voutilainen A, Vrijheid M, Walton J, Wan Bebakar WM, Wan Mohamud WN, Wang C, Wang H, Wang N, Wang Q, Wang W, Wang YX, Wang Y-R, Wang Y-W, Wannamethee SG, Webster-Kerr K, Wedderkopp N, Wei W, Westbury LD, Whincup PH, Widhalm K, Widyahening IS, Więcek A, Wijemunige N, Wilks RJ, Willeit K, Willeit P, Wilsgaard T, Wojtyniak B, Wong-McClure RA, Wong A, Wong EB, Woodward M, Wu C-C, Wu FC, Xu H, Xu L, Xu Y, Yaacob NA, Yan L, Yan W, Yasuharu T, Yeh C-Y, Yoosefi M, Yoshihara A, You S-L, Yu Y-L, Yusoff AF, Zainuddin AA, Zamani F, Zambon S, Zampelas A, Zargar AH, Zaw KK, Zeljkovic Vrkic T, Zeng Y, Zhang B, Zhang L, Zhang L, Zhang Z-Y, Zhao M-H, Zhao W, Zholdin B, Zimmet P, Zins M, Zitt E, Zoghalmi N, Zuñiga Cisneros J, Ezzati M. Worldwide trends in diabetes prevalence and treatment from 1990 to 2022: a pooled analysis of 1108 population-representative studies with 141 million participants. *The Lancet* 2024 Nov;404(10467):2077–2093. doi: 10.1016/S0140-6736(24)02317-1 [[CrossRef](#)]

7. Ali MK, Imperatore G, Benoit SR, O'Brien MJ, Holliday CS, Echouffo-Tcheugui JB, McKeever Bullard K. Impact of changes in diabetes screening guidelines on testing eligibility and potential yield among adults without diagnosed diabetes in the United States. *Diabetes Res Clin Pract* 2023;197. doi: 10.1016/j.diabres.2023.110572 [[CrossRef](#)]
8. Misra A, Gopalan H, Jayawardena R, Hills AP, Soares M, Reza-Albarrán AA, Ramaiya KL. Diabetes in developing countries. *J Diabetes*. 2019. doi: 10.1111/1753-0407.12913 [[CrossRef](#)]
9. Suh S, Kim JH. Glycemic variability: How do we measure it and why is it important? *Diabetes Metab J*. 2015. doi: 10.4093/dmj.2015.39.4.273 [[CrossRef](#)]
10. Bermingham KM, Smith HA, Gonzalez JT, Duncan EL, Valdes AM, Franks PW, Delahanty L, Dashti HS, Davies R, Hadjigeorgiou G, Wolf J, Chan AT, Spector TD, Berry SE. Glycaemic variability, assessed with continuous glucose monitors, is associated with diet, lifestyle and health in people without diabetes. *Res Sq*. 2023. doi : 10.21203/rs.3.rs-3469475/v1 [[CrossRef](#)]
11. Wahidin M, Achadi A, Besral B, Kosen S, Nadjib M, Nurwahyuni A, Ronoatmodjo S, Rahajeng E, Pane M, Kusuma D. Projection of diabetes morbidity and mortality till 2045 in Indonesia based on risk factors and NCD prevention and control programs. *Sci Rep* 2024;14(1). doi: 10.1038/s41598-024-54563-2 [[CrossRef](#)]
12. Zanelli S, Ammi M, Hallab M, El Yacoubi MA. Diabetes Detection and Management through Photoplethysmographic and Electrocardiographic Signals Analysis: A Systematic Review. *Sensors*. 2022. doi: 10.3390/s22134890 [[CrossRef](#)]
13. Gusev M, Poposka L, Spasevski G, Kostoska M, Koteska B, Simjanoska M, Ackovska N, Stojmenski A, Tasic J, Trontelj J. Noninvasive Glucose Measurement Using Machine Learning and Neural Network Methods and Correlation with Heart Rate Variability. *J Sens*. 2020. doi: 10.1155/2020/9628281 [[CrossRef](#)]
14. Shi B, Dhaliwal SS, Soo M, Chan C, Wong J, Lam NWC, Zhou E, Paitimusa V, Loke KY, Chin J, Chua MT, Liaw KCS, Lim AWH, Insyirah FF, Yen S-C, Tay A, Ang S Bin. Assessing Elevated Blood Glucose Levels Through Blood Glucose Evaluation and Monitoring Using Machine Learning and Wearable Photoplethysmography Sensors: Algorithm Development and Validation. *JMIR AI* 2023;2. doi: 10.2196/48340 [[CrossRef](#)]

15. Ang S Bin, Chua MT, Shi B, Chan SHC, Liaw CSK, Dhaliwal SS. Utility of photoplethysmography in detecting elevated blood glucose among non-diabetics. *Singapore Med J* 2024 Sep 17; doi: 10.4103/singaporemedj.SMJ-2023-156 [[CrossRef](#)]
16. Zeynali M, Alipour K, Tarvirdizadeh B, Ghamari M. Non-invasive blood glucose monitoring using PPG signals with various deep learning models and implementation using TinyML. *Sci Rep Nature Research*; 2025 Dec 1;15(1). doi: 10.1038/s41598-024-84265-8 [[CrossRef](#)]
17. Chu J, Yang WT, Lu WR, Chang YT, Hsieh TH, Yang FL. 90% accuracy for photoplethysmography-based non-invasive blood glucose prediction by deep learning with cohort arrangement and quarterly measured hba1c. *Sensors MDPI*; 2021 Dec 1;21(23). PMID:34883817 [[CrossRef](#)]
18. Januraga PP, Lukitosari E, Luhukay L, Hasby R, Sutrisna A. Mapping Key Populations to Develop Improved HIV and AIDS Interventions: Multiphase Cross-Sectional Observational Mapping Study Using a District and City Approach. *JMIR Public Health Surveill* 2025 Jan 30;11:e56820. doi: 10.2196/56820 [[CrossRef](#)]
19. Priyanto H, Aulia FA, Kahar H, Faizi M, Marpaung FR, Aryati A. Neonatal Thyroid-Stimulating Hormone Reference Intervals in Multi-Ethnics Population. *Children Multidisciplinary Digital Publishing Institute (MDPI)*; 2025 Jan 1;12(1). doi: 10.3390/children12010104 [[CrossRef](#)]
20. Metherall B, Berryman AK, Brennan GS. Machine learning for classifying chronic kidney disease and predicting creatinine levels using at-home measurements. *Sci Rep* 2025 Feb 5;15(1):4364. doi: 10.1038/s41598-025-88631-y [[CrossRef](#)]
21. Tang Y, Yang D. Overcoming dietary complexity in type 2 diabetes: influencing factors and coping strategies. *Eur J Med Res* 2025 Feb 6;30(1):82. doi: 10.1186/s40001-025-02318-8 [[CrossRef](#)]
22. Rodin D, Kirby M, Sedogin N, Shapiro Y, Pinhasov A, Kreinin A. Comparative accuracy of optical sensor-based wearable system for non-invasive measurement of blood glucose concentration. *Clin Biochem* 2019 Mar;65:15–20. doi: 10.1016/j.clinbiochem.2018.12.014 [[CrossRef](#)]
23. Monte-Moreno E. Non-invasive estimate of blood glucose and blood pressure from a photoplethysmograph by means of machine learning techniques. *Artif Intell Med* 2011 Oct;53(2):127–138. doi: 10.1016/j.artmed.2011.05.001 [[CrossRef](#)]
24. Zhang K, Qi Y, Wang W, Tian X, Wang J, Xu L, Zhai X. Future horizons in diabetes: integrating AI and personalized care. *Front Endocrinol (Lausanne) Frontiers Media SA*; 2025;16. doi: 10.3389/fendo.2025.1583227 [[CrossRef](#)]
25. Zou X, Zhou X, Ji L, Yang W, Lu J, Weng J, Jia W, Shan Z, Liu J, Tian H, Ji Q, Zhu D, Ge J, Lin L, Chen L, Guo X, Zhao Z, Li Q, Zhou Z. The characteristics of newly diagnosed adult early-onset diabetes: A population-based cross-sectional study. *Sci Rep* 2017;7. doi: 10.1038/srep46534 [[CrossRef](#)]
26. Xiong X, Wei L, Xiao Y, Han Y, Yang J, Zhao H, Yang M, Sun L. Effects of family history of diabetes on pancreatic β -cell function and diabetic ketoacidosis in newly diagnosed patients with type 2 diabetes: A cross-sectional study in China. *BMJ Open* 2021;11(1). doi: 10.1136/bmjopen-2020-041072 [[CrossRef](#)]
27. Liu XL, Willis K, Fulbrook P, Wu CJ, Shi Y, Johnson M. Factors influencing self-management priority setting and decision-making among Chinese patients with acute coronary syndrome and type 2 diabetes mellitus. *European Journal of Cardiovascular Nursing* 2019;18(8). doi: 10.1177/1474515119863178 [[CrossRef](#)]
28. Donazar-Ezcurra M, Lopez-del Burgo C, Martinez-Gonzalez MA, Basterra-Gortari FJ, de Irala J, Bes-Rastrollo M. Soft drink consumption and gestational diabetes risk in the SUN project. *Clinical Nutrition* 2018;37(2). doi: 10.1016/j.clnu.2017.02.005 [[CrossRef](#)]
29. Penelitian A, Aritonang JP, Widiastuti IAE, Harahap IL. Gambaran Tingkat Aktivitas Fisik Mahasiswa Pendidikan Dokter Fakultas Kedokteran Universitas Mataram di Masa Pandemi COVID-19 Description of Physical Activity Level of Medical Students Faculty of Medicine, University Of Mataram In Covid-19 Pandemic. 2022;10(1). doi: 10.23886/ejki.10.129.58-63 [[CrossRef](#)]

30. Koshy AN, Sajeev JK, Nerlekar N, Brown AJ, Rajakariar K, Zureik M, Wong MC, Roberts L, Street M, Cooke J, Teh AW. Utility of photoplethysmography for heart rate estimation among inpatients. Intern Med J 2018;48(5). doi: 10.1111/imj.13777 [[CrossRef](#)]

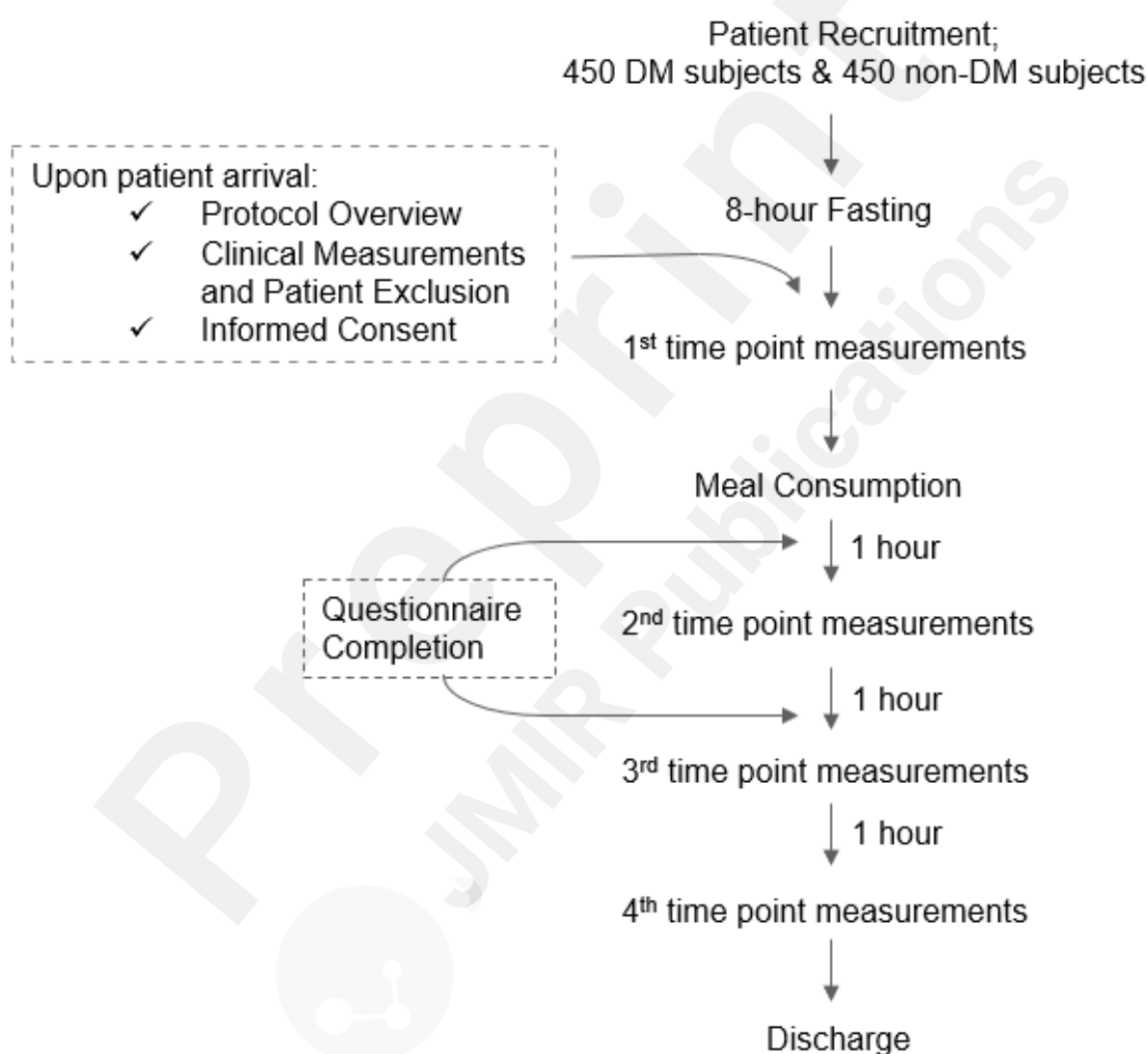


Figure 1. Conceptual framework of study design from recruitment, data collection to discharge

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TOTAL MEAL ANALYSIS																									
Energy (kcal)	Water (g)	Protein (g)	%	Fat (g)	%	Carb. (g)	%	Dietary fiber (g)	PUFA (g)	Cholesterol (mg)	Vit. A (µg)	Carotene (mg)	Vit. E (eq.) (mg)	Vit. B1 (mg)	Vit. B2 (mg)	Vit. B6 (mg)	Tot. fol. acid (µg)	Vit. C (mg)	Sodium (mg)	Potassium (mg)	Calcium (mg)	Magnesium (mg)	Phosphorus (mg)	Iron (mg)	Zinc (mg)
552.1	241.8	19.0	206.0	19.3	331.0	79.8	780.0	5.2	1.8	33.0	1396.8	0.4	0.8	0.0	0.1	0.6	31.8	10.7	1015.5	549.4	59.2	66.2	231.5	2.5	1.6

Table 1. Nutritional value of set meal for the subjects

Measurements	Smart Ring (JC Smart Health Ring 2301B)	Smart Watch (Actxa Spark+ Series 2)	Glucose Meter (Roche, ACCU-CHEK® Guide)	Plasma Blood Full Blood Count: Sysmec XN-550 Plasma Glucose: Roche, Cobas c111 Analyzer HbA1c Level: Finecare™ FIA Meter III Plus
1 st time point (fasted state)	Yes	Yes	Yes	Yes
2 nd time point (1 hour postprandial)	Yes	Yes	Yes	No
3 rd time point (2 hours postprandial)	Yes	Yes	Yes	Yes
4 th time point (3 hours postprandial)	Yes	Yes	Yes	No

Table 2. Blood glucose metabolism related data collection from photoplethysmography sensors, glucometer and blood samples based on time points before and after meal

Questionnaire & Test	Description of Content	Reff
Demographic	5 items; Age, Gender, Ethnicity, Handedness &	[15]

		Fitzpatrick Skin type	
Diabetic Status & History		6 items; Family History, Status, Year Diagnose, Medication, Gestational Diabetes, Drink consumption	[15,25–28]
Relevant Medical History		4 items; Smoking, Hypercholesterol, Hypertension & Related Medication	[15,26–28]
Physical Activity		IPAQ Questionnaire long form; 27 items	[29]
Clinical Measurements		4 items; Weight, Height, Waist Circumference & Blood Pressure	[15,25,26,28]
Pre measurements questions	PPG	7 items; Time of Medication, Time of Meal, Meal Content, Physical Activity in 24h, Last, Duration & Intensity	[14,30]

Table 3. Baseline study questionnaire and test description that was collected from the study's subject

MEAL 1	INGREDIENTS	WEIGHT (g)	MEAL ANALYSIS																									
			Energy (kcal)	Water (g)	Protein (g)	%	Fat (g)	%	Carb. (g)	%	Dietary fiber (g)	PUFA (g)	Cholesterol (mg)	Vit. A (µg)	Carotene (mg)	Vit. E (eq.) (mg)	Vit. B1 (mg)	Vit. B2 (mg)	Vit. B6 (mg)	Tot. fol.acid (µg)	Vit. C (mg)	Sodium (mg)	Potassium (mg)	Calcium (mg)	Magnesium (mg)	Phosphorus (mg)	Iron (mg)	Zinc (mg)
Oriental fried rice with chicken, vegetable and chili sauce	Boiled rice	150	195	0	3.6	8	0.3	1	42.9	89	0.5	0.2	0	0	0	0	0	0.1	3	0	0	43.5	4.5	19.5	55.5	0.3	0.6	
	Chicken breast	50	50.9	37.3	11.8	94	0.3	6	0	0	0	0.1	33	13.5	0	0.1	0	0	0.3	4.5	0	36	165	7	13.5	105	0.3	0.3
	Flour	15	54.6	0	1.5	11	0.2	2	11.4	85	0.4	0.1	0	0	0	0	0	0	0	2.7	0	0.3	16	2.3	3.3	16.2	0.2	0.1
	Cooking oil 1	6	51.7	0	0	0	6	103	0	0	0	0.1	0	300	0	0.2	0	0	0	0	0	0	0	0.4	0	0.5	0	0
	Carrot	5	1.3	4.5	0	15	0	7	0.2	76	0.2	0	0	78.7	0.4	0	0	0	0	0.6	0.3	3	14.5	2	0.9	1.8	0.1	0
	String beans	5	1.7	0	0.1	22	0	8	0.4	92	0.2	0	0	3.3	0	0	0	0	0	1.6	0.5	0.2	14.9	2.3	1.3	2	0.1	0
	Corn kernel	5	5.4	0	0.2	12	0.1	11	1.3	94	0.1	0	0	0	0	0	0	0	0	2.3	0.3	0.9	12.4	0.1	1.6	5.2	0	0
	Cooking oil 2	10	86.2	0	0	0	10	103	0	0	0	0.2	0	500	0	0.4	0	0	0	0	0	0	0	0.6	0	0.7	0	0
	Salt	2.5	0	0	0		0		0		0	0	0	0	0	0	0	0	0	0	0	968.1	0.2	1.1	0.1	0	0	0
	Pepper	2	6.5	0	0.3	16	0.3	38	1.2	73	0.7	0.1	0	2	0	0	0	0	0	5.6	0.2	1	30.9	9.6	5.1	7	0.6	0.1
	Chili	12	38.2	0	1.4	15	2.1	48	6.8	72	3	1	0	499.3	0	0.1	0	0.1	0.2	10.6	9.1	3.6	241.7	17.8	18.2	35.2	0.9	0.3
	Garlic	3	2.6	0	0.1	13	0	4	0.6	94	0.1	0	0	0	0	0	0	0	0	0.9	0.3	0.2	10	1.3	0.7	2.1	0	0
Iced jasmine tea	Sugar	15	58	0	0	0	0	0	15	105	0	0	0	0	0	0	0	0	0	0	0.2	0.3	0.2	0	0.3	0	0	
	Drinking water	200	0	200	0		0		0		0	0	0	0	0	0	0	0	0	0	2	0	10	2	0	0	0.2	
Total		480,5	552.1	241.8	19.0	206.0	19.3	331.0	79.8	780.0	5.2	1.8	33.0	1396.8	0.4	0.8	0.0	0.1	0.6	31.8	10.7	1015.5	549.4	59.2	66.2	231.5	2.5	1.6

Table S1. Nutritional value breakdown of each ingredient from the meal set given to break the subjects fast

Supplementary Files

Figures

Conceptual framework of study design from recruitment, data collection to discharge.

