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7CCSMPRJ

Individual Project Submission 2024 - 2025

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Student Number:	K24012370
Degree Programme:	MSc. Advanced Computing
Project Title:	GluCORRECT - Harnessing Artificial Intelligence to scrutinize Hypoglycemia in hospitalised patients with diabetes to classify, anticipate and analyse hypoglycemic episodes [Knowledge Exchange Project with NHS England]
Supervisor:	Dr. Rita Borgo
Word Count:	==== Word count goes here ====

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Department of Informatics
King's College London
United Kingdom

7CCSMPRJ Individual Project

GluCORRECT - Harnessing Artificial Intelligence to scrutinize Hypoglycemia in hospitalised patients with diabetes to classify, anticipate and analyse hypoglycemic episodes [Knowledge Exchange Project with NHS England]

Name: **Siddharth Kishor Samarth**
Student Number: K24012370
Course: MSc. Advanced Computing

Supervisor: Dr. Rita Borgo

This dissertation is submitted for the degree of MSc Advanced Computing.

Acknowledgements

I would like to express my sincerest gratitude towards my project supervisor, Dr. Rita Borgo, for her invaluable advice and consistent direction throughout the course of this project. Her mentorship and ideas have been instrumental in shaping the development of this work, leading to its successful completion.

I am also deeply thankful & appreciative of my industry advisor, Dr. Piya Sen Gupta, for providing the dataset that has served as the foundation of this work. Her contributions have significantly enhanced the practical relevance and quality of this project.

Ultimately I would like to thank my friends and my parents, especially my dad, without whose sacrifices I would not be where I am today.

Abstract

Project Variant: Variant 4 - Develop a weighted score and design score to predict risk of a hypoglycaemic episode before it occurs.

It is well known that hypoglycemia as well as hyperglycemia are common adverse events in patients who receive blood sugar control medication, and they are also one of the most frequently cited causes of hospital admissions in people with diabetes. National quality improvement programmes from the Healthcare Quality Improvement Partnership (HQIP) and the study of ambulance call-out data have shown that ***lack of awareness*** by both affected individuals and their attendants is associated with a dramatically increased rate of complications, amongst other factors. Guy's & St. Thomas' NHS Foundation Trust (hereafter referred to as GSTT) has found, after careful deliberation and departmental review, that hypoglycemic episodes have been occurring with unusual frequency. The Trust now seeks to take measures to resolve such problems with a greater focus on prevention combined with early corrective action. This research project has been undertaken in close collaboration with GSTT, one of the largest NHS trusts in the UK and an indispensable element of London's healthcare system, with almost 24000 staff across 5 major hospitals, handling over 3 million patients a year and generating an annual turnover of over £3 billion.

This analytical study serves as a foundation and proof-of-concept to aid GSTT in pre-emptively reducing hypoglycemia within hospitalised inpatients, by utilising statistics & machine learning techniques. Through exploratory data analysis I draw out relevant conclusions about the dataset around patient age, ethnicity and

I go on to identify the significant factors responsible for hypoglycemia within the dataset provided by the industry advisor from GSTT through exploratory data analysis, while also . I explore how they can be utilized to devise a risk score, to classify patients based on their risk of hypoglycemia.

RESULTS: HbA1c values identified as risky - 56 or so eGFR ethnicity major is glucose value

In conclusion, exhibit my findings with potential ways of applying them in practise in hospitals.

All abbreviations and symbols used in the report must be listed and defined in alphabetic order.

Nomenclature

AUROC	Area Under Receiver Operating Characteristic Curve - a measure of model performance
GSTT	Guy's and St Thomas' NHS Foundation Trust
HQIP	Healthcare Quality Improvement Partnership
"Hypo" or "Hypos"	Hypoglycemic episode(s)
"Inpatient"	Referring to the the fact that a patient is required to stay overnight in order to be treated (in case of surgeries or long term observation for example)
NCAPOP	National Clincal Audit & Patient Outcomes Programme
NDA	National Database Audit
NDISA	National Diabetes Inpatient Safety Audit
NHS	The publicly funded healthcare system of the United Kingdom, the National Health Service.

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a	The number of angels per unit area
A	The area of the needle point
c	Speed of light in a vacuum inertial frame
h	Planck constant
LMI	Linear Matrix Inequalities
N	The number of angels per needle point

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1 Introduction

1.1 Clinical Overview

Hypoglycaemia (also known as a "hypoglycaemic episode" or a "hypo" for short) is the condition that occurs when the human body's blood glucose (sugar) level drops below the normal healthy range of 4.0 to 6.0 mmol/L. While it can affect anyone, it is most common in diabetic individuals who are prescribed drugs like insulin or metformin to inhibit glucose. Hypoglycaemic events are relatively simple and straightforward to resolve, but they need to be treated immediately to avoid serious damage to the brain and heart as a result of loss of consciousness or arrhythmias. High-sugar consumables are generally effective in correcting mild cases and are commonly recommended for immediate treatment, but severe cases of hypoglycaemia such as when the person is unconscious or having a seizure can only be resolved with an urgent, immediate glucagon injection to prevent them from deteriorating into a coma (or in rare cases, even leading to death).

To underscore how and why this matters, diabetes is one of the most significant and expensive long-term health conditions faced by the NHS, with recent figures from Diabetes UK suggesting that over 5.8 million people in the UK are living with diabetes, regardless of a formal diagnosis. It is estimated to cost the NHS over £10.7 billion a year, approximately 10% of its entire annual budget, which could go up to £18 billion by 2035 [1]. A stark finding is that almost 60% of this cost (around £6.2 billion) is spent on treating the largely preventable complications of diabetes, such as heart attacks, strokes, blindness, and so on, including hypoglycaemia [2]. Hypoglycaemic instances make up a major component of these preventable costs, mainly accounting for the emergency, ambulance, and acute care expenses associated with diabetes. The Local Impact of Hypoglycaemia Tool (LIHT) suggests that hypoglycaemia can cost up to £2,195 per episode, possibly increasing substantially with a longer stay in hospital [3], and it is estimated that there are up to 100,000 ambulance callouts annually according to the Diabetes Research and Wellness Foundation (DRWF) [4]. DRWF's study hinted that 1 in 10 individuals that experience a severe hypo (meaning requiring medical intervention or resuscitation) have considerable chances of another one within a fortnight.

1.2 Background

After introspective analysis supported by information from the National Diabetes Inpatient Safety Audit (NDISA) it has been recognized that severe hypoglycaemia and recurrent severe hypoglycaemia have been occurring relatively frequently across GSTT medical facilities. The NDISA forms part of the National Diabetes Audit (NDA), and it maintains that "The prevalence of diabetes continues to increase. In England

between 2017-18 and 2021-22 prevalence of type 1 diabetes went up from 248,240 to 270,935 and the prevalence of type 2 and other diabetes from 2,952,695 to 3,336,980", as of 2022 [5].

GSTT administers upwards of 500,000 point-of-care glucose tests (POCT) annually, in addition to kidney function and glycated haemoglobin (HbA1c) tests as well. The Trust also possesses blood glucose / ketone data with additional linked data including demographics, dates of admission and discharge, patient as well as family history and current or previous medications. They have two major kinds of patient records, inpatient records for patients that have to stay over the course of one or multiple nights (for example, in case of surgeries or for long term care), and outpatient records where the patient doesn't require overnight stay. The Trust manages all of this data through their electronic health record management system called Epic, and facilitates patient access to their own records through the MyChart web application.

Hypoglycaemia is a frequent complication amongst inpatients having complex health conditions, especially within those in intensive care settings that have been / are critically ill due to advanced diseases or comorbidities, or in patients following major surgical interventions. The Trust is undertaking proactive measures to identify and mitigate the risk of hypoglycaemic episodes at an early stage, to support better planning, reduce healthcare costs, efficiently allocate hospital resources and also schedule operations optimally. The ideal way to assess risk would along the lines of developing tools to predict individualized risk scores for inpatients after considering all relevant factors. However, this presents a herculean task due to the sheer volume and complexity of factors involved, compounded by the challenges of producing reliable results even within small populations — such as those in remote areas — while also adhering to legal and governmental regulations:

1. Weighing up the risk of hypoglycaemia depends upon numerous aspects such as lifestyle, renal function, recent food intake, blood glucose history and current medication to name a few, making this a highly complicated modelling problem. In addition to this, patients differ widely in age, comorbidities, ethnic factors and even insulin sensitivity. This variability makes it a formidable challenge to develop a model that is generalizable, dependable and unbiased.

2. Any such analytical tool in the vicinity of patient healthcare requires medical evaluation and approval, validation trials, governance oversight as well as ethical considerations. Even a good model may fail if it does not fit the clinical workflow. Initial skepticism towards AI, the effort required to train staff, defining clear responsibilities and limits of liability, and rehearsing procedures or plans of action for every possible scenario will all produce appreciable organizational inertia.

Successfully implementing even a small-scale solution, within GSTT to begin with, would be a significant strategic breakthrough that serves as a foundational model which other

NHS trusts or institutions could adapt and build upon. This positions this research initiative which is a Knowledge Exchange Project (KEP) with Guy's & St.Thomas' NHS Foundation Trust, an indispensable constituent of London's healthcare system, as a valuable and worthwhile research endeavour.

1.3 Aims and Objectives

This research project has the following objectives:

- **To extract insights from provided dataset for the given time period and population.** GSTT has expressed a strong interest towards gaining a deeper understanding of their inpatient population. The dataset they have provided includes demographic details, length of hospital stay, and ward information in addition to the main clinically relevant variables such as glycated haemoglobin levels, renal function measurements, patient age and so on. This enables a comprehensive, multifaceted analysis. The knowledge gained from this study, such as identifying which hospital wards have more vulnerable or at-risk patients, will be used to enhance staff training, in turn improving both future admissions routines as well as post-discharge support for patients. Every observation, regardless of scale, holds potential to refine hospital processes and operating procedures.
- **To identify the main influencing / contributing factors for hypoglycaemia and develop a weighted risk score to predict episodes (Variant 4 KEP).** The Trust is establishing and implementing measures to "pre-assess" inpatients to evaluate their risk of a hypoglycaemic episode, which will allow medical professionals to design protocols and policies to prevent episodes from occurring as well as take early remediative action as soon as possible to resolve an episode should it occur. I aim to find data-backed values for the key features responsible for hypoglycaemia, through statistical tests and machine learning algorithms, in order to create a risk score. This risk score can then be applied in hospital to determine the best course of early action or precautions to take based on the patient's reason for being admitted.

1.4 Report Structure

Section 2 contains a comprehensive, detailed review of similar research carried out by other universities, teaching hospitals and medical facilities including references to relevant medical literature. I have compared and contrasted datasets used, approaches taken and results obtained.
Section 3 delves deeper into the dataset provided by GSTT, elaborating on the raw features provided and those that were derived from them for analysis.
Section 4 (Methodology & Implementation) outlines the statistical and mathematical theory behind the concepts used for analysis, ranging from machine learning algorithms to hypothesis testing methods.

Sections 5 (Main Results) onwards discuss the main research executed within the project and deliberates on the results achieved
Section 6 (Ethical Professional Legal Social issues)
Section 7 (Conclusion and Applicability)

1.4.1 Dissertation Length

This dissertation comprises a total of wordcount XXXX words excluding references and appendices.

2 Literature Survey & Review

2.1 The Diabetes Management Tightrope

Managing diabetes often draws parallels with walking a metabolic tightrope. On one side lies the danger of hyperglycaemia and its associated *long-term complications* such as diabetic retinopathy(damage to blood vessels in the eye leading to blindness) or renal function impairment (diabetic nephropathy), while on the other lies the *immediate peril of hypoglycaemia*. For the longest time, clinicians have helped patients navigate this delicate balance, by utilising methods or practises that show where they are, but not necessarily where they are going, in terms of blood glucose measurements. Such a reactive approach with little account for anticipative elements has made hypoglycaemic episodes an unavoidable consequence of striving for tight glycaemic control.

This "tightrope" extends beyond just taking efforts to stay safe, requiring diabetics and patients to perform constant risk assessments in everyday life. UK driving law from the DVLA mandates a blood glucose reading of above 5.0mmol/L with a repeat test every two hours for longer journeys in order to be considered safe to drive. Patients are required to carry a "hypo kit" with fast-acting glucose at all times. The worry about having episodes in public and having to rely on the awareness of strangers or being a hindrance to social situations is a constant concern. As discussed here previously this also places notable financial strain on NHS resources through emergency or ambulance costs.

With scientific and technological progress that inevitably comes with time, comes the promise of a potential safety net: the ability to anticipate or foresee signs of an episode before they present. The dangerous tightrope walk can then be transformed into a manageable path, with the help of predictive systems built with advanced sensing technologies and computational power, that can assist patients to take pre-emptive action. This review will chart the progress in this field, understanding the methodologies and ideas that have been applied to forecast hypoglycaemic events, from early tracking methods to highly optimized modern algorithms.

2.2 Methods Of Monitoring Blood Glucose Over Time

The success rate of recognising patterns in blood glucose has been vastly upgraded through the years, spurred by both technological and procedural refinements in the monitoring of blood glucose, but it has been an arduous journey to get here. The earliest methods of testing blood glucose involved urine tests, where chemical reagents like Benedict's solution were used which changed colour in the presence of sugar. Such methods were only qualitative and retroactive - they offered no actionable information as they confirmed that blood glucose had been elevated at the time of the test or in the recent past. The first blood glucose meters did not appear until the 1960s, were large and cumbersome to work with, and were mainly found in clinics. Smaller, portable meters became available around the 1970s - 1980s yet still all such meters had to be used

repetitvely throughout the day, offering only a snapshot of blood glucose level in time without any means of showing a trend, stability or lack thereof.

The introduction of Continuous Glucose Monitoring (CGM) solutions from 2005 onwards completely revolutionized diabetic healthcare, allowing measurements to be taken effortlessly through sensors attached to the body. Medtronic and Dexcom's devices released after 2015 with highly improved sensor accuracy and user-friendliness even allowed connecting to smartphones and automatic insulin pumps, which could automatically stop insulin delivery if the patient did not respond to an alarm. Today's CGM's are even more cutting-edge, in that they continuously transmit data to a receiver. They are smartphone-app based for ease of use, offering enhanced features to show the trend and speed of glucose changes, alarms and alerts to proactively warn users, as well as sharing data with family members or doctors for remote monitoring and emergency handling [6].

In modern times, there is huge amounts of data available to probe into, but the challenge lies in finding the correct relevant features, at the correct level of granularity as well as the right distribution, as medical data is exceptionally rarely obtained in balanced form. The availability of rich continuous streams of data from CGMs has stimulated additional research dedicated to developing and applying algorithms to both forecast hypoglycaemic events as well as identify outliers or patterns within the data, and I delve into this next.

2.3 Review Of Relevant Literature and Similar Research

A substantial body of literature now exists on the development of models for predicting hypoglycaemia in various settings. In many scenarios, a significant proportion of the research focuses on optimizing predictive accuracy of models. For instance H. Yang et al. in 2022 [7] have used electronic health records(EHR) of patients admitted to West China Hospitals to develop a predictive model based on laboratory derived biomarkers (like lipoproteins, creatinine, globulin etc.). A similar research to this was undertaken by S. Mantena et al. [8] but on the publicly-available eICU Collaborative Research v2.0 database (eICU-CRD) that holds de-identified data for 200,000+ admissions in 553 ICUs across the USA. In reinforcement to this, UK-based studies have also been executed by Y. Ruan et al. [9] on four years worth of EHRs provided by Oxford University Hospitals NHS Foundation Trust in which they compared the performance of eighteen different predictive models based on demographic, laboratory, vital signs and previous medication predictors.

A significant commonality was observed in all the three research works, which I have incorporated into my approach as well - the emergence of XGBoost as the best predictive model with highest Area Under Receiver Operating Characteristic Curve(AUROC). Even though all studies produce excellent results in terms of predictive performance, they are not primarily aimed at finding the critical values or "turning points" of the predictors at which predictions / classifications change, which is my objective for this project that also lines up with GSTT priorities.

but almost all of this is based on highly controlled circumstances where a

Various kinds of different prediction models have already been devised and developed for predicting hypoglycemia. Yi Wu and others have systematically compared, and evaluated the applicability of models in clinical practice in a paper in Biological Research for Nursing[1] where it was found that the major predictors were age, HbA1c, history of hypoglycemia, and insulin use. Lin Yang, Zhiguang Zhou have carried out similar research in the Frontiers in Public Health journal[2] uncovering risk factors that could possibly lead to hypoglycemic events, after employing various data driven models based on ML techniques such as neural networks, autoregressive / ensemble learning and such.

In silico proof of concept studies like the one from Zecchin[3] have also been researched to investigate how continuous glucose monitoring short-term glucose prediction algorithms could be exploited to recognise the run up to hypoglycemic episodes, allowing the patient to take appropriate countermeasures to mitigate events. They found that there was a significant reduction in both the time spent in a hypoglycemic event as well as the number of hypoglycemic events.

3 Dataset

3.1 Raw Data

Our industry advisor from GSTT has graciously provided a year's worth of data in multiple .xlsx files, which have been combined into one for the purposes of analysis and research for this project. The **raw fields provided** within the data were:

- **UniqueID:** Unique identifier for the patient and test, which is just a number. Meant to identify same patients (not personally) when considered together with Order Time, Order Date and Age, as same patients can have multiple blood glucose tests during their stay.
- **Order Date:** The date when the glucose measurement was ordered or taken.
- **Order Time:** The timestamp at which the glucose measurement was ordered or taken.
- **Inpatient Admission Date:** The date at which the patient was admitted into the medical facility.
- **Discharge Date:** The date the patient was discharged from the medical facility.
- **Length of Stay:** The amount of time the patient has spent in the medical facility in days and hours (for eg. "5d 6h").
- **Ward:** The ward that the glucose measurement was taken in, usually matches the ward that the patient was admitted to.
- **Last Lab Test Results:** The result of the glucose measurement in mmol/L. Most values in this column are of the format "Manual blood glucose: 8.70 mmol/L" or "POCT Glucose Blood Manually: 2.7 mmol/L".
- **Age:** Age of the patient at the time of measuring blood glucose in years.
- **Ethnicity:** Specific ethnicity of the patient, values ranging from "South American - Columbian" to "Black or Black British - Nigerian" to "Other" or even missing.
- **Gender Identity:** Gender of the patient.
- **HbA1c:** Numerical value of HbA1c in mmol/mol, which is a measure of the average blood glucose over the past 2-3 months. Glucose in the body sticks to red blood cells to be transported around, and gets consumed to generate energy. If the body cannot use up sugar properly then more of it sticks to blood cells and builds up. Red blood cells are active for around 2-3 months, so the reading is generally taken quarterly, and is an indicator for blood sugar problems. [10].
- **HbA1c Date:** Date the HbA1c test was done for that patient.

- **eGFR:** Estimated Glomerular Filtration rate, which is a measurement of how well the kidneys are functioning. This is a percentage from 0 to 90, with anything 91 and over displayed by the NHS electronic health record system (Epic) as ">91" because an eGFR of 91 percent and above indicates healthy renal function.
- **eGFR Date:** The date the eGFR test was conducted.

3.2 Cleaned Dataset

The following variables were **derived from the raw features** and used for analysis:

- **Age_Range:** Categorical variable to store the age category of the patient based on their age to aid in visualisation. Possible values for this column are: "Young (1 to 25)", "Adult / Middle Aged (26-50)", "Older Adult / Old (51-75)" and "Elderly (76-100)".
- **Has_Hypoglycemia:** Binary variable to store whether the patient has hypoglycemia. A glucose measurement of 4mmol/L and below means the patient is hypoglycemic and has 1 in this column, 0 otherwise.
- **Glycemia_Type:** Categorical variable to store the type of glycemia based on the patient's glucose measurement. **For the purposes of this project, the classes we have been instructed to use are (all units in mmol/L):**
  1. "Severe Hypoglycemia" - for blood glucose values 2.2 and below
  2. "Hypoglycemia"- for blood glucose values from 2.3 to 4 both inclusive
  3. "Target Range"- for blood glucose values from 4.1 to 11 both inclusive
  4. "Hyperglycemia"- for blood glucose values above 11.
- **eGFR_Category:** Categorical variable that shows how serious the loss of kidney function is, based on the eGFR percentage. The possible values for this column are:
  1. "eGFR less than 20 - Kidney Failure" - for eGFR less than or equal to 20%
  2. "eGFR between 20 & 40 - Critical Loss of Kidney Function"- for eGFR above 20% but less than or equal to 40%
  3. "eGFR between 40 & 60 - Significant Loss of Kidney Function"- for eGFR above 40% but less than or equal to 60%
  4. "eGFR between 60 & 80 - Moderate Loss of Kidney Function"- for eGFR above 60% but less than or equal to 80%
  5. "eGFR between 80 & 90 - Minor Loss of Kidney Function"- for eGFR above 80% but less than or equal to 90%
  6. "eGFR above 90 - Normal kidney function"- for eGFR above 90% (data has been processed to only include "91" for this class as healthy eGFR is 91% and above).

- **Wider_Ethnic_Group:** Categorical variable to store the overarching ethnic group based on the one specified in the ethnicity column, as that had a total of 57 unique values. Possible values are: “Unknown or Not Stated”, “White”, “Mixed”, “Asian or Asian British”, “Black or Black British” and “Other Ethnic Groups”.

Note that columns obtained after cleaning the original data to extract a numerical value (such as blood glucose) ***have been omitted for brevity.***

Please see Appendix A subsection A.1 for screenshots of the dataset(s).

4 Methodology and Implementation

4.1 Research Strategy and Approach

Before receiving the dataset, I have conducted an exhaustive investigation of the clinical landscape surrounding hypoglycaemia as a health condition, including studying the situations in which it commonly occurs, both in hospital settings as well as in public or everyday life. I have scrutinized a plethora of factors contributing to hypoglycaemia, including associated medicines (even conflicting medications), at-risk patient profiles, habits and lifestyles, dosing errors (both excessive as well as insufficient (*insulin*)), missed meals and even alcohol consumption. This has allowed me to better assess the quality of the incoming dataset and the relevance of its features. Upon requesting additional information regarding current patient medication and alcohol intake as it was not provided originally, GSTT advised that this data is unavailable because of its inconsistent self-reported nature and due to restrictions under their information governance policy that permits access to only the data deemed necessary for the project's scope.

After receiving the data, I have thoroughly preprocessed it to ensure it was suitable for meaningful analysis. This included addressing data type mismatches, deriving variables to aid in visualisation and understanding, and performing necessary imputations using appropriate methods. Duplicate and missing records were handled, categorical variables were encoded to make them compatible for predictive modelling, data validity and consistency checks were enacted to confirm that values were in expected ranges (for e.g. the glucose value field), normalization was carried out where necessary. These steps were necessary to lay a strong foundation for the subsequent application of statistical tests and machine learning models. The full preprocessing workflow is depicted in Figure 1 below.

Following this, my focus was on exploratory data analysis to spot any anomalies or patterns near the surface. After devising research questions around the dataset, I have generated a collection of plots through Python's widely used seaborn library that I describe in detail in the main results section, which shed light on the prevalence of hypoglycaemia across various different scenarios. Special attention was paid to drawing comparisons between hypoglycaemic and non hypoglycaemic patients, in alignment with GSTT's interests that they had clarified in the project's early stages.

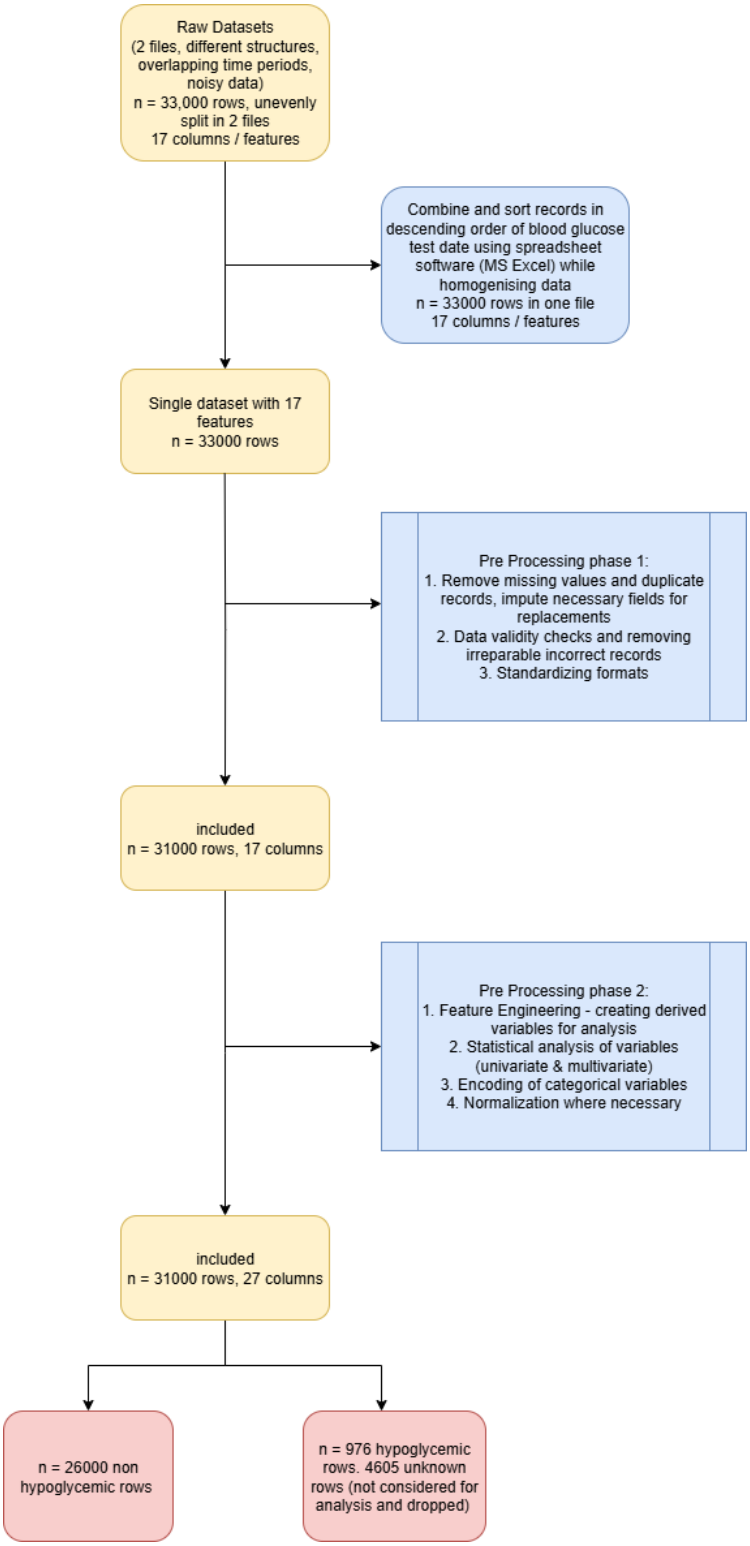


Figure 1: Data preprocessing workflow

4.2 Dealing With Imbalanced Data

augmentation / sampling

4.3 Machine Learning Theories

Decision tree random forest grid search cv conditional sampling xgboost

The content of “Main results” is in “\contents\introduction.tex”

5 Main Results and Findings

The chapter reports the contributions of your work. For example, it could contain the following sub-sections to summarise the contribution of the project such as Theoretical Development, Analysis and Design, Implementation and Experimental Work, Results, Observation and Discussion.

5.1 Interpretation Analysis and Evaluation

It summarises the results obtained from the proposed design and methodology. The way to obtain the results should be described in detail. Analysis and evaluation have to be performed. Comparisons should be made. It should justifies if the project aims, objectives, requirements and specifications have been achieved.

6 Math equations

This section is for demonstration of equations, figures, tables, which is not required for the report.

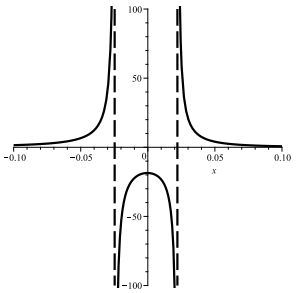
6.1 Maths

$$\frac{\mathrm{d}S_t}{S_t} = r\mathrm{d}t + \sigma\mathrm{d}W_t, \qquad S_0 > 0, \tag{6.1}$$

The equation $\sigma = ma$ follows easily [**?**].

6.2 Figures

Here is an example [**?**] of how to insert a picture:



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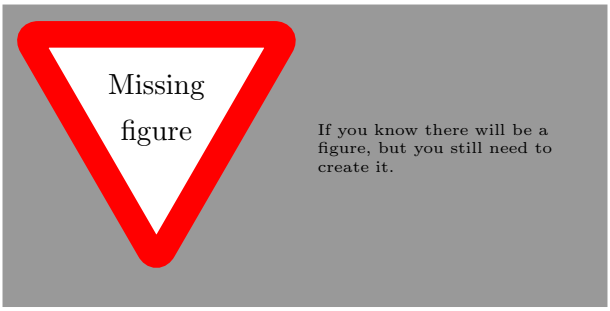

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or two side-by-side pictures:

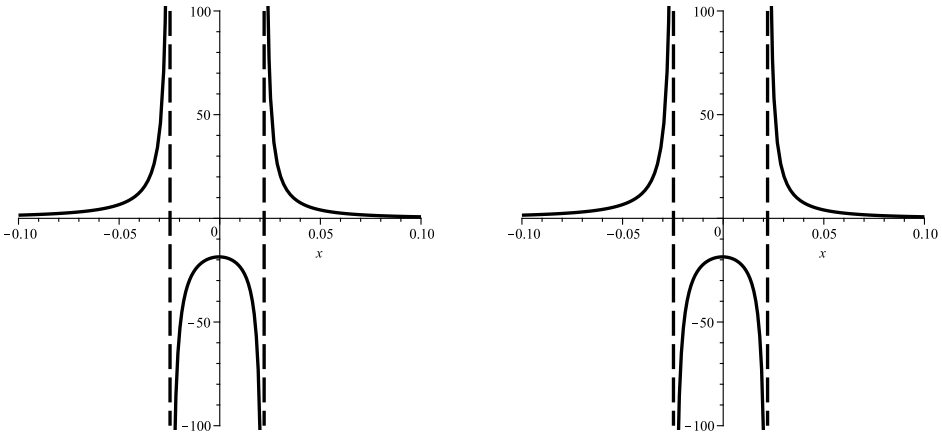

Figure 4: Another caption

7 Legal, Social, Ethical and Professional Issues

Research and projects within the medical domain are always inherently sensitive regardless of the kind of data involved or the presence of human participants. This sensitivity is amplified when a highly prominent industry stakeholder such as the NHS is interested, in view of the fact that it oversees public health across all of the UK. Right from the start, I have prioritized regular and transparent communication with our industry advisor through recurring meetings, while upholding implicit confidentiality agreements regarding the nature of the data and the project's specific objectives. All analysis was conducted within the agreed-upon scope. All deliverables were presented in a coherent and actionable format, thereby reflecting my commitment to their distinct requirements and towards fostering a trustworthy working relationship. Being cognizant of my social and ethical responsibility in this undertaking to advance public welfare, I have submitted an application in KCL's Research Ethics Management Application System (REMAS) which should supplement the agreements and principles established at the time of inception of the project, considering that the project is a KEP with industry (NHS England). According to KCL and REMAS guidelines, this project is classed as "Minimal Risk" [ref], in that it involves the study of pre-existing data that is not available to the general public, but is fully anonymous at the point which I as a researcher gain access to it. The industry advisor has kindly provided us the necessary data after complete anonymization, which removes any risk of personal identification. (Still submitted a Full Application Form instead of a minimal risk application) To further support this and in line with the guidelines listed in the General Data Protection Regulation (GDPR) as well as the Data Protection Act (DPA) 2018, the data was both shared with me and only accessed through secure organization / university credentials, meaning that it did not need to be fetched at all through any resource or API calls, eliminating the risk of interception. It was stored locally for on-machine data analysis and modelling through frequently used, open-source Python libraries, without the involvement of any online tools where the data has to be uploaded for research. Efforts have been taken to determine whether the project requires approval from any external entities, for example the Health Research Authority[ref] https://www.hra.nhs.uk/planning-and-improving-research/research-planning/student-research/. This was found to be not necessary. No recruitment of human participants was in the picture. Every care was taken to prevent any conflicts of interest from occurring, whether around other similar research, intellectual property, project objectives or any other sectors. I have also considered reliability measures to minimize the possibility of any kind of "reverse engineering" that may be carried out on my work. This substantiates that I have displayed special adherence to the British Computer Society (BCS) Code of Conduct and Code of Practise[ref], especially the directives regarding "Public Interest" and "Professional Competence and Integrity".

Socially, care has been taken to ensure that no adverse effects can occur as a result of this research

The content of “Conclusion” is in “\contents\conclusion.tex”

8 Conclusion

It is a chapter to sum up the main points and findings of the work; how you achieve the project aims and address the research questions; the contributions and results you have achieved. Future plan and development can be mentioned in this section as well. It is normally in one or two pages.

References

[1] Diabetes UK, "Cost of devastating complications highlights urgent need to transform diabetes care in the UK." URL. Accessed: 2025-07-07.

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A Appendix

A.1 Dataset

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	UniqueID	Order Date	Order Time	Order ID	Inpt Admsn Date	Discharge Date	Length of Stay	Ward	Last Lab Test Results	Age	Ethnicity	Gender Identity	Last HbA1c	Last HBA1C Dt	Last eGFR	EGFR Date	Admit Weight
266	265	05,06,2025	10:58:03	248956356	05,06,2025	06,06,2025	1d 9h	GH RICHARD BRIGHT WARD	Manual blood glucose: 6.20 mmol/L	64	Not stated/Undefined	Male	82	19,12,2024	23	27,06,2025	
267	262	05,06,2025	11:02:08	248958252	05,06,2025	06,06,2025	1d 9h	STH GYNAECOLOGY WARD	Manual blood glucose: 10.80 mmol/L	52	Black or Black British - Unspecified	Female			77	06,06,2025	
268	267	05,06,2025	11:02:22	248958363	05,06,2025	06,06,2025	1d 9h	STH GYNAECOLOGY WARD	Manual blood glucose: 12.00 mmol/L	52	Black or Black British - Unspecified	Female			77	06,06,2025	
269	267	05,06,2025	11:21:12	248968251	05,06,2025	05,06,2025	3h	STH ADMISSIONS WARD	Manual blood glucose: 10.10 mmol/L	56					78	05,06,2025	
270	269	05,06,2025	11:58:35	248986846	24,01,2025		157d 18h	STH WILLIAM GULL WARD	Manual blood glucose: 5.20 mmol/L	59	Black or Black British - African	Female	43	20,01,2024	58	01,07,2025	121 kg
271	3	05,06,2025	11:59:38	248987330	25,05,2025	18,06,2025	24d 2h	STH WILLIAM GULL WARD	Manual blood glucose: 10.40 mmol/L	88	White - Any other White background	Choose not to disclose	53	30,04,2024	59	18,06,2025	
272	4	05,06,2025	12:06:47	248990954	05,06,2025	06,06,2025	1d 9h	GH RICHARD BRIGHT WARD	Manual blood glucose: 5.70 mmol/L	64	Not stated/Undefined	Male	82	19,12,2024	23	27,06,2025	
273	262	05,06,2025	12:21:30	248998333	16,05,2025	27,06,2025	42d 1h	STH SARAH SWIFT WARD	Manual blood glucose: 11.90 mmol/L	76	White - British				61	27,06,2025	
274	273	05,06,2025	12:54:34	249011417	17,05,2025		45d 9h	STH HILLYERS WARD	Manual blood glucose: 7.40 mmol/L	74	Black or Black British - Caribbean		54	22,04,2024	50	30,06,2025	95 kg
275	11	05,06,2025	13:43:17	249031415	31,05,2025		30d 18h	STH WILLIAM GULL WARD	POCT Glucose Blood Manually En...: 7.	52	White - English				>90	27,06,2025	55 kg
276	275	05,06,2025	14:16:46	249045211	04,06,2025	07,06,2025	3d 3h	GH FLORENCE WARD	Manual blood glucose: 4.80 mmol/L	74	White - English	Male			32	24,06,2025	
277	276	05,06,2025	15:07:28	249067395	04,06,2025	20,06,2025	16d	STH GI PAGE WARD	Manual blood glucose: 7.20 mmol/L	81	Not stated/Undefined		61	13,11,2023	82	20,06,2025	
278	277	05,06,2025	15:07:40	249067474	01,06,2025	06,06,2025	5d 16h	STH ALEXANDRA WARD	Manual blood glucose: 6.50 mmol/L	78	Black or Black British - Caribbean	Female	39	24,04,2025	5	17,06,2025	
279	278	05,06,2025	15:42:24	249082295	06,06,2025	06,06,2025	16h	STH ADMISSIONS WARD	Manual blood glucose: 9.60 mmol/L	68	Black or Black British - African	Male	47	03,05,2024	58	06,06,2025	
280	279	05,06,2025	15:56:30	249087656	01,06,2025	09,06,2025	8d 17h	STH ALBERT WARD	Manual blood glucose: 5.70 mmol/L	34	Black or Black British - African	Male			>90	25,06,2025	
281	280	05,06,2025	16:07:02	249091566	05,06,2025	06,06,2025	1d 10h	GH ASTON KEY WARD	Manual blood glucose: 6.10 mmol/L	72	Black or Black British - Caribbean	Male	43	17,04,2024	60	06,06,2025	
282	281	05,06,2025	16:59:47	249109429	05,06,2025	06,06,2025	1d 9h	STH GYNAECOLOGY WARD	Manual blood glucose: 7.50 mmol/L	52	Black or Black British - Unspecified	Female			77	06,06,2025	
283	267	05,06,2025	17:36:36	249118534	05,06,2025	06,06,2025	1d 10h	GH ASTON KEY WARD	Manual blood glucose: 6.30 mmol/L	72	Black or Black British - Caribbean	Male	43	17,04,2024	60	06,06,2025	
284	281	05,06,2025	17:55:00	249122117	05,06,2025	06,06,2025	1d 1h	GH SARAH WARD	Manual blood glucose: 6.50 mmol/L	69	White - English				>90	05,06,2025	
285	284	05,06,2025	18:03:54	249123786	22,04,2025		70d 9h	STH MARK WARD	Manual blood glucose: 5.10 mmol/L	68	White - British		47	12,04,2024	>90	30,06,2025	75 kg
286	285	05,06,2025	19:02:34	249132405	03,06,2025	07,06,2025	4d 13h	GH ASTON KEY WARD	Manual blood glucose: 10.80 mmol/L	50	Black or Black British - Any other Black	Female	109	10,06,2025	>90	10,06,2025	
287	118	05,06,2025	19:25:07	249134589	17,05,2025		45d 9h	STH HILLYERS WARD	Manual blood glucose: 6.00 mmol/L	74	Black or Black British - Caribbean		54	22,04,2024	50	30,06,2025	95 kg
288	11	05,06,2025	19:26:43	249134739	05,06,2025	12,06,2025	6d 21h	STH WILLIAM GULL WARD	Manual blood glucose: 11.10 mmol/L	65	White - English	Male			70	30,06,2025	
289	288	05,06,2025	19:27:27	249134791	30,04,2025		61d 17h	STH WILLIAM GULL WARD	Manual blood glucose: 13.00 mmol/L	59	White - Any other White background	Male			72	26,06,2025	62.3 kg
290	12	05,06,2025	19:56:11	75513886	05,06,2025	06,06,2025	14h	STH ADMISSIONS WARD	Manual blood glucose: 9.20 mmol/L	41	Black or Black British - Caribbean				63	06,06,2025	
291	290	05,06,2025	20:42:10	249140609	14,04,2025		77d 17h	STH SOMERSET WARD	Manual blood glucose: 3.40 mmol/L	35	Any Other Ethnic Group	Male			81	29,06,2025	77 kg
292	148	05,06,2025	20:42:48	249140642	14,04,2025		77d 17h	STH SOMERSET WARD	Manual blood glucose: 4.30 mmol/L	35	Any Other Ethnic Group	Male			81	29,06,2025	77 kg
293	148	05,06,2025	20:44:12	249140769	06,06,2025	07,06,2025	1d 13h	STH SOMERSET WARD	Manual blood glucose: 6.60 mmol/L	53	Black or Black British - Caribbean	Female	40	08,12,2023	>90	05,06,2025	
294	293	05,06,2025	21:07:42	249142353	06,06,2025	06,06,2025	16h	STH ADMISSIONS WARD		68	Black or Black British - African	Male	47	03,05,2024	58	06,06,2025	
295	279	05,06,2025	21:07:45	249142357	06,06,2025	06,06,2025	16h	STH ADMISSIONS WARD	POCT Glucose Blood Manually E...: 11.	68	Black or Black British - African	Male	47	03,05,2024	58	06,06,2025	
296	279	05,06,2025	21:16:33	249143099	05,06,2025	06,06,2025	1d 1h	GH SARAH WARD	Manual blood glucose: 12.40 mmol/L	69	White - English				>90	05,06,2025	
297	284	05,06,2025	21:43:01	249144918	21,05,2025		40d 19h	STH ALEXANDRA WARD	Manual blood glucose: 6.20 mmol/L	82	Not stated/Undefined				53	01,07,2025	67.2 kg
298	297	05,06,2025	22:01:57	249146383	25,05,2025	18,06,2025	24d 2h	STH WILLIAM GULL WARD	Manual blood glucose: 11.00 mmol/L	88	White - Any other White background	Choose not to disclose	53	30,04,2024	59	18,06,2025	
299	4	05,06,2025	22:13:12	249147160	24,01,2025		157d 18h	STH WILLIAM GULL WARD	Manual blood glucose: 6.10 mmol/L	59	Black or Black British - African	Female	43	20,01,2024	58	01,07,2025	121 kg
300	3	05,06,2025	22:46:05	249149081	06,06,2025	10,06,2025	4d 9h	STH MARK WARD	Manual blood glucose: 9.20 mmol/L	72	Asian or Asian British - Arab	Male	64	13,05,2024	59	26,06,2025	
301	300	05,06,2025	23:44:45	249152341	14,04,2025		77d 17h	STH SOMERSET WARD	Manual blood glucose: 5.80 mmol/L	35	Any Other Ethnic Group	Male			81	29,06,2025	77 kg
302	148	06,06,2025	16:48:01	249383961	07,06,2025	14,06,2025	7d 18h	STH ALEXANDRA WARD	Manual blood glucose: 6.80 mmol/L	99	Black or Black British - Caribbean	Female			26	16,06,2025	

Figure 5: Raw dataset

	J	K	L	M	N	O	P	Q	R	U	V	W	Y	Z	AA
1	Age	Ethnicity	Gender Identity	Last HbA1c	Last HBA1C Dt	Last eGFR	EGFR Date	Admit Weight	Glucose Value	Length of Stay (Ti	Age_Range	Has_Hypo	Glycemia_Type	eGFR_Category	Wider_Ethnic_Group
269	56						78	05,06,2025		10.1 0 days 03:00:00	Older Adult / Old (51-75)	0	Target Range	eGFR between 60 & 80 - Moderate Loss of Kidney f	Unknown or Not Stated
270	59	Black or Black British - African	Female	43	20,01,2024	58	01,07,2025	121 kg		5.2 157 days 18:00:00	Older Adult / Old (51-75)	0	Target Range	eGFR between 40 & 60 - Significant Loss of Kidney	Black or Black British
271	88	White - Any other White background	Choose not to disclose	53	30,04,2024	59	18,06,2025			10.4 24 days 02:00:00	Elderly (76-100)	0	Target Range	eGFR between 40 & 60 - Significant Loss of Kidney	White
272	64	Not stated/Undefined	Male	82	19,12,2024	23	27,06,2025			5.7 1 days 09:00:00	Older Adult / Old (51-75)	0	Target Range	eGFR between 20 & 40 - Critical Loss of Kidney Fun	Unknown or Not Stated
273	76	White - British				61	27,06,2025			11.9 42 days 01:00:00	Elderly (76-100)	0	Hyperglycemia	eGFR between 60 & 80 - Moderate Loss of Kidney f	White
274	74	Black or Black British - Caribbean		54	22,04,2024	50	30,06,2025	95 kg		7.4 45 days 09:00:00	Older Adult / Old (51-75)	0	Target Range	eGFR between 40 & 60 - Significant Loss of Kidney	Black or Black British
275	52	White - English				>90	27,06,2025	55 kg		7.5 30 days 18:00:00	Older Adult / Old (51-75)	0	Target Range	eGFR above 90 - Normal kidney function	White
276	74	White - English	Male			32	24,06,2025			4.8 3 days 03:00:00	Older Adult / Old (51-75)	0	Target Range	eGFR between 20 & 40 - Critical Loss of Kidney Fun	White
277	81	Not stated/Undefined		61	13,11,2023	82	20,06,2025			7.2 16 days 00:00:00	Elderly (76-100)	0	Target Range	eGFR between 80 & 90 - Minor Loss of Kidney Func	Unknown or Not Stated
278	78	Black or Black British - Caribbean	Female	39	24,04,2025	5	17,06,2025			6.5 5 days 16:00:00	Elderly (76-100)	0	Target Range	eGFR less than 20 - Kidney Failure	Black or Black British
279	68	Black or Black British - African	Male	47	03,05,2024	58	06,06,2025			9.6 0 days 16:00:00	Older Adult / Old (51-75)	0	Target Range	eGFR between 40 & 60 - Significant Loss of Kidney	Black or Black British
280	34	Black or Black British - African	Male			>90	25,06,2025			5.7 8 days 17:00:00	Adult / Middle Aged (26-50)	0	Target Range	eGFR above 90 - Normal kidney function	Black or Black British
281	72	Black or Black British - Caribbean	Male	43	17,04,2024	60	06,06,2025			6.1 1 days 10:00:00	Older Adult / Old (51-75)	0	Target Range	eGFR between 40 & 60 - Significant Loss of Kidney	Black or Black British
282	52	Black or Black British - Unspecified	Female			77	06,06,2025			7.5 1 days 09:00:00	Older Adult / Old (51-75)	0	Target Range	eGFR between 60 & 80 - Moderate Loss of Kidney f	Black or Black British
283	72	Black or Black British - Caribbean	Male	43	17,04,2024	60	06,06,2025			6.3 1 days 10:00:00	Older Adult / Old (51-75)	0	Target Range	eGFR between 40 & 60 - Significant Loss of Kidney	Black or Black British
284	69	White - English				>90	05,06,2025			6.5 1 days 01:00:00	Older Adult / Old (51-75)	0	Target Range	eGFR above 90 - Normal kidney function	White
285	68	White - British		47	12,04,2024	>90	30,06,2025	75 kg		5.1 70 days 09:00:00	Older Adult / Old (51-75)	0	Target Range	eGFR above 90 - Normal kidney function	White
286	50	Black or Black British - Any other Black	Female	109	10,06,2025	>90	10,06,2025			10.8 4 days 13:00:00	Adult / Middle Aged (26-50)	0	Target Range	eGFR above 90 - Normal kidney function	Black or Black British
287	74	Black or Black British - Caribbean		54	22,04,2024	50	30,06,2025	95 kg		6 45 days 09:00:00	Older Adult / Old (51-75)	0	Target Range	eGFR between 40 & 60 - Significant Loss of Kidney	Black or Black British
288	65	White - English	Male			70	30,06,2025			11.1 6 days 21:00:00	Older Adult / Old (51-75)	0	Hyperglycemia	eGFR between 60 & 80 - Moderate Loss of Kidney f	White
289	59	White - Any other White background	Male			72	26,06,2025	62.3 kg		13 61 days 17:00:00	Older Adult / Old (51-75)	0	Hyperglycemia	eGFR between 60 & 80 - Moderate Loss of Kidney f	White
290	41	Black or Black British - Caribbean				63	06,06,2025			9.2 0 days 14:00:00	Adult / Middle Aged (26-50)	0	Target Range	eGFR between 60 & 80 - Moderate Loss of Kidney f	Black or Black British
291	35	Any Other Ethnic Group	Male			81	29,06,2025	77 kg		3.4 77 days 17:00:00	Adult / Middle Aged (26-50)	1	Hypoglycemia	eGFR between 80 & 90 - Minor Loss of Kidney Func	Other Ethnic Groups
292	35	Any Other Ethnic Group	Male			81	29,06,2025	77 kg		4.3 77 days 17:00:00	Adult / Middle Aged (26-50)	0	Target Range	eGFR between 80 & 90 - Minor Loss of Kidney Func	Other Ethnic Groups
293	53	Black or Black British - Caribbean	Female	40	08,12,2023	>90	05,06,2025			6.6 1 days 13:00:00	Older Adult / Old (51-75)	0	Target Range	eGFR above 90 - Normal kidney function	Black or Black British
294	68	Black or Black British - African	Male	47	03,05,2024	58	06,06,2025			0 days 16:00:00	Older Adult / Old (51-75)			eGFR between 40 & 60 - Significant Loss of Kidney	Black or Black British
295	68	Black or Black British - African	Male	47	03,05,2024	58	06,06,2025			11.4 0 days 16:00:00	Older Adult / Old (51-75)	0	Hyperglycemia	eGFR between 40 & 60 - Significant Loss of Kidney	Black or Black British
296	69	White - English				>90	05,06,2025			12.4 1 days 01:00:00	Older Adult / Old (51-75)	0	Hyperglycemia	eGFR above 90 - Normal kidney function	White
297	82	Not stated/Undefined				53	01,07,2025	67.2 kg		6.2 40 days 19:00:00	Elderly (76-100)	0	Target Range	eGFR between 40 & 60 - Significant Loss of Kidney	Unknown or Not Stated
298	88	White - Any other White background	Choose not to disclose	53	30,04,2024	59	18,06,2025			11 24 days 02:00:00	Elderly (76-100)	0	Target Range	eGFR between 40 & 60 - Significant Loss of Kidney	White
299	59	Black or Black British - African	Female	43	20,01,2024	58	01,07,2025	121 kg		6.1 157 days 18:00:00	Older Adult / Old (51-75)	0	Target Range	eGFR between 40 & 60 - Significant Loss of Kidney	Black or Black British
300	72	Asian or Asian British - Arab	Male	64	13,05,2024	59	26,06,2025			9.2 4 days 09:00:00	Older Adult / Old (51-75)	0	Target Range	eGFR between 40 & 60 - Significant Loss of Kidney	Asian or Asian British
301	35	Any Other Ethnic Group	Male			81	29,06,2025	77 kg		5.8 77 days 17:00:00	Adult / Middle Aged (26-50)	0	Target Range	eGFR between 80 & 90 - Minor Loss of Kidney Func	Other Ethnic Groups
302	99	Black or Black British - Caribbean	Female			26	16,06,2025			6.8 7 days 18:00:00	Elderly (76-100)	0	Target Range	eGFR between 20 & 40 - Critical Loss of Kidney Fun	Black or Black British
303	76	White - British				61	27,06,2025			7.3 42 days 01:00:00	Elderly (76-100)	0	Target Range	eGFR between 60 & 80 - Moderate Loss of Kidney f	White
304	88	White - British	Female	61	22,01,2024	49	10,06,2025			4.8 6 days 21:00:00	Elderly (76-100)	0	Target Range	eGFR between 40 & 60 - Significant Loss of Kidney	White
305	71	White - British				>90	07,06,2025			6.2 3 days 08:00:00	Older Adult / Old (51-75)	0	Target Range	eGFR above 90 - Normal kidney function	White

Figure 6: Dataset with cleaned features (this is in addition to the fields of the raw dataset)