3D Fabrication of Food through Software Implementation for Patients of Various Diseases and Dysphagia

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DECLARATION

This is a submission to the Department of Computer Science and Engineering for the purpose of obtaining a Bachelor's degree Bachelor of Science in Computer Science Engineering. We, hereby declare that the results of this research are solely dependent on our research. Credits for any resources used are provided in the reference section. This paper was not used for any other academic or non-academic purpose and was not submitted for any other degree.

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ABSTRACT

3D printing can be considered as a means of creating solid 3-dimensional objects using additive manufacturing with the aid of computer design software. With respect to time and newer technologies, 3D printing has advanced far more than we have ever anticipated. Though the potential of 3D printing has been under philosophical discussion for some time, creating food using 3D printers has always been a challenge. In order to print 3D food using 3D printing technology, a solid software is required that will count and personalize the nutrient information per patient and individual. In this research, a software has been developed that computes the required macronutrients according to the requirements per individual. Seven diseases have been outlined in this thesis and calculations for ingredients based on different ratios and equations have been made which have been derived after intensive research, from which two unique self-deduced algorithms have been developed to run the software logic. The system takes in the age, height, weight, gender and disease information from the hospital patients' charts, uses the variables to run the first own algorithm to calculate personalized protein, fat and carbohydrate counts and then based on the diseases the software runs the second own algorithm to calculate the exact amounts of the ingredients required to prepare their meals per day. In this thesis, 3D models have also been designed to maximize user experience and the patient's visual appeal for the food. The final output of the software is expected to print out a list of the ingredient count per day and display the selected 3D model. Further work of this thesis aims to explore the world of 3D printing and come up with nutrition specific solutions for people suffering from different diseases and have 3D printing technology make their lives easier because the potential of 3D printing of food is vast in a sense that it could provide an exciting alternative to help people customize their food, make them visually more appealing so that people requiring special care would be able to consume food with much more ease which would otherwise have been unachievable through conventional cooking and food preparation techniques.

Keywords: Additive manufacturing, 3D printing, Food printing, Macronutrients.

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CHAPTER 1: INTRODUCTION

1.1 Introduction

Advancements in 3D technology have enabled users to move from subtractive printing techniques to additive and now to transformative as food printing requires ingredients to be combined, heated and cooled, and chemical reactions transform these ingredients into new ones in the process of creating new shapes, textures and flavors. Even though there are many applications of 3D printing and it dates back to almost the mid 1980's, the prospect of fabricating food with additive manufacturing is a fairly new concept and it is safe to say that there is a high potential for research on this field which would eventually enable us to fashion food according to an individual's requirements. When technological science is integrated with gastronomy, it is possible to architecture food, the most essential thing for any living thing's survival, into personalized molds for individuals. The customization of food can not only help set nutrition individualized to each human being, but it can also help bring preferred visual appeal to the food as well. Added to that, correct nutrition is very important for a healthy living because improper intake of nutrition may result in people to suffer from chronic diseases which would hamper their lifestyle. This thesis project works to come up with a computer system which would be able to suggest what nutrients to incorporate into a person's diet when the system is provided with relevant background information about the patient and the ways through which the food can be printed out according to the suggestions provided by our system.

1.2 Motivation

Currently the population of the world stands at a whopping 7.6 billion people [1]. The world is already overpopulated as it is and it is estimated that by 2050 the population will hit a staggering 9 billion mark [1]. With the ever increasing population and the world food supplies increasing ever so slightly, comes an even greater danger. World hunger. The scarcity of food can be a direct consequence of overpopulation and poses a dire threat. This is evident from the fact that in overpopulated areas, the elderly, women and children suffer from malnutrition and are the leading cause of deaths [2]. The research team pondered on the ways to come up with an effective solution and combine nutritional science to counter this problem to come up with the idea that 3D printing can be a solution to counter world hunger by utilizing the food that we throw away namely ingredients such as fish bones/skin, vegetable stalks etc. which could be put to use using 3D printing and subsequently reduce the amount of food wastage. It was also realized that there was a strong connection between overpopulation and people suffering from diseases which compelled to realize that another application of 3D printing could include ways to help people suffering with different diseases caused by poor nutrition. It was also discovered that certain people require extensive care due to the fact that they cannot swallow food properly due to dysphagia and realized that 3D printing could be put to good effect in order to reduce their sufferings by printing food which could be customized according to their taste and visual satisfaction. This gave direction to research on 3D printing and its applications, particularly on the concept of printing food in order to provide an answer to the problems as stated above.

1.3 Thesis Contribution

The purpose of this thesis is to focus on the modern innovations and possibilities of healthcare and nutrition to tackle few of the very important requirements in the society. To do this, we have developed a prediction software that will take in the information and data specific to a patient, make necessary calculations regarding their required macronutrients and measure out the amount of ingredients needed to make the food customized as per the patient's needs. Predesigned options in 3D models will also be generated and be available to choose from by the patient. Our thesis is not only supposed to contribute in the quality of healthcare of the patient but it also focuses on the quality of the patient's standard of living.

1.4 Problem Statement

Food is essential to keep a balance of nutrition for all living things. When getting treated, however, certain food plan and specific diet chart is often followed to ensure the patient gets all basic and required nutrition. Patients under serious medical care or patients of old age often face difficulty chewing food. For this, they are either fed soft, unpleasant looking hospital meals. This monotony of unappealing bland food often lead patients into states of depression and repulsion for their own condition. Also often these meals are not completely specific to the diet requirements of a patient. This system plans to take into account all these problems.

CHAPTER 2: LITERATURE REVIEW

2.1 Background Study

The diverse interest in the 3-dimensional world and the world of food and nutrition have led this research to find a connection between the two. To make established arguments about the possibility of the development of such a system a thorough research was done into the existing technologies and the upcoming innovations.

2.2.1 3D printing and Healthcare

3D printing has many applications in many sectors which proved to be quite valuable to the advancement of mankind. Among these sectors 3D printing is expected to benefit the medical and healthcare sector in a vast way. Organ failure poses a serious threat to us because of old age, accidents and diseases etc. This technology can be extremely beneficial in a sense that 3D printing can not only be used fabricate tissues and organs but to product them in a cost effective manner so that the general populace can afford it in the future. However researchers are still working on being able to print whole organs but a company called Organavo has been able to print liver tissues which proves that organ printing is just a matter of time [5]. Amputees can also be given a new set of customized prosthetic limbs who lost limbs due to accidents. Open bionics is a company who are offering prosthetic limbs to people by utilizing 3D printing and they sure that their products are comfortable to use and are made up of material that will last for a long time [3]. Nutritional sciences can also utilize 3D printing technology in an effective manner. Food with vital nutrients can be printed according to a person's specified diet using a range of macronutrients counts to alleviate the suffering caused due to poor or incorrect intake of vital nutrients. In 2012 a group of Researchers were able to experiment with hydrocolloids (a material which is able to solidify with contact with water) infused with flavors and textures to replicate solid foods. From then on printers such as ChefJet, Foodini, f3d, NASA printer, Choc Creator, Cake and Chocolate Extruder, Discov3ry Extruder, 3D Fruit Printer, 3D Everything Printer, Palatable-Looking Goop Printer, and Original Food Printers etc. have been used to print experimental food products [6]. These printers were able to print food ranging from chocolates to even pizzas

2.2.2 Nutrition and Swallowing Disorder

Nutrition is specific to every single individual based on multiple factors. Our body requires a particular count of macronutrients when healthy, and a quite different count when they suffer from any form of chronic illnesses. In this thesis we are covering 7 chronic illnesses and using our system to calculate the exact macronutrients required per patient, assuming one patient has one type of chronic illness.

Apart from this, the concept of 3D printing food mainly arose from the inability of most patients at a critical condition or if elderly to chew and swallow food. This condition is called Dysphagia.

Swallowing Disorder (Dysphagia) is a condition which renders an individual unable to chew or swallow food properly from the oral cavity to the stomach and sometimes can be accompanied by pain as well. Dysphagia can be a direct result of certain neurological disorders or just simply be a consequence of aging. Among hospitalized patients, it is estimated that 15% of them suffer from dysphagia while 53%-74% of nursing home residents also suffer from the consequence of dysphagia. Dysphagia can be a major component of stroke and can affect about 45% of stroke patients as well.

People can suffer from a range of problems including malnutrition, weight loss, dehydration, aspiration pneumonia and choking resulting from Dysphagia due to the fact that it becomes harder for individuals to take satisfactory nutrient intake [4, 5]. As a result those suffering from dysphagia generally never receive the required amount of nutrients because they cannot eat properly and also due to the fact that the food that they are offered are bland and monotonous which as a result leads to undertaking of important nutrients in order to survive.

2.2 Related Work

While 3D printing of food has been a research concern for engineers and scientists alike for almost the past 40 years, however the introduction of printers which can create palatable food has been fairly recent. The ChefJet 3D printer being the first of its kind and was released commercially near the end of 2014. Therefore we came across many similar studies and researches done in order to make life better for Dysphagia patients. This paper will try to draw special attention to the works done which are similar to our research topic. A group of students from Deakin University stressed upon creating visually appetizing pureed food for people with dysphagia. They described the process of printing a tuna fish made up of pureed tuna, pureed pumpkin, and pureed beetroot [7] to add visual appeal to the food being made. They modelled the tuna fish using a CAD software named Solidworks by Dassault Systèmes.

Another group of students from Deakin University were able to 3d print Pavlova using the same hardware and software as mentioned above. However they had to bake the product from 3D printing to make it edible [8].

A project funded by European Commission has been researching on ways to improve mealtimes for its aging citizens [9]. The Performance Project is a company who started their operations on 1st November 2012, aims to develop a personalized food supply chain for elderly individuals facing swallowing concerns is developing a system that uses food 3D printers to create custom meals for elderly patients who are dealing with dysphagia. They have already made a working test model which use algorithms designed by Sanalogic, a German IT company which utilizes an app which records patient's dietary requirements and food textures in their profile. A person can order any food that they like and their information is sent to a Foodjet 3D printing institute where the meals are 3D printed in a tray, covered and shipped to the users who can later reheat it to ensure that there are no cold spots in the food and enjoy it.

Initial rapid prototyping and fabrication of food-printing concept designs were introduced over 15 years ago in 2001 which was patented by Nanotek Instruments, Inc [16-18]. The inventors were able to create a customized cake mix from this device, however a physical prototype was not built. Nico Kläber [17, 19] the finalist of the Electrolux Design Lab competition 2009, came up with the concept of Moléculaire concept which incorporated molecular gastronomy into his design which utilized normal food to create fully customized meals by using a small robotic arm. Philips Design introduced the Philips Food Creation Printer [17, 18] which consisted of graphical user interface to create customized food products by choosing ingredients, quantities, shapes, textures etc. from using food cartridges was proposed in 2010. However these were all conceptual designs which lacked solid implementation in the near future. These papers have discussed 3 more conceptual designs which are deemed to be far more feasible than the previous ones and they include the Virtuoso Mixer, Digital Fabricator and the Robotic Chef [16, 17, 20]

The paper contribution on food texture, ingredients used and texture outcome of Solid Freeform Fabrication (SFF) of food has been researched on by researchers at Cornell University[21], that elaborate on the use of multiple tested hydrocolloid mixtures to understand the texture of printed food required to result in an enjoyable meal-time experience.

A 2015 paper [15] notes that by controlling the amount of nutrition content and printing material an engineering solution to designing and customizing 3D printed food with personalized nutrition control can be provided. It can also facilitate new food product development and be a potential machine to reconfigure a customized food supply chain.

According to the paper [15], different food ingredients affect different individuals differently and public interest has increased on the prospect of tailored diet according to different health conditions. “Traditional food preparation processes even with advanced processing technologies cannot meet such demands (Zoran and Coelho 2011). Three-dimensional (3D) Food Printing, also known as Food Layered Manufacture (Wegrzyn et al. 2012), can be one of the potential ways to bridge this gap. It is a digitally controlled, robotic construction process which can build up complex 3D food products layer by layer (Huang et al. 2013)”

CHAPTER 3: METHODOLOGY AND WORKING PRINCIPLE

3.1 System Overview

A block figure of the overview of the system has been illustrated in figure 3.1. This is to give the readers of the paper a one glance look into the system in order to make an understanding of the steps of using the software function.

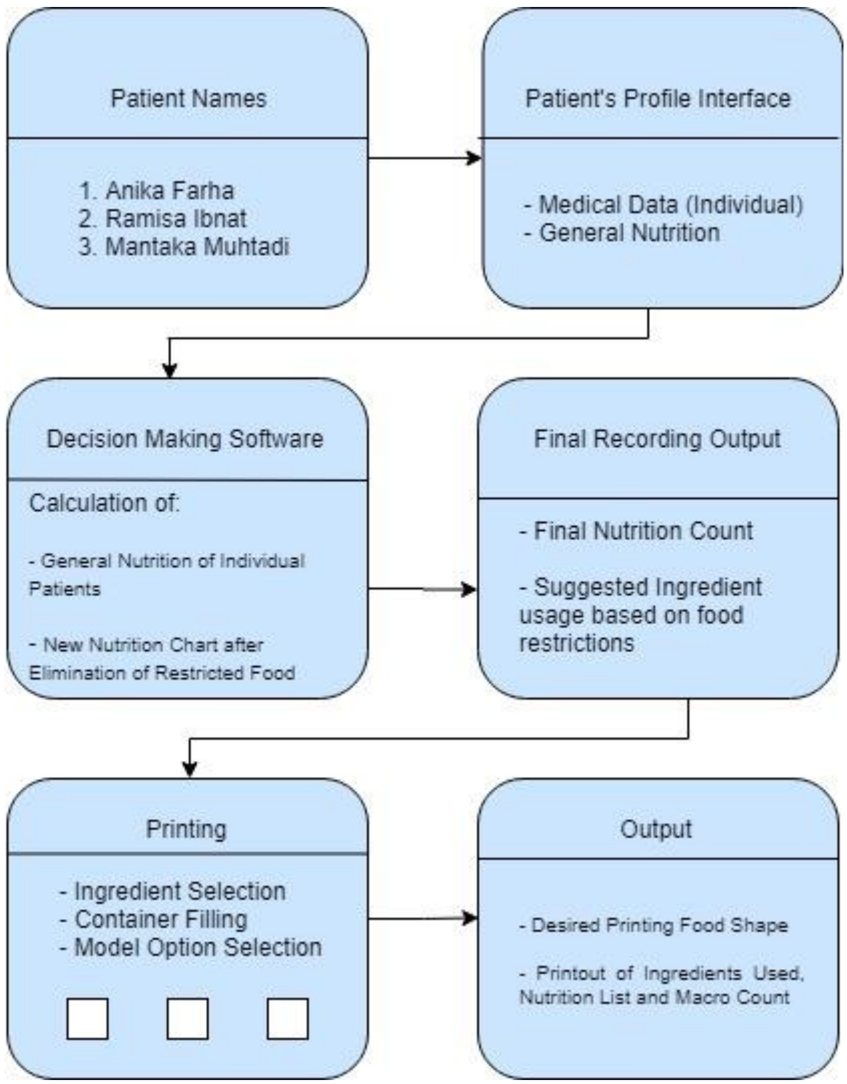


Figure 3.1: System overview of the program.

The thesis comprises of a software system that will take in patients' information, calculate their personalized macronutrients and finally suggest recipes based on the diseases they have so that the system can print 3D modeled food for the patients. Initially, the system will extract the height, weight, age and any of the 7 programmed chronic diseases the patients will have from their charts. It will then use the first three information to calculate the general macronutrients required for each individual using the Harris-Benedict equation and based on any disease they will have, it will be recalculated and the suggestion of a completely personalized macronutrient requirement for them will be deduced. Once the macronutrient count has been determined, the software will match the preprogrammed ingredients list and then calculate the required quantities necessary. Finally, the user of the software will be able to select a predesigned food model, match the personalized recipe and print the customized food.

3.2 Dataset

To start, a dataset of patient's names, their varying personal information and the diseases they might have has been created. .

Table 3.1: Information about patients along with their diseases

Name	Age	Gender	Height	Weight	Disease
Ahmad Salahuddin	25	M	180	82	Hypertension
Afroz Ara	68	F	152	71	Diabetes Type-2
Zarif Qazi	19	M	170	51	Kwashiorkor
Mamun Quader	33	M	168	65	
Hasan Sadiq	71	M	182	68	Chronic Kidney Disease(Stage 2-4)
Afrida Faiza	88	F	151	45	
Shabbir Ahmed	92	M	177	66	Cardiovascular Disease
Ferdous Ara	45	F	168	58	
Nabila Maruf	59	F	152	68	Diabetes Type-1
Nuha Qazi	77	F	149	52	
Sayem Baqi	85	M	168	74	Chronic Kidney Disease(Stage 1-2)
Sohel Rana	26	M	188	102	
Rezwana Moqaddes	64	F	154	50	
Habib Bari	78	M	166	204	Cardiovascular Disease
Nanziba Nawar	26	F	161	124	
Nazifa Mamun	84	F	157	49	Kwashiorkor
Md Muslehuddin	25	M	182	112	
Nayeema Sultana	51	F	152	53	Hypertension
Md Mahmood	79	M	167	60	
Shakera Khatun	47	F	150	90	Cardiovascular Disease

A database of all food restrictions and recommendations as per diseases has been maintained to store and extract information.

Table 3.2: Food restrictions and recommendations for different diseases

Disease	Recommendation	Restriction
Cardiovascular	Whole grains | Fruits | Vegetables | Legumes | High Protein | Food high in monosaturated fat	Saturated fat | Artificial Trans fat | Cholesterol from high fat dairy | Sugary food | Excessive salt
Hypertension	Increase the amounts of natural potassium | magnesium | fiber	Less salt
Diabetes Type-1	Very high protein | High Fat | Moderate fat oil and fibrous veggies | Less nuts | Very low fibrous fruits	Heavy and fatty meals | Saturated fats | Salty food | Food high in sugar |
Diabetes Type-2	Very high protein | High Fat | Moderate fat oil and fibrous veggies | Less nuts | Very low fibrous fruits	High carb fruits/veggies | sugar | Starch | Grains | Cereals | Legumes | Milk | Reduced fat
Kwashiorkor	Protein rich food	Avoid Dairy
Chronic Kidney Disease(Stages 1-2)	Limit saturated and trans fats	<2300 mg sodium | less phosphorus | correct amount of potassium (not too high or too low)
Chronic Kidney Disease(Stages 3-4)	Lean cuts of meat |Poultry without the skin | Fish | Beans | Vegetables | Fruits | Low-fat or fat-free milk, yogurt, and cheese	<2300 mg sodium | less phosphorus | correct amount of potassium (not too high or too low)

3.3 Algorithm

After trialling with tables to use as dataset, we realized the normal distribution of values required two to three values for a longer range of the same variable for which tables are inconsistent and inaccurate. Instead we decided to tackle the problem by using equations. In order to build the system, we derived multiple equations to execute the calculations required in our system.

To execute the equations we had to develop our own set of algorithms. We created two algorithms, one for calculating the macronutrient requirement per patient and another for calculating ingredients per meal.

3.3.1 Algorithm for calculating the macronutrient per patient:

Firstly, we took into account the following variable:

Patient's Information:

Age = A;

Height = H; [in cm]

Weight = W; [in kg]

Gender;

We started with calculating the total calories required in a day or the daily energy expenditure and named the variable DEE. This is call the Harris-Benedict equation [14]:

Calculate DEE (Daily Energy Expenditure/ Total Calories Burnt)

For Males:

$$66.5 + 13.8 \times (W\ in\ kg) + 5 \times (H\ in\ cm) + 6.8 \times A$$

For Females:

$$655.1 + 9.6 \times (W\ in\ kg) + 1.9 \times (H\ in\ cm) + 4.7 \times A$$

Now, to calculate the personalized macronutrients we ran the following equations:

General Protein Equation (in calories) (GP): $1.82 \times (W)$

Total Protein (in grams): $GP/4$

General Fat (in calories) (GF): $0.25 \times DEE$

Total Fat (in grams): $GF/9$

Sum of Protein and Fat (PF): $GP + GF$

Carbs (GC)(in calories): $Total\ DEE - PF$

Total Carbs (in grams): $GC/4$

We were able incorporate the amount of calories a gram of protein fat and carbohydrates contain to give to new equations for our algorithm.

In order to get the amount of protein required by a person in grams, we divided GP and GC by 4 because 1g of protein and carbohydrate contains 4 calories. Similarly we divided GF by 9 because 1g of fat contains 9 calories [15].

Finally, in order to personalize macronutrient counts, we divided the main equation into seven different new equations to personalize the nutrient counts as per patient based on their diseases.

I. Cardiovascular Disease:

General Protein Equation (GP)(in calories) : $1.82 \times (W)$

Total Protein (in grams): $GP/4$

General Fat (GF)(in calories) : $0.3 \times DEE$

Total Fat (in grams): $GF/9$

Add (PF) : $GP + GF$

Carbs (GC)(in calories) : $Total\ DEE - PF$

Total Carbs (in grams): $GC/4$

For a person suffering from cardiovascular disease, it recommended for them to take in 25%-35% of calories from fat [10]. Therefore we took the median of the range which equals to 30%, in order to calculate the amount of calories required from fat for this specific disease. Therefore the equation for GF becomes 0.3 x DEE instead of 0.25 x DEE with the other equations remaining unchanged.

II. Hypertension:

General Protein Equation (GP)(in calories) : $(0.18 \times DEE)$

Total Protein (in grams): $GP/4$

General Fat (GF)(in calories) : $(0.27 \times DEE)$

Total Fat (in grams): $GF/9$

Carbs (GC)(in calories) : $(0.55 \times DEE)$

Total Carbs (in grams): $GC/4$

The recommended percentage of calorie intake for protein carbs and fat are 27%, 55% and 18% respectively for a person suffering from hypertension [10]. Therefore we simply converted GP GF and GC according to these values. As a result, GP becomes x DEE, GF becomes 0.27 x DEE and GC becomes 0.55 x DEE.

III. Diabetes Type-1:

General Protein Equation (*GP*) (in calories): $1.82 \times (W)$

Total Protein (in grams): $GP/4$

General Fat (GF)(in calories) : $(0.275 \times DEE)$

Total Fat (in grams): $GF/9$

Add (PF) : $GP + GF$

Carbs (GC)(in calories) : $Total\ DEE - PF$

Total Carbs (in grams): $GC/4$

The recommended fat intake of a person suffering from Type-1 diabetes is 20%-35% of recommended total calorie intake for the person [11]. Therefore we took the median of the range which equals to 27.5%, in order to calculate the amount of calories required from fat for this specific disease. Therefore the equation for GF becomes 0.275 x DEE with the other equations remaining unchanged.

IV. Diabetes Type-2:

General Protein Equation (GP) (in calories): $0.25xDEE$

Total Protein (in grams): $GP/4$

General Fat (GF)(in calories) : $(0.25 \times DEE)$

Total Fat (in grams): $GF/9$

Add (PF) : $GP + GF$

Carbs (GC)(in calories) : $Total\ DEE - PF$

Total Carbs (in grams): $GC/4$

The recommended amount of protein intake as a percentage of total calories consumed is 20% - 30% for a person with Type-2 Diabetes [11]. Therefore the median of this range was taken which equals to 25% to calculate GP. Hence GP becomes 0.25 x DEE.

V. Kwashiorkor:

General Protein Equation (GP)(in calories) : $(0.11 \times DEE)$

Total Protein (in grams): $GP/4$

General Fat (GF)(in calories) : $(0.25 \times DEE)$

Total Fat (in grams): $GF/9$

Add (PF) : $GP + GF$

Carbs (GC)(in calories) : $Total\ DEE - PF$

Total Carbs (in grams): $GC/4$

The required amount of protein intake for Kwashiorkor is suggested to be 11% of total calorie intake [12]. Therefore GC becomes 0.11 x DEE with the other equations remaining the same.

VI. Chronic Kidney Disease (Stages 1-2):

General Protein Equation (GP)(in calories) : $(0.18 \times DEE)$

Total Protein (in grams): $GP/4$

General Fat (GF)(in calories) : $(0.3 \times DEE)$

Total Fat (in grams): $GF/9$

Carbs (GC)(in calories) : $(0.52 \times DEE)$

Total Carbs (in grams): $GC/4$

It is advised to consume 30% and 18% of calories from fats and protein respectively for a person suffering from stages 1 to 2 Chronic Kidney Disease. It has also been mentioned that the amount of carb intake should be in the range of 50%-60% of calories [13]. We used this information to come up with customized equations for GP GF and GC respectively. Therefore GP becomes 0.18 x DEE, GF becomes 0.3 x DEE while GC become 0.52 x DEE because using the median of the range would yield a result that would exceed DEE after combining GP GF GC.

VII. Chronic Kidney Disease (Stages 2-4):

General Protein Equation (GP)(in calories) : $(0.10 \times DEE)$

Total Protein (in grams): $GP/4$

General Fat (GF)(in calories) : $(0.3 \times DEE)$

Total Fat (in grams): $GF/9$

Carbs (GC) (in calories): (0.60 x DEE)

Total Carbs (in grams): $GC/4$

The only difference between stages 2-4 of CVD and stages 1-2 of CVD is that the recommended protein intake is 10 % of the total calories consumed as opposed to 18% in stages 1-2 CVD with the other dietary recommendations remaining same [13]. Therefore we simply changed GP to DEE x 0.1 with GF remaining unchanged but had to change GC to 0.60 x DEE as otherwise combing GP GF and GC would yield a result lower than DEE.

3.3.2 Summary of the Macronutrient count for Different Diseases

To compare how different diseases required different percentages of daily macro nutrient intake, a reference age weight and height was taken for a male patient. The age was taken to be 24, weight 82 kg and height 180 cm of a male patient. So the DEE has been calculated by simply plugging in the above values as follows:

$$DEE = 66.5 + 13.8 \text{ x } 82 + 5 \text{ x } 180 + 6.8 \text{ x } 24 = 2261 \text{ kcal}$$

(i) Cardiovascular Disease:

GP = 149.24 kcal

GF = 678.30 kcal

GC = 1489.98 kcal

Therefore GP contributes 6.6%, GF 30% and GC 63.4% of DEE as shown in the bar chart.

(ii) Hypertension:

GP = 406.98 kcal

GF = 610.47 kcal

GC = 1243.55 kcal

Therefore GP contributes 18%, GF 27% and GC 55% of DEE as shown in the bar chart.

(iii) Diabetes Type-1:

GP = 149.24 kcal

GF = 621.78 kcal

GC = 1489.99 kcal

Therefore GP contributes 6.6%, GF 27.5% and GC 65.9% of DEE as shown in the bar chart.

(iv) Diabetes Type-2:

GP = 565.25 kcal

GF = 565.25 kcal

GC = 1130.50 kcal

Therefore GP contributes 25%, GF 25% and GC 50% of DEE as shown in the bar chart.

(v) Kwashiorkor:

GP = 248.71 kcal

GF = 565.25 kcal

GC = 1447.04 kcal

Therefore GP contributes 11%, GF 25% and GC 64% of DEE as shown in the bar chart.

(vi) Chronic Kidney Disease [Stages 1-2]:

GP = 406.98 kcal

GF = 678.30 kcal

GC = 1152.32 kcal

Therefore GP contributes 18%, GF 30% and GC 55% of DEE as shown in the bar chart.

(vii) Chronic Kidney Disease [Stages 2-4]:

GP = 226.10 kcal

GF = 678.30 kcal

GC = 1356.60 kcal

Therefore GP contributes 10%, GF 30% and GC 60% of DEE as shown in the bar chart.

For better understanding, the individual macro count of per individual depending on their diseases have been internally compared by illustrating the graph below.

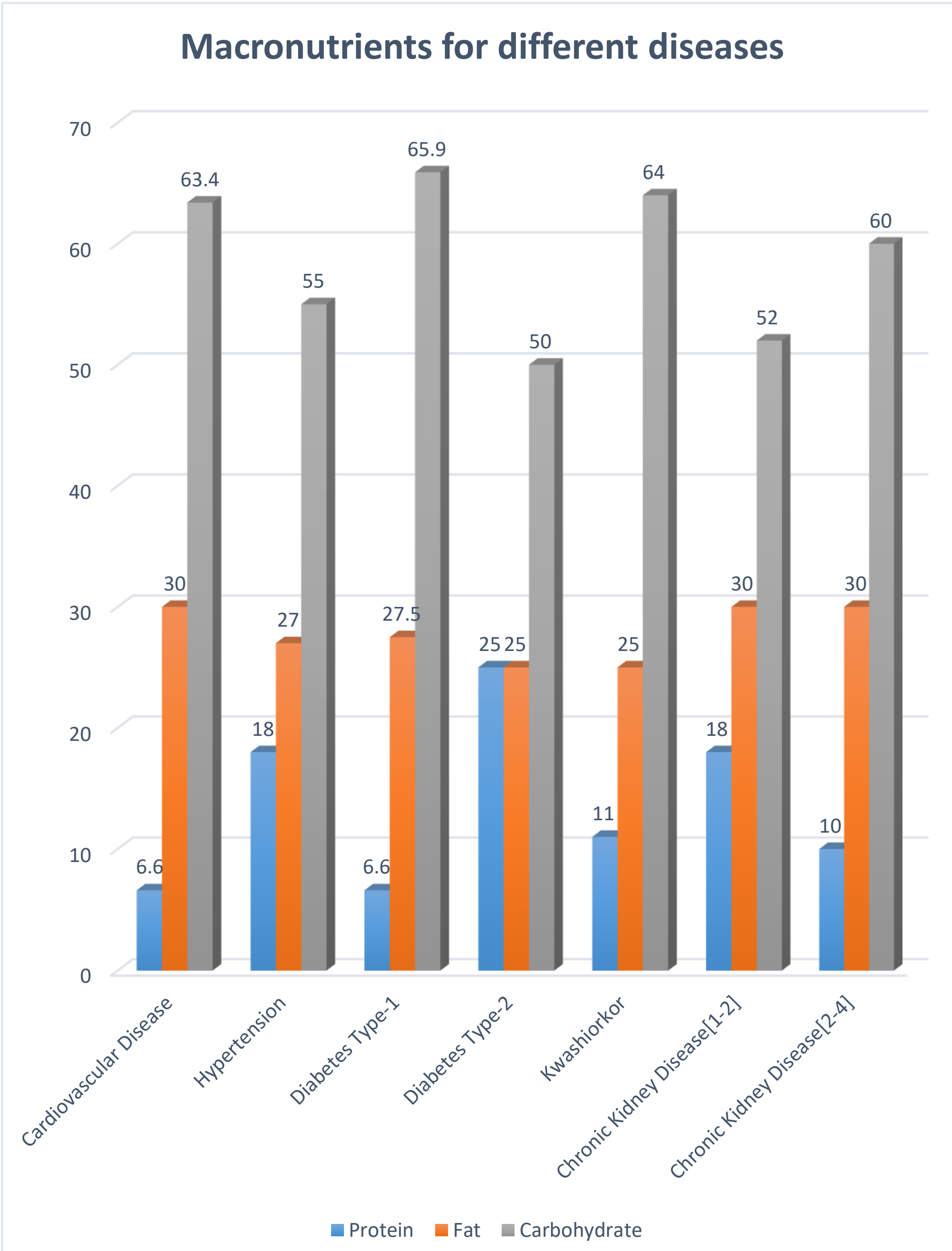


Figure 3.2: Macronutrient Percentages for Different Diseases.

3.3.3 Algorithm for calculating ingredients per meal.

In this section we will show how our system recommends final ingredients tailored to a patient's specific medical condition. We took the same reference age weight height and gender as we did to derive the equations for personalized macronutrients in the above section. The age was taken to be 24, weight as 82 kg and height as 180 cm for a male patient. Given that the patient has cardiovascular disease, his daily calorie intake was calculated in the previous section where:

GP = 149.24 kcal

GF = 678.30 kcal

GC = 1489.98 kcal

We know that 1g of protein and carbohydrate contains 4 calories whereas 1g from fat contains 9 calories [15] therefore to calculate macronutrients in grams we divide GP and GC by 4 and GF by 9 to get the following results for our patient.

Protein: 37.25g

Fat: 75g

Carbs: 358.5g

We have the following list of ingredients selected for a patient with Cardiovascular Disease:

Table 3.3: Ingredient list for cardiovascular disease

Disease	Ingredients	Tags	Quantity(g)	Protein (g)	Fat (g)	Carbs (g)	Sugar (g)	Cholesterol (mg)	Potassium (mg)	Calories
Cardiovascular	Red Rice	grains	100	2.6	0	23	0.3	0	43	111
Cardiovascular	sweet potatoes	vegetable	100	1.6	0	20.3	4.5	0	336.8	86
Cardiovascular	Chicken Breasts	meat	100	27	5	0	0	0	0	151
Cardiovascular	spinach	vegetable	100	2.9	0	3.6	0	0	558	23
Cardiovascular	gelatin	-	14.3	6	0	0	0	0	1.1	0
Cardiovascular	EVOO	oil	14.3	0	14	0	0	0	0	0

To make calculations easier, we will take one macro count at a time.

To sort ingredients in order to choose ingredients specific either to carbohydrate or proteins we will check their gram values and compare against each other.

While iterating through each ingredient, we will check whether the values of protein is greater or less than carbs. For example:

```
Item 1:     Red Rice {
                 if (protein>carbs)
                 Select item 1 for protein array
                 else
                 Select for carbs array 1
                }
Item 2:     Sweet potatoes {
                 if (protein>carbs)
                 Select item 2 for protein array
                 else
                 Select for carbs array 1
                 }
...
...
…
```

Run through all items.

In order to make calculations easier and realistic, we have categorized each ingredients under specific tags. For instance, it is unusual for a person to intake 300g of rice (grains) in one meal. Which is why, we will keep certain tags constant, and use other tags to calculate the measurements of ingredients required to meet micronutrient counts. Therefore, the altering change for carbohydrates will be vegetables and for protein will be meat.

Now we have two list of ingredients designated for proteins and carbs.

Table 3.4: Sources of protein and carbohydrates

Protein List	**Carb List**
Chicken breasts	Red Rice
Gelatin	Sweet Potatoes
	Spinach

To make calculations easier, we will start with the ingredients in the protein list to calculate the total ingredients (in grams) required to meet the essential protein counts for the day.

Now, we know 100g of chicken breasts have 27g of protein and gelatin has 6g of protein.

100g chicken----> 27g
6 tbsp gelatin--->+ 6g

33g

This value is less than the required protein for the day and since gelatin is a fixed ingredient, only chicken (meat) measurements will be altered.

Total protein requirement per day - protein from ingredient list
= 37.25g - 33g
= 4.25g

Which means we need an extra 4.25g of protein to meet the daily requirement. We will calculate how many grams of chicken is required for this additional 4.25g of protein.

Extra chicken required= (4.25/27) * 100g
= 15.7g

Therefore, a total of 115g of chicken is required per day.

Now to calculate the amount of carbs required, we will look at the designated list of ingredients.

We know 100g of Red Rice gives 23g of carbs, 100g of Sweet Potatoes gives 20.3g of carbs and 100g of Spinach gives 3.6g of carbs.

100g red rice----------> 23.0g
100g sweet potato---> 20.3g
100g Spinach--------->   3.6g

46.9g

Like before, we will use specific tags for specific ingredients. For Carbohydrate calculations, we will ignore grain tags and will only use vegetable tags to calculate. Which means, grain tag values will remain unchanged.

A patient will consume 100g of Red Rice per meal. Therefore, in one day they will consume 300g of Red Rice which will give 69g of Carbohydrates.

Total Carbohydrate requirement per day - Carbohydrate from rice
= 358.5g - 69g
= 289.5g

This is the value of the remaining carb requirement.

Total carb counts from the vegetables
20.3g + 3.6g = 23.9g of carbs

Therefore, the following ratio adjusts the ingredient measurements specific to the remaining value.

Extra vegetables required= (200g of vegetables)/(23.9g of carbs) * 289.5g of carbs required

= 2426g

Since there are two vegetables, we can divide the extra vegetables required by half. Therefore, we need 1212g of each vegetable per day.

Final Protein Ingredient per day:

Table 3.5: Recalculated protein source measurements

Disease	Ingredients	Tags	Quantity(g)	Protein (g)	Fat (g)	Carbs (g)
Cardiovascular	Chicken Breasts	meat	115.7	31.2	5.6	0
Cardiovascular	gelatin	-	14.3	6	0	0

Final Carbohydrate Ingredient per day:

Table 3.6: Recalculated carbohydrate source measurements

Disease	Ingredients	Tags	Quantity(g)	Protein (g)	Fat (g)	Carbs (g)
Cardiovascular	Red Rice	grains	300	7.8	0	69
Cardiovascular	sweet potatoes	vegetable	1212	19.32	0	246
Cardiovascular	spinach	vegetable	1212	2.9	0	44

After re-adjusting all fat values, we can calculate that 5Tbsp of extra virgin olive oil is required per day which will give 69.25g. This value added to the table values will help us meet the total daily requirements of 75g of Fat.

Therefore, the final macro counts from the adjusted ingredients after calculations come down to 99.359g of protein, 358.6g of carbs and 74.82g of Fat.

For per meal, we will divide the values by 3 to give 33.11g of protein, 119.55g of carbs and 24.94g of fat per meal.

Final output will give us a calculated list of ingredient measurements:

Ingredient in grams per meal:
Red Rice -> 100g
Sweet Potato -> 400g
Chicken Breast -> 37.1g
Spinach -> 400g
Gelatin -> 4.8g
EVOO -> 7.9g

CHAPTER 4: SOFTWARE

4.1 Software Development

This thesis mainly focuses on the development of the software which is used to make calculations based on particular patient information to calculate their daily macronutrients in order to eventually print their food. The entire software development process has been briefed with a block diagram in figure 4.1.

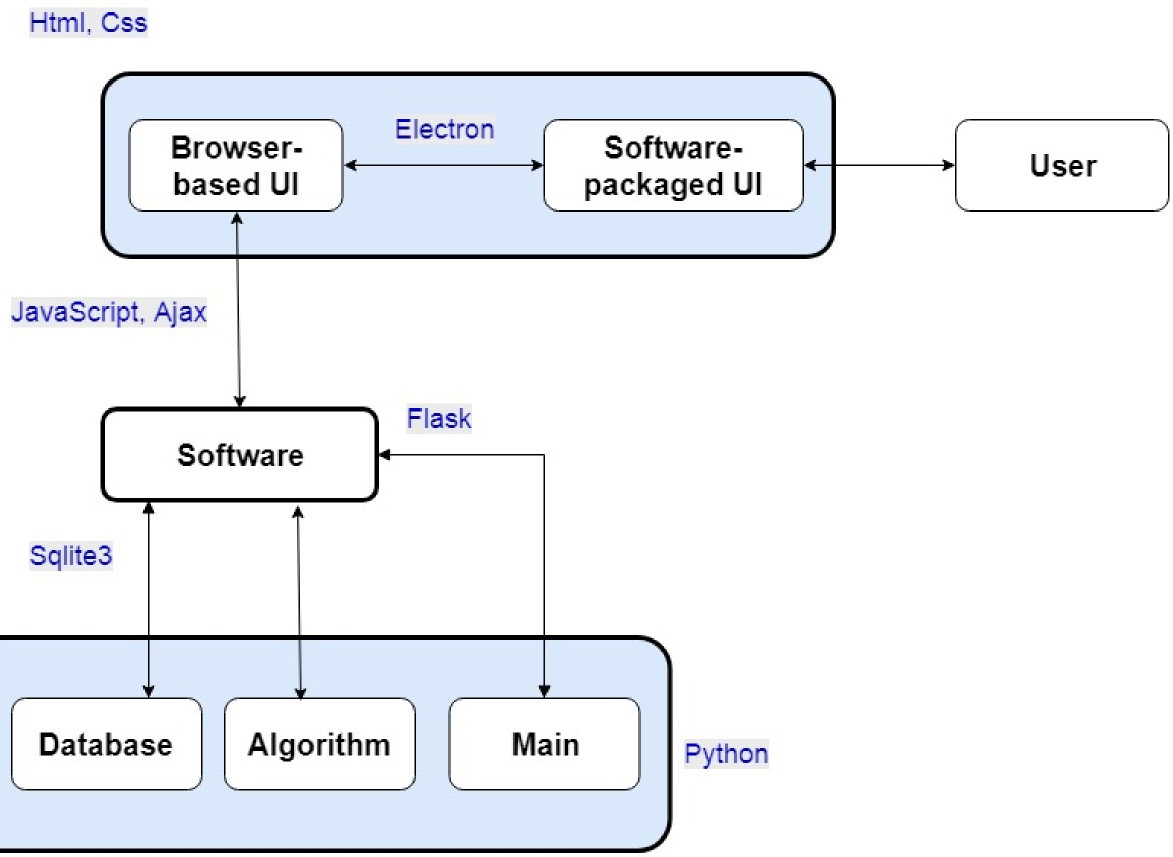


Figure 4.1: System Architecture of the Software.

4.1.1 Language

The algorithm and code for our software have been written and edited in Sublime text. Sublime text is a text editor which interconnects numerous platforms and contains a Python application programming interface (API). It can be used to code in many programming languages and mark up languages. For the development of our software, Python has been used. Python is a high level programming language that supports object oriented programming, efficient and technical programming and comprehends a wide range of libraries that can be used by everyone. It is made in a way that both small scale and large scale projects can be built in it.

4.1.2 Frameworks

Following are the frameworks and their uses. They are discussed in brief, and later on their purpose and role in building the software will be explained in detail.

The frameworks that have been used are:

- **Flask:**

Flask is a micro framework for python because it does not contain libraries, database abstraction layer, form validation or other components requiring pre-existing libraries. Flask, however, contains extensions that can add application features within itself. These extensions can be used for various purposes including object-relational mapping, form validation, upload handling and other common framework related tools. Flask is exceptionally lightweight and is easily adaptable to developers' requirements.

```python
from flask import Flask

app = Flask(__name__)

if __name__ == '__main__':

    app.run(host=IP_Address,port=Port_Number, debug=True)
```

Figure 4.2: General Implementation of how Flask Works.

- **Sqlite3:**

SQLite3 is a database management system where people can create and manipulate simple databases where all the tables can be created using SQL. However it is not a fully featured database system, but it can be used to plug in databases in an application with ease.

Therefore due to its simplicity SQLite3 has been used for creating the database in our software as it is basically just a simple command line interface.

- **OpenPyExcel:**

Excel is a very standard effective tool for spreadsheet management in windows. Openpyxl is a useful module which permits a user to read and modify Excel xlsx/xlsm/xltx/xltm files. It can be used to import database tables in the form of excel files, injecting it into the backend database. Features include:

- Tables
- Data Validation
- Charts

4.2 Graphical User Interface

4.2.1 Frameworks

Html5 and CSS:

Html and CSS are two of the main technologies used in order to build working web pages. While Html gives the webpage its structure, CSS gives it a visual layout. Along with JavaScript, it forms the World Wide Web. Therefore, Html and CSS has provided us with easy to use opportunities to implement Graphical User Interface in various applications.

- **JavaScript and AJAX:**

JavaScript is a high level interpreted, programming language which is used to program the behavior of the webpage by controlling the flow of data from python server to the front end and back. Even though it is widely known for its use in Web pages, other non-browser environments also use it, such as node.js and ApacheCouchDB. It supports object-oriented, imperative, and declarative programming styles.

AJAX (Asynchronous JavaScript and XML) is used to create asynchronous Web applications where they can send and retrieve data to change content dynamically without interfering with the display of the page

- **Electron:**

Electron is an open-source framework based on Node.js and Chromium that has been established and sustained by GitHub. This framework is a method of interconnecting JavaScript, HTML and CSS for building desktop applications. Electron helps develop desktop GUI applications by combining the frontend and backend components that have been developed for web applications, node.js being the runtime for the backend and Chromium for the frontend. Electron has been the primary GUI framework in creating a variety of applications.

4.3 Integration

In this section it will be shown how the whole software came together using all the frameworks and what role each of the frameworks played to help build the software from scratch. As the previous chapters have explained, the main purpose of this software is to provide accurate nutrition content for patients with diseases related to the macronutrients. Two Algorithms have implemented our software:

1. For Calculating the daily Macronutrient for patients: calculates required macronutrient for a healthy individual, personalized according to their age, weight and height, along with personalized required macronutrient for a patient with Cardiovascular disease, Hypertension, type 1 and type 2 Diabetes, Kwashiorkor disease and Kidney diseases of different stages.

The following flowchart shows the steps of how the algorithm was created and later on, explained how it has been integrated into a software.

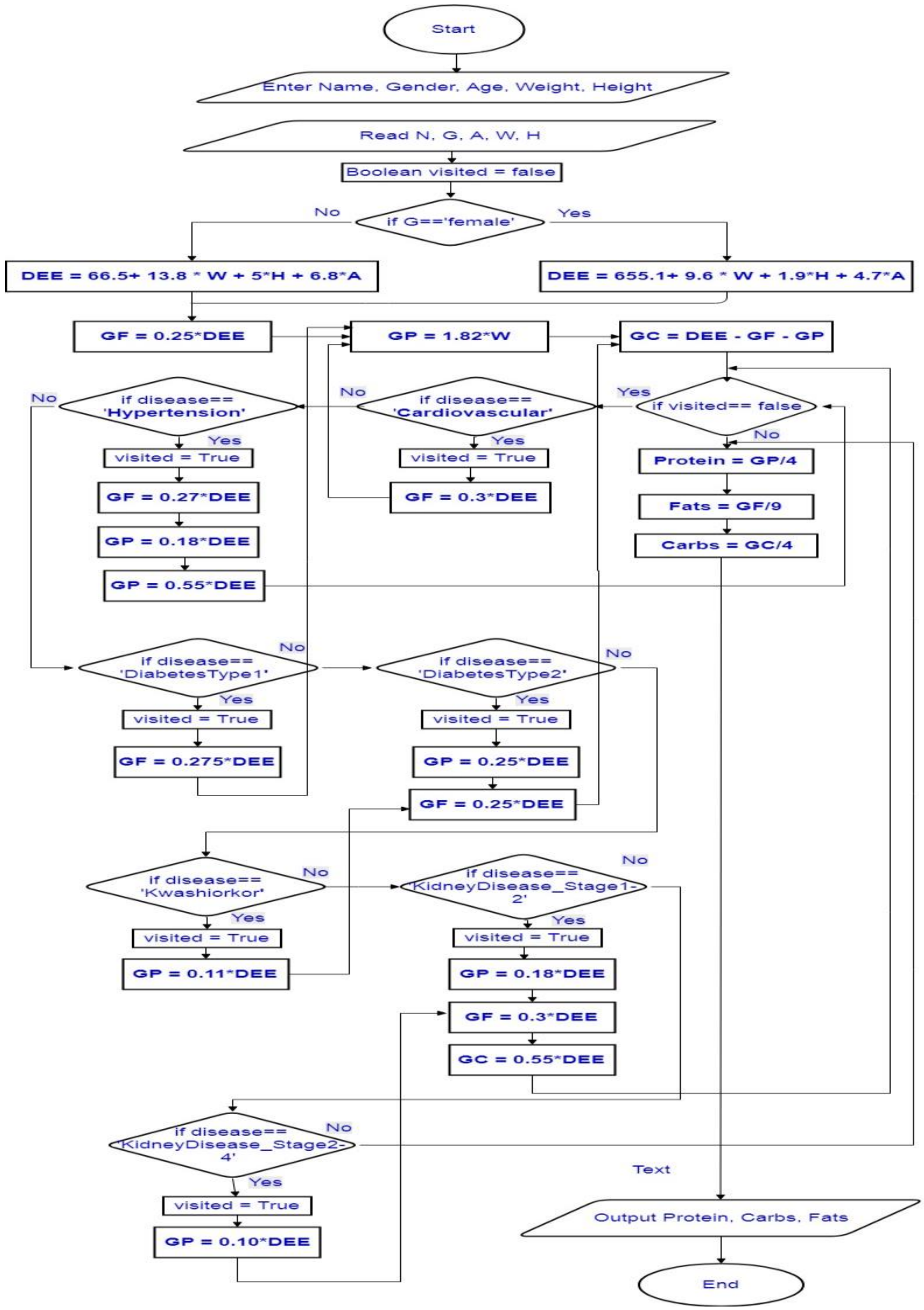


Figure 4.3: Flowchart of the System.

2. Taking the result of the first algorithm (required daily macro intake) and calculating the exact amount of suggested nutrients per meal. The second stage included using this information to recalculate selected ingredient amounts per disease.

Taking the algorithms and implementing it into a software required a wide variety of frameworks for the backend and the frontend and to connect the two and packaging it into a software. As described at the beginning of this chapter, the frameworks that have been used are: **Flask, SQlite3, Openpyxl, Html, CSS, JavaScript, AJAX** and **Electron.**

To begin with, the software needed to be connected to the server, for which Flask has been used. The framework hosts the html page for which the software has been created. Flask and Django both have similar use, but flask was chosen by us because it is simpler and serves our purpose, whereas Django would have been much more complex and extensive.

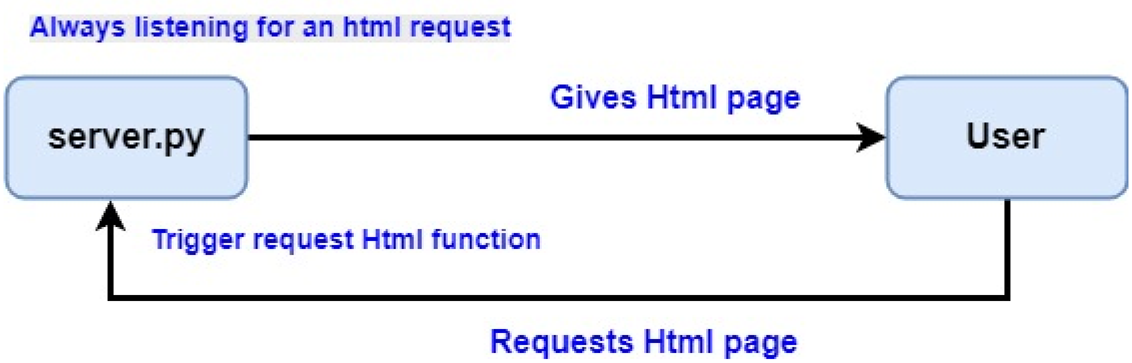


Figure 4.4: How Flask has been used to connect the software to the server.

For the software to be true to its purpose, a database needed to be created to store sample patient information data, recommended data, and the nutrient content of each of the sample food. Our database and database tables have been created using Sqlite3. SQLite3 is a database engine that is very simple to use. Along with being able to store the database in a single disk file, it also possesses the quality of being lightweight with higher speed [4]. The extension or framework named "sqlite3" exists in Python, and has hence been used to create for working with the database for our software.

For the database, mainly four tables are created:

- **Patient information table** - Patients' personal information is stored.
  [Name, Age, Gender, Weight, Height, Disease.]
- **Recommendation table** - All the recommended data for patients are stored.
  [Name, Age, Disease, Protein, Carbohydrate, Fats, Advised Recipe, Suggested Diet Recommendation, Suggested Diet Restriction]
- **Ingredients table** – Amount of Macronutrients and other nutrients contained by a specified form of each Ingredient with specific amounts for each particular disease.
  [Disease, Ingredients, Food Group, Quantity, Protein, Fats, Carbohydrates, Sugar, Cholesterol, Potassium, Calories]
- **Diet Suggestions table** – Additional advice and restrictions for specific diseases are stored.
  [Disease, Recommendation, Restrictions]

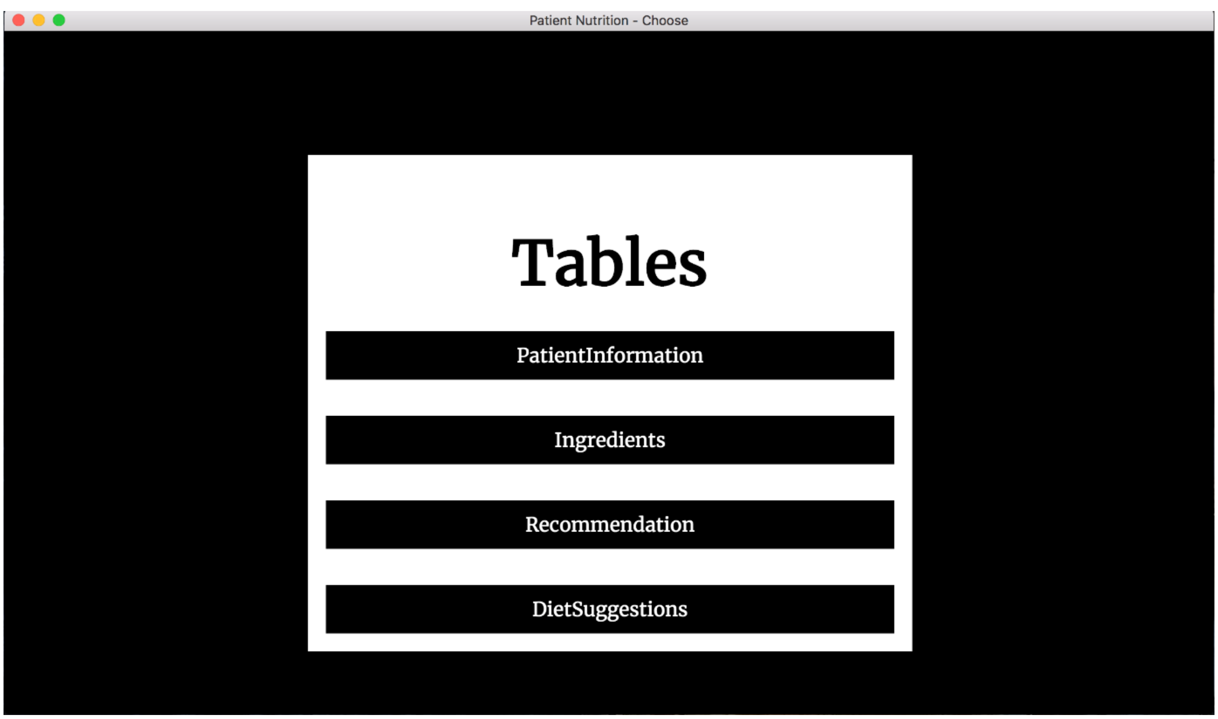


Figure 4.5: List of Tables in our Software.

For each of the tables, there are a multiple set functions that help with the software utility. Those include:

i. **Enter data:** To take in user input. (discussed more in detail later)
ii. **Refresh Table:** The table refreshes after taking in new user input.
iii. **User Query:** Brings up the User Query page.
iv. **Clear Table:** Clears all the data in the table, so that a frest set of data can be entered or imported.
v. **Import:** Imports Excel files(discussed more in detail later)
vi. **Choose Another Table:** Takes the User back to the Choose table page so that a different table can be used.

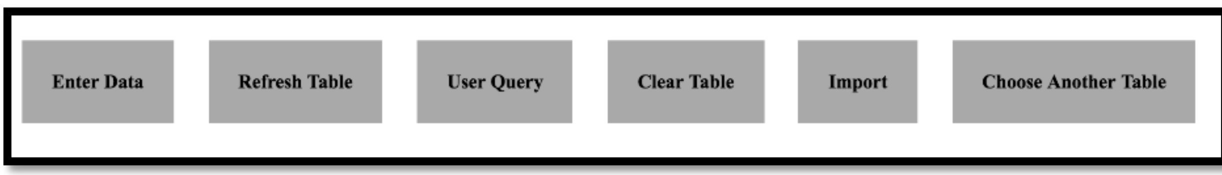


Figure 4.6: A section of the Table pages where all the functions lie.

In our database, there are three ways to insert data into our database tables:

- **Preset tables with data** entered into the software through Python (which is not efficient)
- **Through Graphical User interface-** taking input from the user and inserting it into the software (which is efficient for inserting new data in real time)
- **By importing data in the form of Excel files** (which is efficient for adding pre-set bulk data)

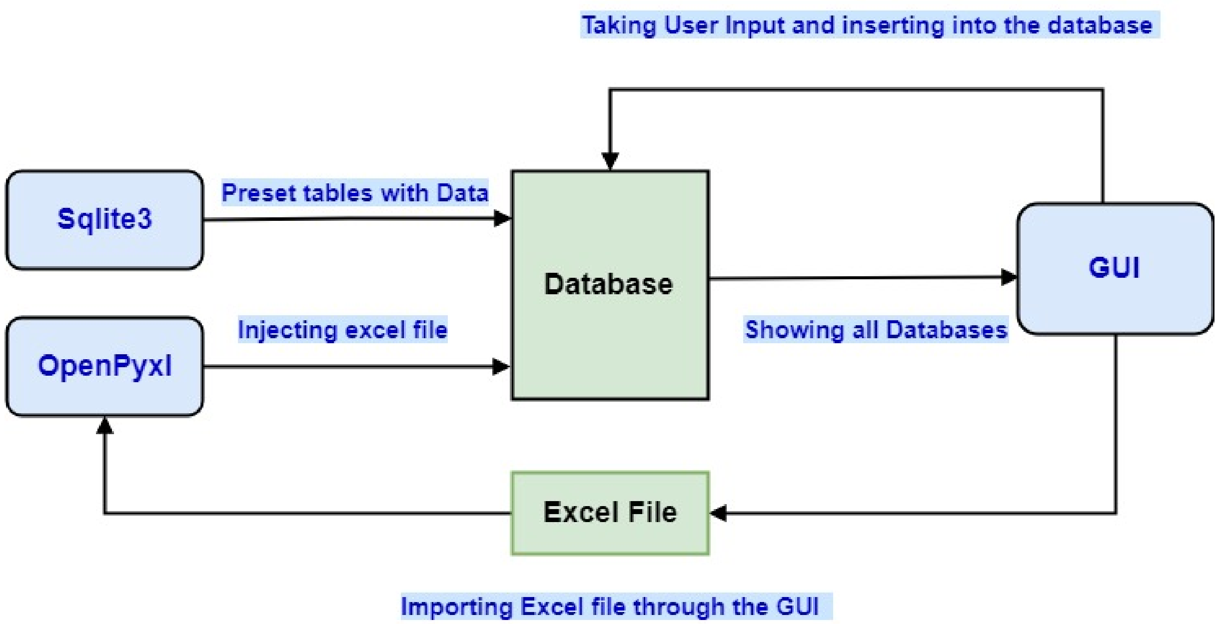


Figure 4.7: How Data can be inserted into the Database.

Although our software was designed in such a way that all the tables in the database are dynamic i.e. they can be inserted into the frontend user interface in the software and they directly get stored in the backend database, (which will be discussed later on), it was more convenient to preserve the pre-set fixed database tables into excel files and then import them into the software. In order to do that, Openpyxl has been used in our project for importing tables from .xls files. This was done so that the patient information that already exists in a hospital or in the possession of a doctor (that is most commonly stored as an excel file) could be easily stored without inserting it one at a time. It was much more efficient to directly import excel files to our database

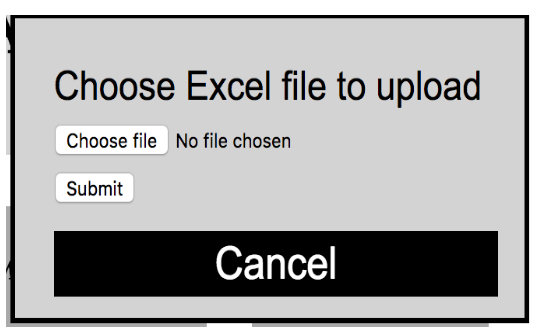


Figure 4.8: How Excel file can be uploaded by the user.

Now that the development of the backend of our software has been explained, hereafter are the explanations of the frameworks to design, build, and connect the Graphical User Interface to the purpose of our software.

There are 8 pages to be displayed in the front-end Graphical User Interface of our software:

a. **Login Page:** Where User ID and Password are taken in order to display the next page.

b. **Choose Table Page:** Where the user gets to choose which table they want to view

c. **Four Table Pages:** Where each of the four Database tables are displayed. In all of the tables, there are functions that will be discussed later on. (As has been shows previously)

d. **User Query Page:** Where the User enters information to calculate the Result.

e. **Recommendation Page:** The Output page that shows the User all the Results that have been calculated, and the data then gets stored in the Recommendation Table page.

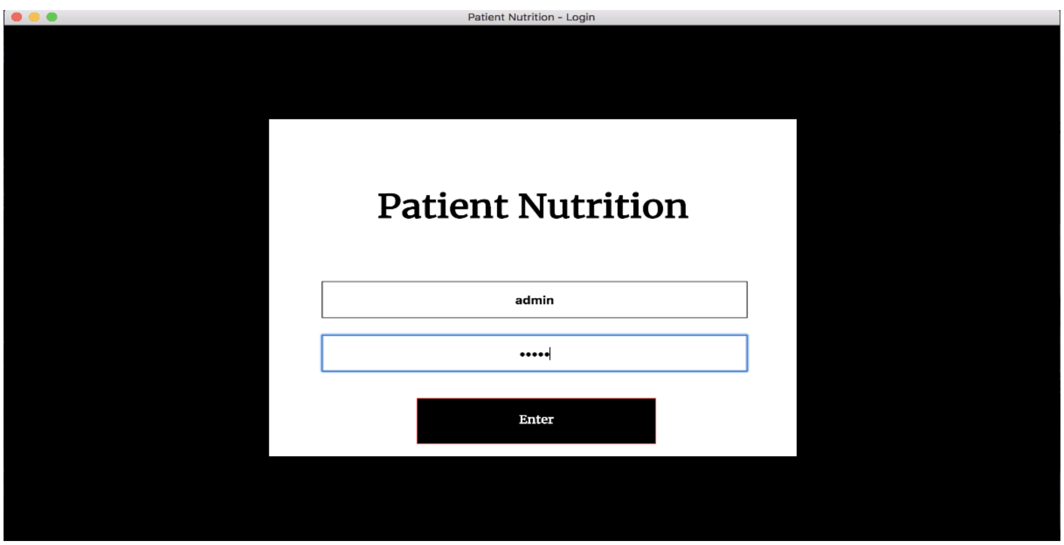
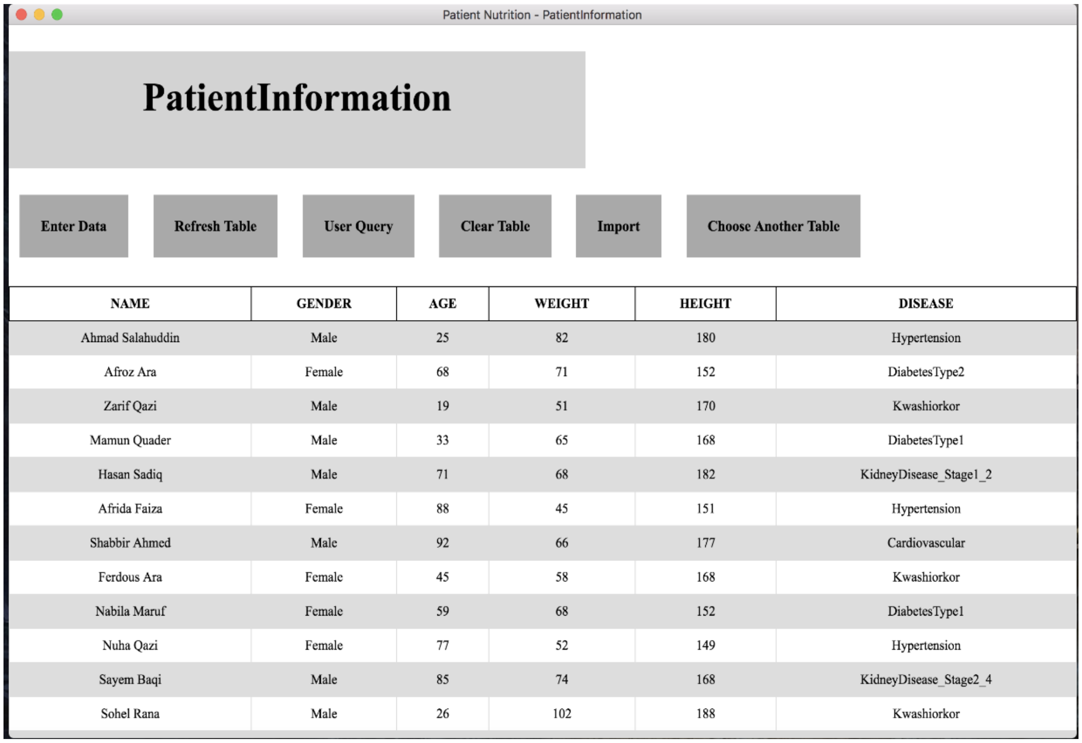
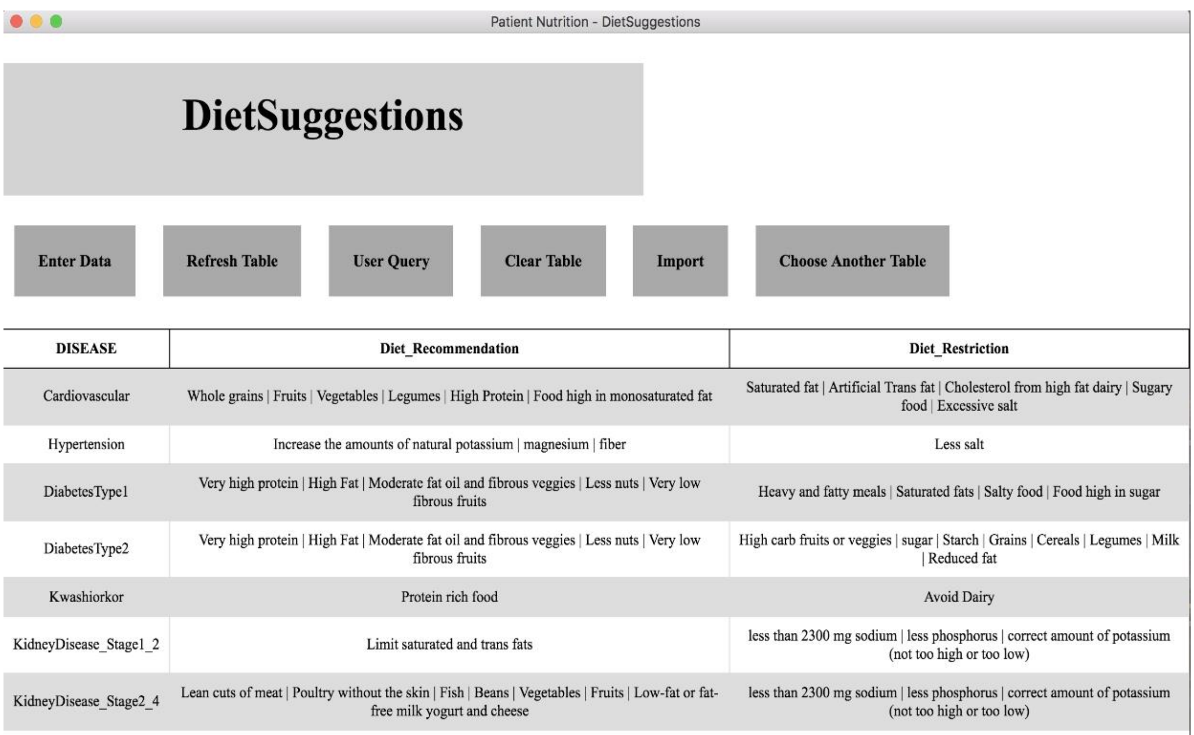


Figure 4.9: User Login Page.



NAME	GENDER	AGE	WEIGHT	HEIGHT	DISEASE
Ahmad Salahuddin	Male	25	82	180	Hypertension
Afroz Ara	Female	68	71	152	DiabetesType2
Zarif Qazi	Male	19	51	170	Kwashiorkor
Mamun Quader	Male	33	65	168	DiabetesType1
Hasan Sadiq	Male	71	68	182	KidneyDisease_Stage1_2
Afrida Faiza	Female	88	45	151	Hypertension
Shabbir Ahmed	Male	92	66	177	Cardiovascular
Ferdous Ara	Female	45	58	168	Kwashiorkor
Nabila Maruf	Female	59	68	152	DiabetesType1
Nuha Qazi	Female	77	52	149	Hypertension
Sayem Baqi	Male	85	74	168	KidneyDisease_Stage2_4
Sohel Rana	Male	26	102	188	Kwashiorkor

Figure 4.10: Patient Information Table.



DISEASE	Diet_Recommendation	Diet_Restriction
Cardiovascular	Whole grains | Fruits | Vegetables | Legumes | High Protein | Food high in monosaturated fat	Saturated fat | Artificial Trans fat | Cholesterol from high fat dairy | Sugary food | Excessive salt
Hypertension	Increase the amounts of natural potassium | magnesium | fiber	Less salt
DiabetesType1	Very high protein | High Fat | Moderate fat oil and fibrous veggies | Less nuts | Very low fibrous fruits	Heavy and fatty meals | Saturated fats | Salty food | Food high in sugar
DiabetesType2	Very high protein | High Fat | Moderate fat oil and fibrous veggies | Less nuts | Very low fibrous fruits	High carb fruits or veggies | sugar | Starch | Grains | Cereals | Legumes | Milk | Reduced fat
Kwashiorkor	Protein rich food	Avoid Dairy
KidneyDisease_Stage1_2	Limit saturated and trans fats	less than 2300 mg sodium | less phosphorus | correct amount of potassium (not too high or too low)
KidneyDisease_Stage2_4	Lean cuts of meat | Poultry without the skin | Fish | Beans | Vegetables | Fruits | Low-fat or fat-free milk yogurt and cheese	less than 2300 mg sodium | less phosphorus | correct amount of potassium (not too high or too low)

Figure 4.11: Disease Restrictions Table.

For a Software, Python has built-in frameworks for the Graphical User Interface. However, its built-in frameworks for UI are very limited and unresponsive. Therefore we decided to combine the best of both worlds. With Html we created the UI where it excels at, while with python we carried out backend server code and calculations where the specialty of Python shines through. Html allowed us to personalize our front end along with the help of CSS, which, apart from being an exceptionally easy language to understand and implement, also saves time and is easy to maintain and change.

In order for front end development, Html and CSS go hand in hand with JavaScript, which has been used in our software for front-end animations and to dynamically parse server data to update the Html and CSS of User Interface. Starting from the login page, the entire User interface has been created in such a way that in case different tables are provided in the backend python code, the front end algorithm/code does not have to be changed. For example, if more database tables are included with different number of rows and columns, algorithm will automatically adjust itself in such a way that it shows the new tables in the same format.

Moreover, regardless of whether the dataset in the table has been imported as an excel file through Openpyxl (as discussed in details before), or whether the datasets have been hard coded in python (which is not necessary or an ideal option, but is still possible), data can be entered into the database through the User Interface as well. To make it simpler for the user, a dynamic form of data input is implemented to the already formed or newly made tables. The user can insert information in each of the fields adjusted by the algorithm for different data tables.

To further improve User experience, **AJAX** has been used. The use of AJAX in our system has been to asynchronously take input data from our UI and transmit it back to the server. The server then asynchronously sends back a response, which is displayed to the user as requested information. This system makes the user interface much more responsive. Furthermore, makes the user able to take in, store and display the information in the database table in real time, preventing it from having to refresh from every single data input. Only the elements that need to be changed are updated dynamically through AJAX.

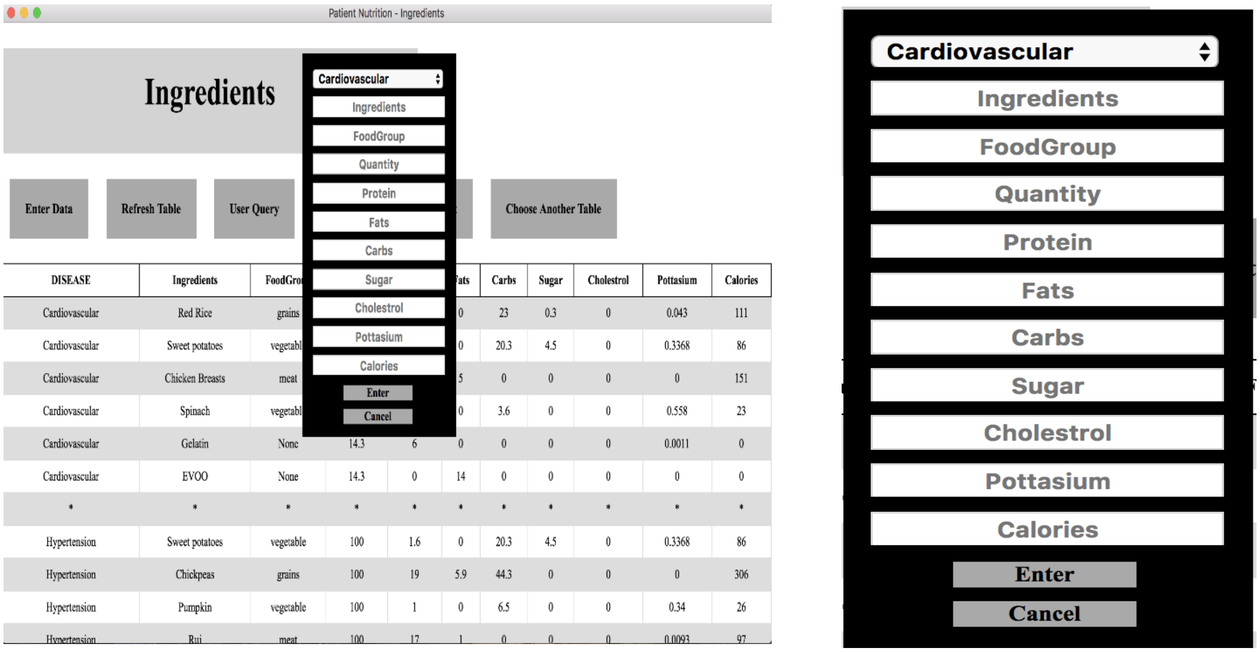


Figure 4.12: How data can be inserted via the UI in each table.

For the Recommendation system, the user will input data (all patient information for e.g. Name, age, weight, height, disease) and click on the submit button, which will make a series of events take place. The data will be exported to the backend server and the algorithm provided by us will calculate the required macronutrient for patients with each of the specified diseases. The system will then show another page where the recommendation is provided to the user, including the ingredients that will be suitable of each user personally and the amount of that ingredients. Along with that, additional comments and advice on how to help with overcoming the diseases (verified by a Nutritionist) will be provided. These information will be imported from the database that we had created and shown to the user as the output. The additional comments and advice mentioned above are also stored in the database, where, like our other table, additional data can be added and stored by the user.

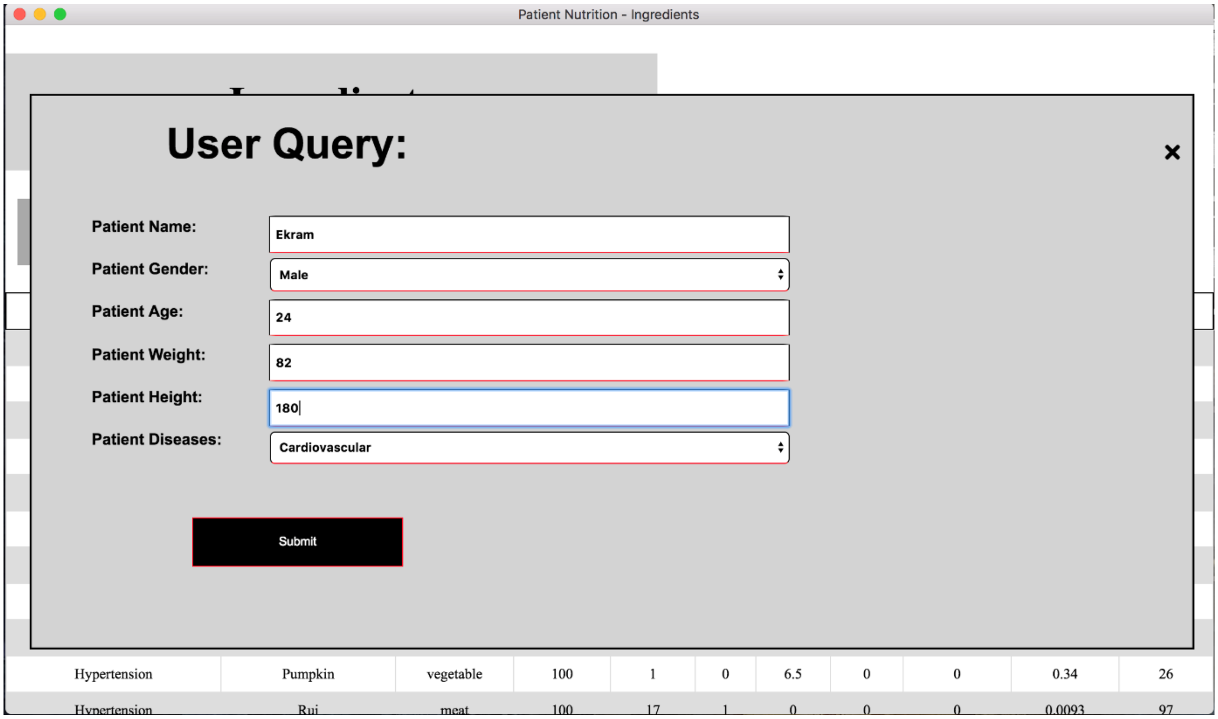


Figure 4.13: User Query Page where users enter data to be calculated.

To package it all into a software, and to connect the backend to the front end, Electron is used. Electron is a node.js framework that used basically lets us change the browser and make it customizable. Our software has been packaged through Electron, which let us remove the browser in an html file and package it into a software-looking interface. This was efficient since we created the GUI with Html5 and CSS, Electron was then used to transform the web-page by editing and eliminating all the browser properties that make it look like a web-page, giving it the appearance of a software.

CHAPTER 5: 3D MODEL DEVELOPMENT AND PRINTING

5.1 3D Model Development

The final part of the system will be selecting from an option of three pre designed 3D models of visually appealing meals and print the food with the calculated unique macronutrient counts.

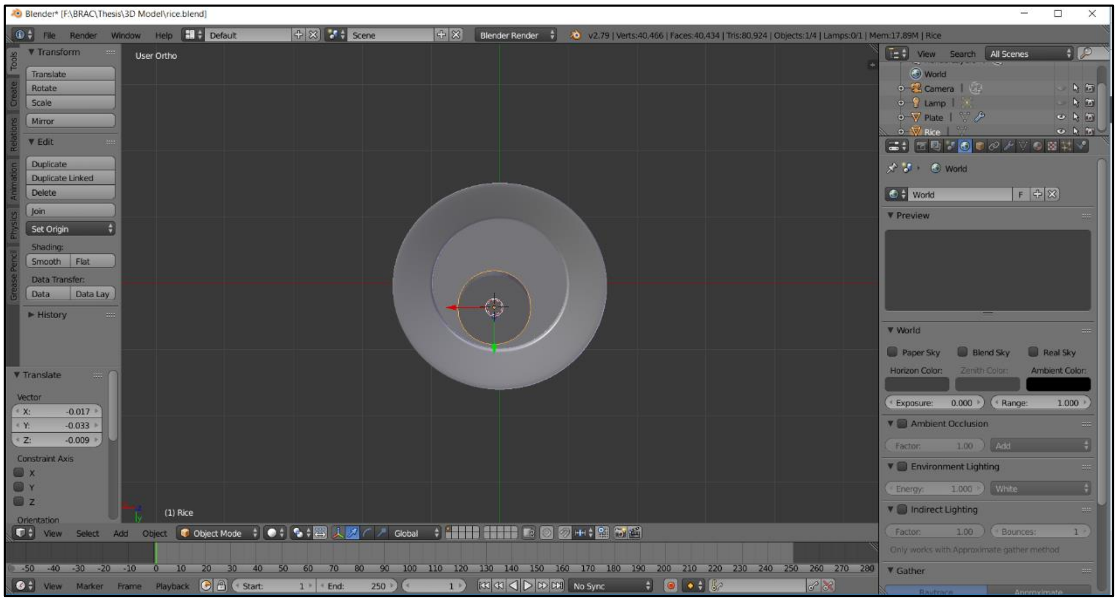


Figure 5.1: Initial stage of model development.

The models have been designed on the free and open source computer graphics software toolset Blender (v2.79b). The images have been rendered on Cycles Render for matte and realistic image output. Several meshes have been used to recreate most of the shapes. Main meshes being cylindrical and cubic. Seamless textures have been used to UV wrap on different elements of the models to recreate a 3D computer version of real world solid food.

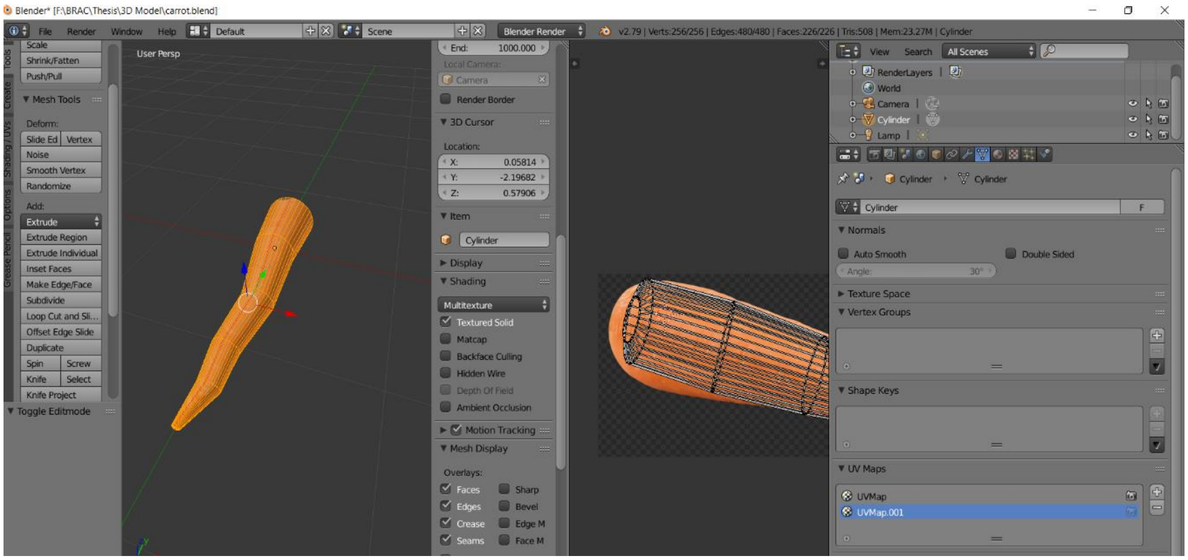


Figure 5.2: UV mapping carrot texture.

To distort and give texture and shape to different elements, the modifier subdivision surface was applied. Other modifiers have also been used to make the objects more realistic and give it the edgy forms that real world objects tend to have. This paper is comprised of each meal with models that complement each other and make the plates look visually pleasing for utmost patient satiety and satisfaction.

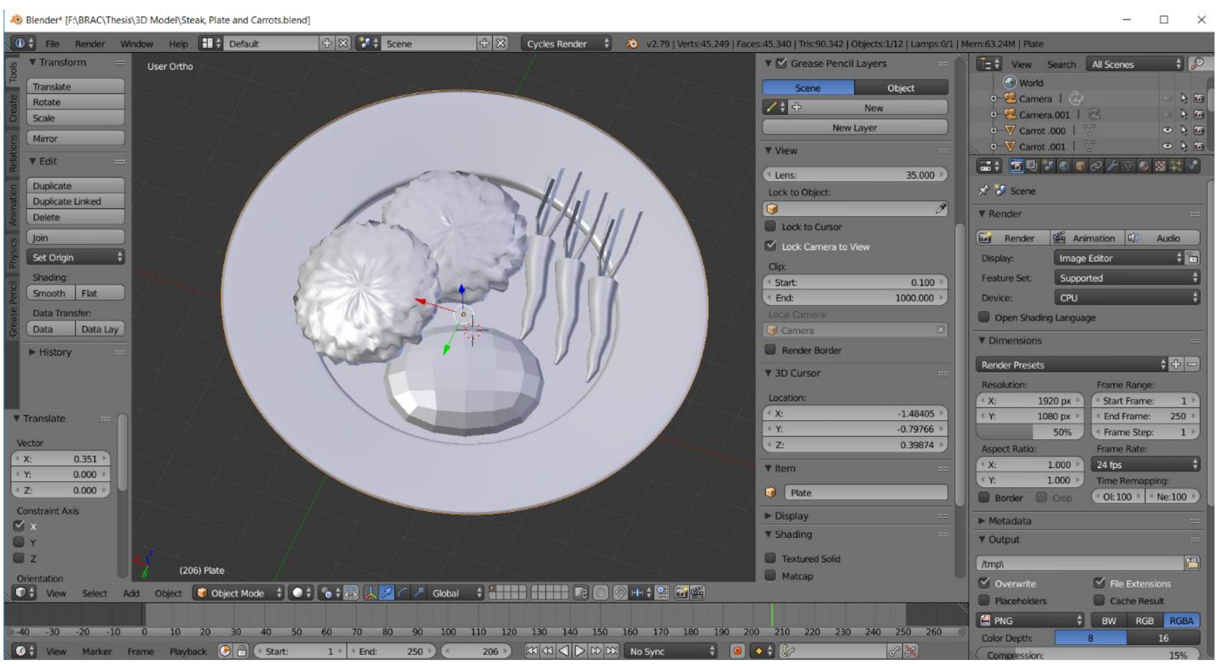


Figure 5.3: Solid, unrendered model of final plate.

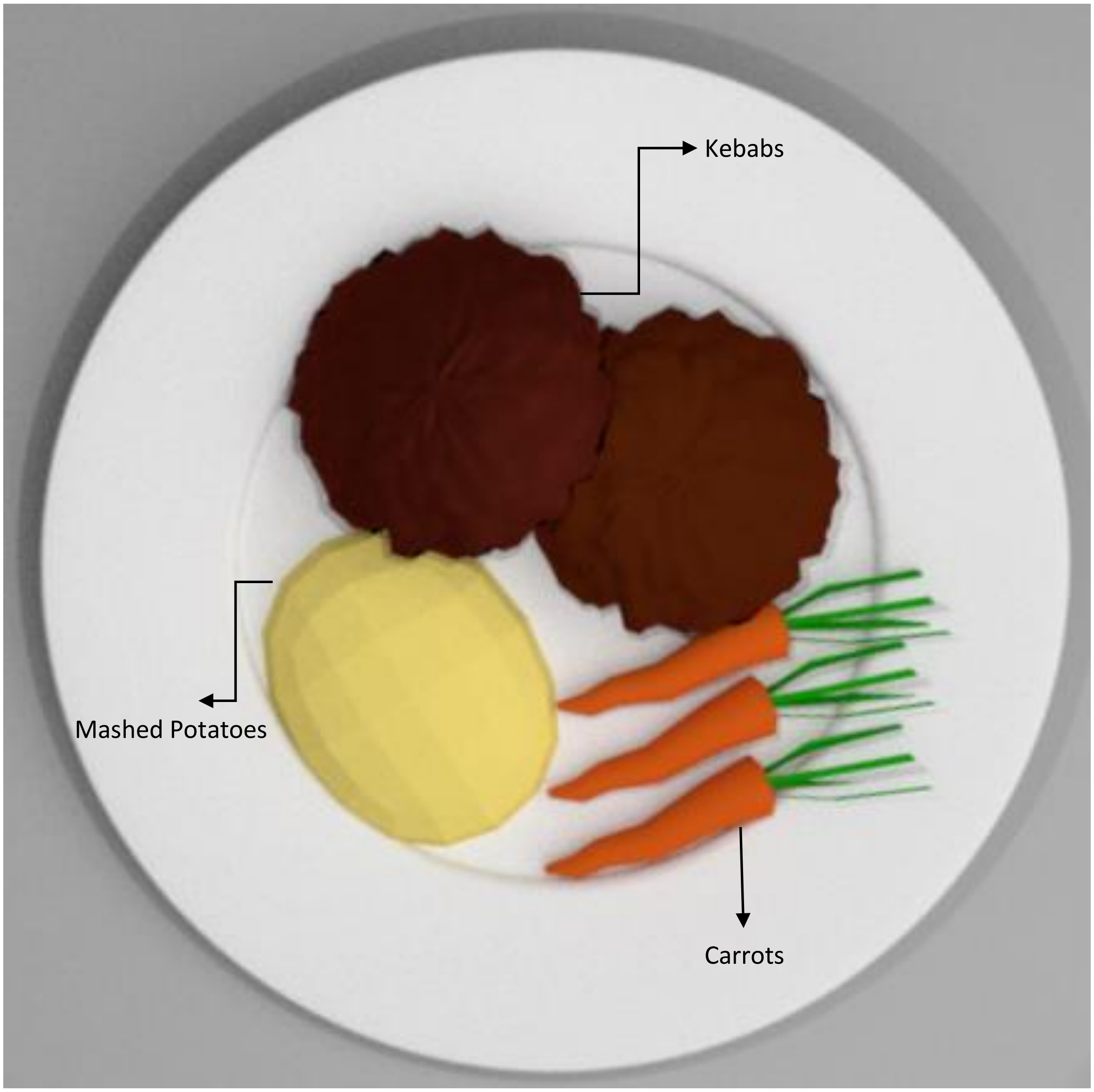


Figure 5.4: Final rendered plate.

For this thesis, the work is limited till developing the 3D models of the expected output, which will eventually be the 3D printed plate of food the patients will receive based on their calculations of personalized macronutrients according to the disease they have.

5.2 3D Printing

The technology behind 3D printing food is still emerging and very new. Food printers are very well out of the reach of students likes us which is why we can still only theorize the science and mechanism behind the technology. An experiment carried forward by a group of students from Deakin University [7] outlines different methods and points to consider while printing food for dysphagia patients. The consistency of the food is of one of the first concerns; whether to cook the food till very soft, mince the food roughly or to make a smooth paste. Another thing of concern is the thickness and viscosity of the paste. Second comes the issue of selecting the right nozzle and to settle on an accurate pressure for discharging the food to print. The stability of the food paste, the duration of printing and the aftermath of printing are all matters of concern and needs to be dealt with a basis of much higher knowledge which is beyond our scope without a 3D printer. However based on our research, we know we must take all of the above into account and also plan food that can be built up in layers for shape stability.

It is expected, that once printed, patients will be able to scoop food, regardless of the complexity of the shape and swallow without the trouble of chewing and breaking down fiber as it will all be prepared before the canisters are filled with food paste to print. Taking note, according to our research, the software will have calculated personalized ingredient amounts to meet the daily macronutrients of individual patients.

CHAPTER 6: OUTPUT AND RESULTS

The output of our thesis remains confined within the software system that we have built. The software is being used to calculate the right macronutrients, from which the system can derive the personalized recipes appropriate for an individual patient. The equations developed takes into account every single factor that affect the daily energy expenditure per person. These calculations enable us to recalculate the exact amount of healthy ingredients required to make the customized recipes. For now, our concept suggests that an external lab personnel will make a mixture of the pureed food, calculated to the dot and fill the food printer canisters for printing.

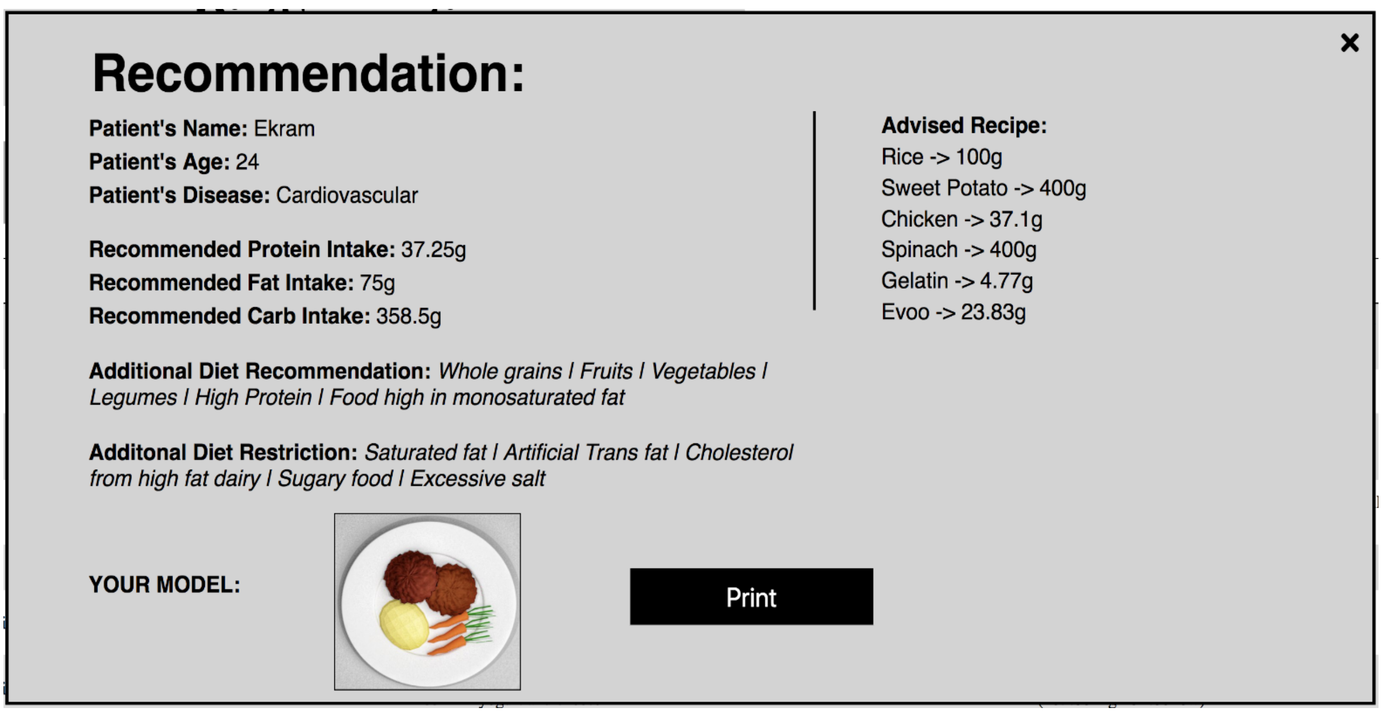


Figure 6.1: Displayed Result for a Sample data input.

CHAPTER 7: CONCLUSION

7.1 Limitations

Since the science of 3D printing food and accurate nutritional specification is outside the scope of our knowledge, reason being food printers are not available in the country and the authors of these paper do not have a degree in nutrition, we had to limit the research until the software concept of the entire system.

7.2 Future Work

Even though the models have been designed, which supports the idea of printing visually presentable food for the patients to choose from, it is not covering the technology of printing those models into edible printed food in this thesis. For future work, it is anticipated to delve deeper into that technology.

Furthermore, for improved performance and superior results, the possibility to implement Neural Networks to make predictions regarding food type, nutrition value and more is foreseen for future work. As for how neural network works, it has to be provided with bulk data points for training the data sets and obtaining results with maximum accuracy. However, it would require a lot of confidential information that doctors were not entitled to provide so far, for which we had to limit our research.

Another focus of our future work will be to minimize the production cost at the value of top nutrient source. For this research, we have considered using every day healthy ingredients as raw material in theory, of course in the long run, this will not be cost effective. For this, we want to also incorporate the idea of nutrient extraction from wasted food 'extras' that are perfectly nutrient dense however get thrown out for not being conventional for cooking. Not only will this help us eliminate food waste but it will also be cost effective to a major degree.

7.3 Conclusion

Through this research a technology has been developed that will be the primary step to designing and solving food architecture for patients with different diseases and or have dysphagia by personalizing the food ingredients and specific macronutrients per individual.

Even though this research has remained in the preliminary stage we believe it is a necessary calculation which is required before attempting to 3D print food for patients. 3D printing food unlocks visual appeal and also provides the core nutrition that is essential for health. Technology is evolving every day and it is hoped that it will reach a stage where we can jump to implement our concepts and ideas to locally 3D print our modelled food concepts into reality.

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