Journal of Innovations in Pharmaceutical and Biological Sciences (JIPBS)
ISSN: 2349-2759
Available online at www.jipbs.com

Research article

A novel approach in adjustment of total daily insulin dosage for type 2 diabetes patients using a fuzzy logic based system

Ahmed Masud Chowdhury*[1], Rubayat Islam Khan[2], Saif Shahriar Rahman Nirzhor[2], Jafrina Jabin[1], Arafat Islam Khan[3]

[1]*Department of Electrical & Computer Engineering, North South University, Dhaka, Bangladesh.*
[2]*Department of Pharmacy, BRAC University, Dhaka, Bangladesh.*
[3]*Department of Aerospace Engineering, San Diego State University, San Diego, California, USA.*

Key words: Insulin, Fuzzy, MATLAB, Type 2 Diabetes, Dose Adjustment, Drug Dosing.

***Corresponding Author: Rubayat Islam Khan,** Department of Pharmacy, BRAC University, Dhaka, Bangladesh.

Abstract

The aim of this study is to adjust the total daily insulin dosage for type 2 diabetes patients, who are already on an insulin treatment regimen, by using a fuzzy-based system. The dose is adjusted by taking into account three patient-related linguistic factors (PRFs) for 39 patients i.e. weight, body mass index (BMI), and average daily carbohydrate intake and utilizing this data to develop rules for a fuzzy-based system in MATLAB. The system was then made to generate an output which was compared to the prescribed doses of insulin by the patients' respective physicians. The fuzzy based system was seen to bring a better regulation to the insulin treatment regimen for a particular patient as compared to the traditional non-fuzzy based methods which calculate total daily insulin dose based on each individual factor discretely. According to the output generated, the reasonable changes that this system suggested may evince better control on patient blood glucose levels. The usage of this system will allow fewer instances of hyperglycemic and hypoglycemic events among type 2 diabetes patients and may be further be translated to type 1 diabetics.

Introduction

Type-2 diabetes is a condition that affects approximately half a billion people worldwide with a prevalence of 8.1% in adults according to the World Health Organization [1]. Its onset is due to the ineffective use of insulin by the human body and accounts for majority of diabetes cases around the world. It is estimated that about 80% of the people with Type-2 diabetes reside in low and middle income countries and in Bangladesh alone, it has a prevalence of 11%. [2,3]. Type-2 diabetes affects many major organs, including the kidneys, eyes, nerves, blood vessels, and the heart. It currently ranks 6th in the top 10 causes of death around the world [1]. However, Type-2 diabetes could be managed better with the help of insulin therapy where patients can self-inject a prescribed dose by the physician in order to regulate their blood glucose levels. The success of this type of therapy is strictly dependent on careful monitoring of certain factors such as their height, weight, BMI, and carbohydrate intake. The prescribed insulin dose by the physician is contingent upon these various factors and mismanagement of blood sugar could often lead to life-threatening complicacies like hyperglycemia (dangerously high blood sugar) or hypoglycemia (extremely low blood sugar) [3]. In order to avoid such problems, a more accurate dosing system is required that takes into account patient-related factors such as weight, body mass index (BMI), and average daily carbohydrate intake, factoring them in determining the precise insulin dose needed for any particular patient. Such a personalized therapy is perfected using a fuzzy-logic based system where a computer system is developed that takes in patient factor data to develop rules and membership functions between each factor, rendering a dosage output optimum for the patient [4, 5].

Controlling blood glucose levels for a type 2 diabetic patient can be a complicated process especially since dosing of insulin based on one single patient related factor can often lead to irregular control of blood sugar. Thus, a variety of factors need to be considered when performing such administration. These factors may include to: age, gender, BMI, and certain diseased conditions a patient might be facing [7]. Often times the dosage of insulin is either overshot or undershot and the patient has to undergo diet and life style changes in order to achieve proper glucose control. Erroneous administration of insulin may cause significant harm to the patients; if insulin is given more than the required amount, the patient may suffer from hypoglycemia. The symptoms for these may include increased hunger, fatigue, frequent urination, blurred vision, etc. [2, 3].

Due to the aforementioned complexities in case of Type-2 diabetes management using insulin, the likelihood of dosage errors in prescription and administration is high. Therefore, it is of utmost interest to provide an effective solution to the above insulin therapy and thus a fuzzy based insulin delivery system is utilized. A precise dosage amount of insulin can be calculated using this system, taking into account the various patient related factors. The fuzzy-based computational system learns through the various inputs provided to it and using inter-factor and intra-factor relations, it derives the various membership functions. This novel personalized dosing approach overcomes the possibilities of hyperglycemic and hypoglycemic events as individual patient dose is calculated individually based on their respective PRFs. Thus exact number of units of insulin can be delivered to the patient, aiding efficient control of glucose level [8-11].

Experimental

Materials and Methods

Patients population

39 type 2 diabetes patients undergoing insulin treatment were randomly selected from the population of the city of Dhaka, Bangladesh; a patient pool comprising of 20 males and 19 females. The patients provided the following individual information: weight, height, average carbohydrate intake per day over a period of a month and the respective prescribed insulin dose by the physician. In each of the cases, first, the physician(s) calculated a nominal insulin dose based on the patient's body weight and then secondly proceeded to adjust the daily amount of insulin given in accordance to subsequent consultation sessions with the patients. The data was then used to calculate the BMI for each patient. Each patient was apprised about the specific method by which this data was to be used and consented to the usage and publication of the results obtained.

Calculation method for insulin dosage and computational tools

MATLAB was used for method development and analysis of the acquired data. The dosage of insulin was calculated by using the fuzzy-based interface developed in MATLAB. Each PRF (i.e. weight, BMI, average carbohydrate intake in a given month in grams)was used as input variables in the system and the resultant predicted insulin dose was the output. Three disparate non-fuzzy based traditional methods used for calculating insulin dose were integrated to one system to generate this output. These standard methods were: calculation of insulin dosage based on body weight, calculation of insulin dosage based on BMI and calculation of insulin dosage based on average carbohydrate consumption discretely. In order to combine these three traditional methods of insulin dosage and produce a fuzzy output, the patient's details were used to calculate insulin dosage separately using each method. These calculations are shown in tables 1, 2, and 3 and for added simplicity, the numerical values of insulin units are shown only for the first 10 patients that were studied. Table 1 shows the insulin dosage calculated when only the patient's weight is used as a determinant factor. In this case, the body weight is simply multiplied by a factor of 0.5 in order to determine the number of units of insulin [12-14].

Table 1. Total daily insulin dose calculation based on patients' body weight (patient number 1 through 10 only)

Patient Number	Weight (kg)	Calculated Insulin Dose (units)
1	85	42.5
2	73	36.5
3	81	40.5
4	95	47.5
5	87	43.5
6	91	45.5
7	78	39.0
8	75	37.5
9	75	37.5
10	89	44.5

Table 2 shows the insulin dosage calculated when only the patient's BMI is used as a determinant factor. In this case, if the patient has a BMI of less than 25 then the body weight is multiplied by a factor of 0.4 in order to determine the number of units of insulin. If the patient has a BMI in between 25-30 then the body weight is multiplied by a factor of 0.5. And finally, if the patient has a BMI of greater than 30 then the body weight is multiplied by a factor of 0.6 in order to determine the number of units of insulin [12-14].

Table 2. Total daily insulin dose calculation based on patients' body mass index (BMI) (patient number 1 through 10 only)

Patient Number	BMI	Calculated Insulin Dose (units)
1	32.4	51.0
2	28.2	36.5
3	33.3	48.6
4	26.3	47.5
5	34.4	52.2
6	34.3	54.6
7	27.6	39.0
8	26.0	37.5
9	23.1	30.0
10	31.9	53.4

Table 3 shows the insulin dosage calculated when the patient's average carbohydrate intake is used as a determinant factor. In this case, the standard 500 rule is used to determine the number of total daily insulin units for that patient [15]. Firstly, the patient's body weight is used to determine the number of daily insulin units required per day. Then the number 500 is divided by this number in order to calculate the number of grams of carbohydrates 1 unit of insulin will cover for that particular patient. Lastly the patients average daily carbohydrate intake is divided by this number in order to determine the number of units of insulin required on a daily basis. (Note: this method does not take correct for the average blood glucose levels of the patient) [15].

Table 3. Total daily insulin dose calculation based on patients' average carbohydrate intake (patient number 1 through 10 only)

Patient Number	Average Carbohydrate Intake (g)	Calculated Insulin Dose (units)
1	410	34.9
2	360	26.3
3	400	32.4
4	470	44.7
5	420	36.5
6	450	41.0
7	385	30.0
8	350	26.3
9	400	30.0
10	440	39.2

Both input and output was made into membership functions according to set ranges and fed into the fuzzy system. The system was then made to generate an output for daily insulin units which incorporated all three patient related factors.

Defining the fuzzy membership functions

The MATLAB Fuzzy Logic Designer Toolbox has been used to determine the output, namely Insulin dosage (insulin dose), against the inputs, i.e. a subject’s Body Mass Index (BMI), Carbohydrate intake (CHO) and Weight. All the variables are fuzzified and the membership functions are set to be triangular, with different ranges. The BMI and CHO has membership functions with three fuzzy values- Low (L), Optimum (O), High (H); the WEIGHT, however, has six fuzzy values Very Low (VL), Low (L), Optimum 1 (O1), Optimum 2 (O2), High (H), Very High (VH). The output variable, insulin dose, has five fuzzy values- A, B, C, D and E. Table 4 shows the ranges of the INPUTS and the OUTPUT, considered for the system. Table 5 illustrates the fuzzy value breakdown and their ranges for BMI and CHO.

Table 4. Ranges of the INPUTS and OUTPUTS

Inputs			Output
BMI	CHO	WEIGHT	Insulin Dose
0 – 40	340 - 490	71 – 100	25 – 55

Table 5. Fuzzy value breakdown and their ranges for BMI and CHO.

		BMI		CHO	
		Range	Unity membership point	Range	Unity membership point
Fuzzy values	L	0 – 25	0	340 - 390	340
	O	25 - 30	27.5	390 - 440	415
	H	30 - 40	40	440 - 490	490

Unity membership point is the point where the membership function has a membership value of 1. The membership of CHO reaches unity at 340 for L, 415 for O and 490 for H; meaning an intake of 340 carbohydrate is Low, 415 is the optimum amount of carbohydrate for a subject and 490 implies a high amount of carbohydrate intake. Anything in the middle has a membership lower than 1.

The variable WEIGHT is fuzzified with six triangular membership functions. Table 6 delineates the breakdown of WEIGHT.

Table 6. Fuzzy value breakdown for WEIGHT.

		WEIGHT	
		Range	Unity membership point
Fuzzy values	VL	71 – 75	71
	L	75 – 80	77.5
	O1	80 – 85	82.5
	O2	85 – 90	87.5
	H	90 – 95	92.5
	VH	95 – 100	97.5

The output variable i.e. the insulin dose is also fuzzified with triangular function, but only five membership functions are made, as stated previously. The fuzzy values, their corresponding ranges, and their unity membership points are given in Table 7.

Table 7. Fuzzy value breakdown for insulin dose.

		Insulin Dose	
		Range	Unity membership point
Fuzzy values	A	25 – 30.5	25
	B	30.5 – 35.5	33
	C	35.5 – 43.5	39.5
	D	43.5 – 49.5	46.5
	E	49.5 – 55	55

As stated previously, all the membership functions are chosen to be triangular. There is no region of overlapping membership in any of the variable. Figure 1 shows the membership functions (L, O, H) of BMI.

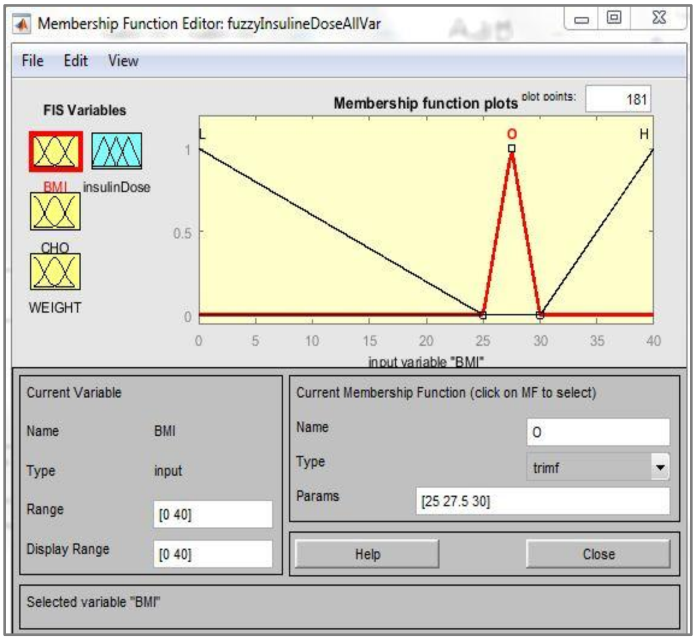

Figure 1. The membership functions of BMI

The three triangular membership functions (L, O, H) of CHO are illustrated in Figure 2.

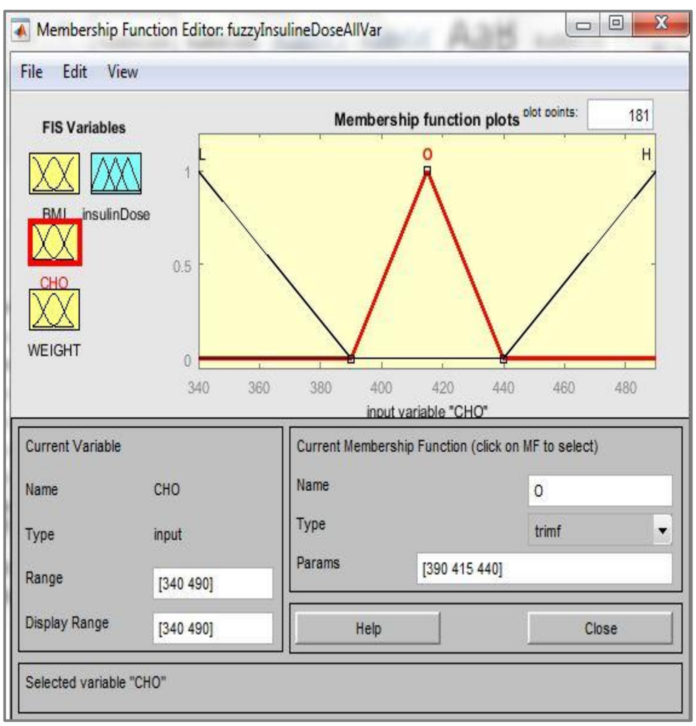

Figure 2.The membership functions of CHO

The last input variable is WEIGHT which has six triangular membership functions (VL, L, O1, O2, H, VH). Shown in Figure 3 are the memberships of the six fuzzy values of WEIGHT.

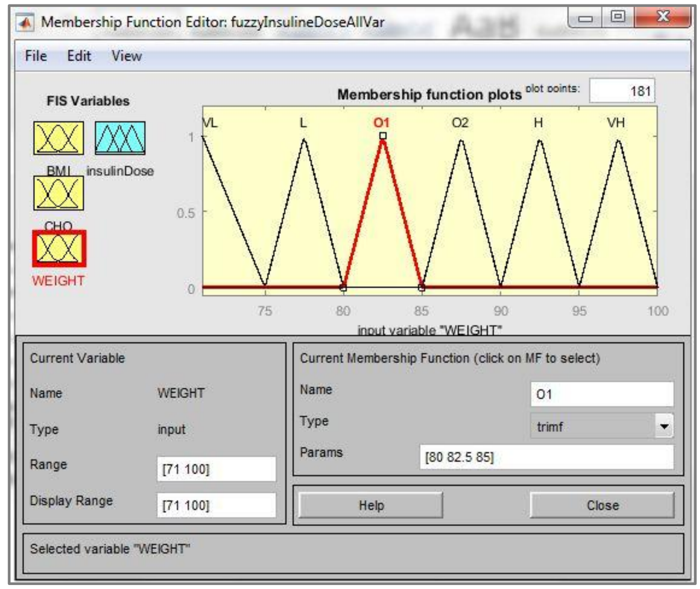

Figure 3. The membership functions of WEIGHT

The last set of membership functions of the system is that of the output, i.e. insulin dose- which includes five membership functions (A, B, C, D, E). Figure 4 illustrates the insulin dose memberships

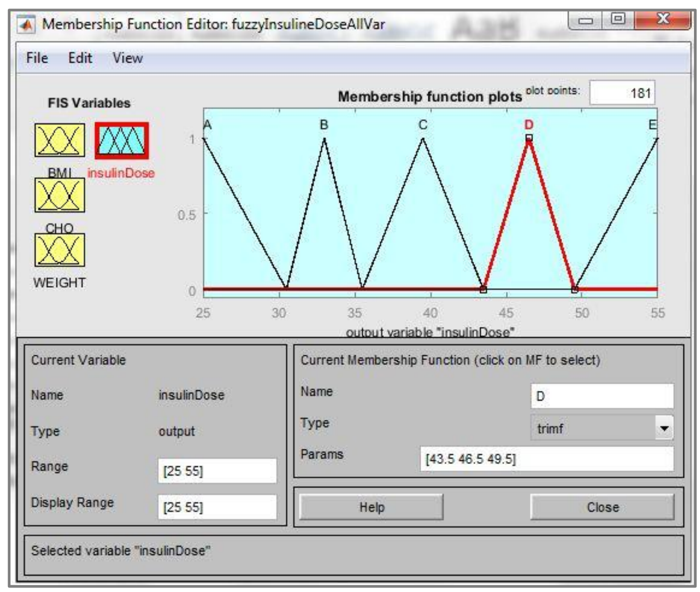

Figure 4. The membership functions of insulin dose

To recapitulate, all of the above figures and tables illustrate that triangular functions were used in the fuzzification of all variables and nowhere in the memberships did any overlapping take place.

Setting the rules for fuzzy inference

Setting the rules for the input/output relationship succeeds after the definition of membership functions, for fuzzy inference. This is where the decision making is outlined. The if/then relationships are used to set the rules for the inference. The system presented in this paper has 54 if/then rules. The rules are set by combining the memberships of the three input variables (BMI, CHO, WEIGHT) to give an output (insulin dose). The decision matrices, used in setting the if/then rules, for insulin dose are shown in the Table 8 to Table13.

Table 8. The decision matrix, considering WEIGHT = VL

		CHO		
		L	**O**	**H**
BMI	**L**	A	C	C
	O	B	C	C
	H	C	C	D

Table 9. The decision matrix, considering WEIGHT = L

		CHO		
		L	**O**	**H**
BMI	**L**	B	C	C
	O	C	C	D
	H	C	D	D

Table 10. The decision matrix, considering WEIGHT = O1

		CHO		
		L	**O**	**H**
BMI	**L**	A	B	C
	O	B	B	D
	H	C	D	E

Table 11. The decision matrix, considering WEIGHT = O2

		CHO		
		L	**O**	**H**
BMI	**L**	A	B	C
	O	B	C	D
	H	C	D	E

Table 12. The decision matrix, considering WEIGHT = H

		CHO		
		L	**O**	**H**
BMI	**L**	B	C	C
	O	B	D	D
	H	C	D	E

Table 13. The decision matrix, considering WEIGHT = VH

		CHO		
		L	**O**	**H**
BMI	**L**	B	C	D
	O	D	D	E
	H	D	E	E

From Table 13, it can be inferred from the decision matrix that, when WEIGHT = VH (95 - 100), BMI = O (25 - 30), CHO = L (340 - 390), the preferred insulin dosage will be, insulin dose = D (43.5 – 49.5). The above contention can be read linguistically as "when a subject's weight is very high (95kg - 100 kg), BMI is optimum (25 - 30), and carbohydrate intake is low (340g – 390g) – his/her insulin dosage should be between 43.5 and 49.5. The fuzzy if/then rules for the inference are set from the decision tables and are depicted as follows:

1. *If* (BMI is L) *and* (CHO is L) *and* (WEIGHT is VL) *then* (insulindose is A)
2. *If* (BMI is L) *and* (CHO is O) *and* (WEIGHT is VL) *then* (insulindose is C)
3. *If* (BMI is L) *and* (CHO is H) *and* (WEIGHT is VL) *then* (insulindose is C)
4. *If* (BMI is O) *and* (CHO is L) *and* (WEIGHT is VL) *then* (insulindose is B)
5. *If* (BMI is O) *and* (CHO is O) *and* (WEIGHT is VL) *then* (insulindose is C)
6. *If* (BMI is O) *and* (CHO is H) *and* (WEIGHT is VL) *then* (insulindose is C)
7. *If* (BMI is H) *and* (CHO is L) *and* (WEIGHT is VL) *then* (insulindose is C)
8. *If* (BMI is H) *and* (CHO is O) *and* (WEIGHT is VL) *then* (insulindose is C)
9. *If* (BMI is H) *and* (CHO is H) *and* (WEIGHT is VL) *then* (insulindose is D)
10. *If* (BMI is L) *and* (CHO is L) *and* (WEIGHT is L) *then* (insulindose is B)
11. *If* (BMI is L) *and* (CHO is O) *and* (WEIGHT is L) *then* (insulindose is C)
12. *If* (BMI is L) *and* (CHO is H) *and* (WEIGHT is L) *then* (insulindose is C)
13. *If* (BMI is O) *and* (CHO is L) *and* (WEIGHT is L) *then* (insulindose is C)
14. *If* (BMI is O) *and* (CHO is O) *and* (WEIGHT is L) *then* (insulindose is C)
15. *If* (BMI is O) *and* (CHO is H) *and* (WEIGHT is L) *then* (insulindose is D)
16. *If* (BMI is H) *and* (CHO is L) *and* (WEIGHT is L) *then* (insulindose is C)
17. *If* (BMI is H) *and* (CHO is O) *and* (WEIGHT is L) *then* (insulindose is D)
18. *If* (BMI is H) *and* (CHO is H) *and* (WEIGHT is L) *then* (insulindose is D)
19. *If* (BMI is L) *and* (CHO is L) *and* (WEIGHT is O1) *then* (insulindose is A)
20. *If* (BMI is L) *and* (CHO is O) *and* (WEIGHT is O1) *then* (insulindose is B)
21. *If* (BMI is L) *and* (CHO is H) *and* (WEIGHT is O1) *then* (insulindose is C)
22. *If* (BMI is O) *and* (CHO is L) *and* (WEIGHT is O1) *then* (insulindose is B)
23. *If* (BMI is O) *and* (CHO is O) *and* (WEIGHT is O1) *then* (insulindose is B)
24. *If* (BMI is O) *and* (CHO is H) *and* (WEIGHT is O1) *then* (insulindose is D)
25. *If* (BMI is H) *and* (CHO is L) *and* (WEIGHT is O1) *then* (insulindose is C)
26. *If* (BMI is H) *and* (CHO is O) *and* (WEIGHT is O1) *then* (insulindose is D)

27. *If* (BMI is H) *and* (CHO is H) *and* (WEIGHT is O1) *then* (insulindose is E)
28. *If* (BMI is L) *and* (CHO is L) *and* (WEIGHT is O2) *then* (insulindose is A)
29. *If* (BMI is L) *and* (CHO is O) *and* (WEIGHT is O2) *then* (insulindose is B)
30. *If* (BMI is L) *and* (CHO is H) *and* (WEIGHT is O2) *then* (insulindose is C)
31. *If* (BMI is O) *and* (CHO is L) *and* (WEIGHT is O2) *then* (insulindose is B)
32. *If* (BMI is O) *and* (CHO is O) *and* (WEIGHT is O2) *then* (insulindose is C)
33. *If* (BMI is O) *and* (CHO is H) *and* (WEIGHT is O2) *then* (insulindose is D)
34. *If* (BMI is H) *and* (CHO is L) *and* (WEIGHT is O2) *then* (insulindose is C)
35. *If* (BMI is H) *and* (CHO is O) *and* (WEIGHT is O2) *then* (insulindose is D)
36. *If* (BMI is H) *and* (CHO is H) *and* (WEIGHT is O2) *then* (insulindose is E)
37. *If* (BMI is L) *and* (CHO is L) *and* (WEIGHT is H) *then* (insulindose is B)
38. *If* (BMI is L) *and* (CHO is O) *and* (WEIGHT is H) *then* (insulindose is C)
39. *If* (BMI is L) *and* (CHO is H) *and* (WEIGHT is H) *then* (insulindose is C)
40. *If* (BMI is O) *and* (CHO is L) *and* (WEIGHT is H) *then* (insulindose is B)
41. *If* (BMI is O) *and* (CHO is O) *and* (WEIGHT is H) *then* (insulindose is D)
42. *If* (BMI is O) *and* (CHO is H) *and* (WEIGHT is H) *then* (insulindose is D)
43. *If* (BMI is H) *and* (CHO is L) *and* (WEIGHT is H) *then* (insulindose is C)
44. *If* (BMI is H) *and* (CHO is O) *and* (WEIGHT is H) *then* (insulindose is D)
45. *If* (BMI is H) *and* (CHO is H) *and* (WEIGHT is H) *then* (insulindose is E)
46. *If* (BMI is L) *and* (CHO is L) *and* (WEIGHT is VH) *then* (insulindose is B)
47. *If* (BMI is L) *and* (CHO is O) *and* (WEIGHT is VH) *then* (insulindose is C)
48. *If* (BMI is L) *and* (CHO is H) *and* (WEIGHT is VH) *then* (insulindose is D)
49. *If* (BMI is O) *and* (CHO is L) *and* (WEIGHT is VH) *then* (insulindose is D)
50. *If* (BMI is O) *and* (CHO is O) *and* (WEIGHT is VH) *then* (insulindose is D)
51. *If* (BMI is O) *and* (CHO is H) *and* (WEIGHT is VH) *then* (insulindose is E)
52. *If* (BMI is H) *and* (CHO is L) *and* (WEIGHT is VH) *then* (insulindose is D)
53. *If* (BMI is H) *and* (CHO is O) *and* (WEIGHT is VH) *then* (insulindose is E)
54. *If* (BMI is H) *and* (CHO is H) *and* (WEIGHT is VH) *then* (insulindose is E)

Insulin dosage recommendation by defuzzification and surface diagrams

After the inputs/outputs are defined and the rules are set, the last step is the defuzzification of the system, where the system will return a crisp value for the output, in this case- insulin dose. There are different methods of defuzzification available in MATLAB. For this paper, the 'Centroid' method is used, as this method gives close approximate results for the subject under consideration. After defuzzification, a single crisp number recommendation, for insulin dosage, is obtained. Figure 5 shows a recommendation for an insulin dose of 39.5, returned by the fuzzy logic system after defuzzification, for a subject with a BMI of 28, a carbohydrate intake of 466gm, and a weight of 72.8kg

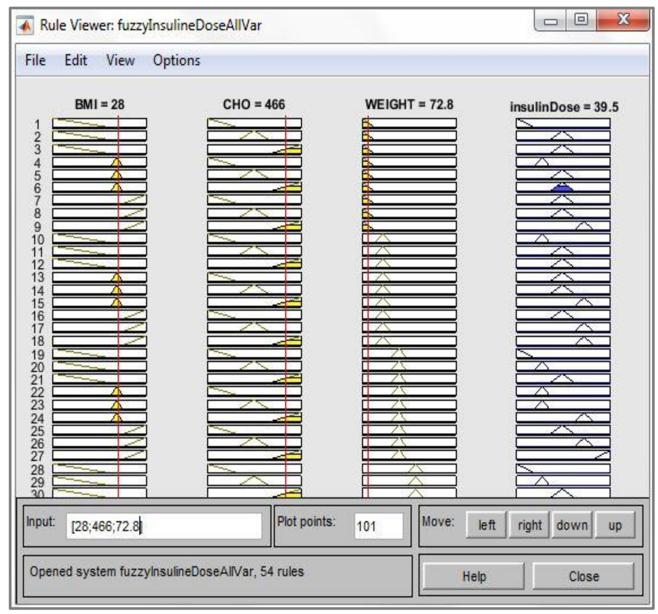

Figure 5. A recommendation of insulin dosage returned by the fuzzy logic system

The surface diagrams, provided in Figure 6 through Figure 8, illustrate the relationships among BMI, CHO, WEIGHT and insulin dose.

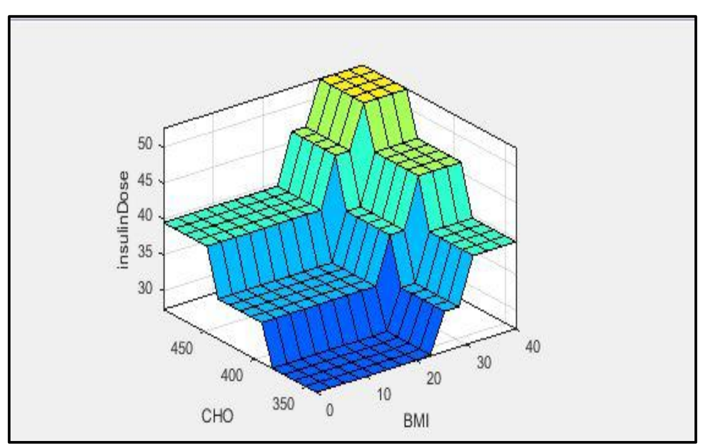

Figure 6. Surface diagram of insulin dose against CHO and BMI

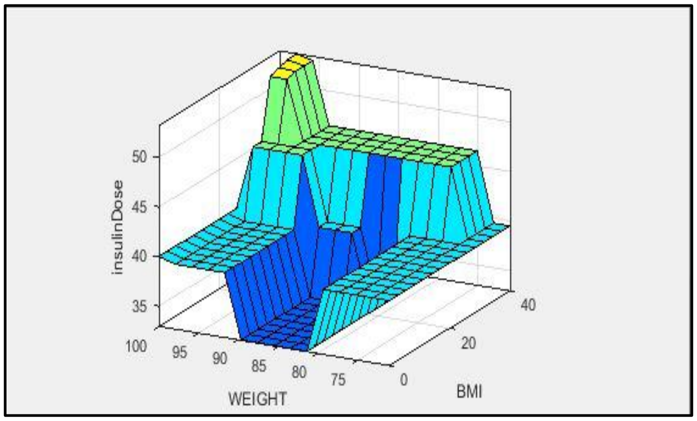

Figure 7: Surface diagram of insulin dose against WEIGHT and BMI

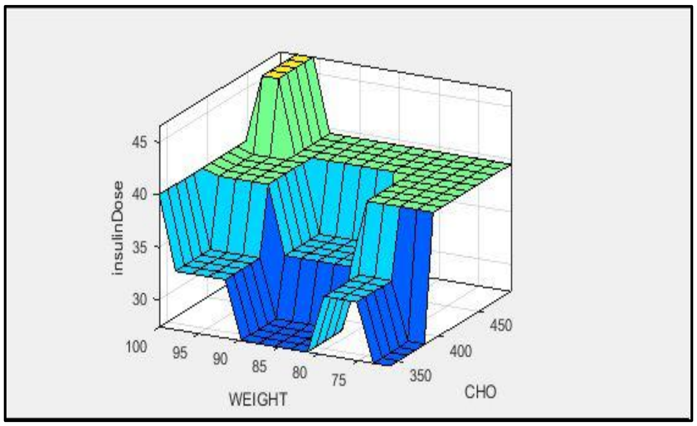

Figure 8: Surface diagram of insulin dose against WEIGHT and CHO

The surface diagram visualizes the relationships between variables, in this case BMI, CHO, WEIGHT and the output insulin dose.

Results and Discussion

All of the patents in the sample population were chosen at random and are residents of Dhaka, Bangladesh. These patients were already undergoing insulin treatment on a regular basis hence they all had prescription knowledge beforehand. The predicted doses for all 39 patients were then compared to the actual prescribed doses by the physicians in Table 14. Table 14 also shows the numerical differences between the two doses for each patient.

The numerical differences between the predicted and the prescribed insulin doses suggest that there was a correction based on the three patient related factors (PRFs) provided. Some doses were significantly different in comparison to the prescribed doses; for example in the case of patient 6. Here the numerical difference in dose was +22.6 units; as in the prescribed dose was significantly lower compared to the predicted dose. This dose was suggested to the patient as a better fit, especially considering the fact that the patient experienced hyperglycemic events on a regular basis.

Table 14. Predicted dose vs. prescribed dose of daily insulin units for each of the 39 patients

Patient number	Predicted insulin dose by the fuzzy system	Physician prescribed insulin dose	Numerical difference
1	40.0	35.0	5.0
2	33.0	32.0	1.0
3	46.5	40.0	6.5
4	40.0	35.0	5.0
5	46.5	40.0	6.5
6	52.6	30.0	22.6
7	39.5	25.0	14.5
8	40.0	30.0	10.0
9	40.0	30.0	10.0
10	40.0	40.0	0.0
11	40.0	35.0	5.0
12	33.0	30.0	3.0
13	39.5	25.0	14.5
14	33.0	32.0	1.0
15	40.0	30.0	10.0
16	46.5	35.0	11.5
17	40.0	34.0	6.0
18	33.0	35.0	-2.0
19	39.5	28.0	11.5
20	46.5	40.0	6.5
21	46.5	35.0	11.5
22	40.0	32.0	8.0
23	39.5	28.0	11.5
24	46.5	38.0	8.5
25	39.5	40.0	-0.5
26	46.5	42.0	4.5
27	39.5	40.0	-0.5
28	33.0	35.0	-2.0
29	52.5	50.0	2.5
30	40.0	35.0	5.0
31	33.0	40.0	-7.0
32	33.0	35.0	-2.0
33	40.0	30.0	10.0
34	46.5	28.0	18.5
35	46.5	45.0	1.5
36	46.5	40.0	6.5
37	39.5	35.0	4.5
38	40.0	30.0	10.0
39	39.5	32.0	7.5

Patient 6 was then observed for one full week with the adjusted dose and the number of hyperglycemic events reduced significantly. Thus, for this one case the higher dose of insulin led to better blood glucose regulation. Only in the cases of six patients was the numerical difference a negative number. This meant that the prescribed dose was higher than the dose predicted by the fuzzy system. Among the patient population, a common trend was observed in terms of the frequency of occurrences of hyperglycemic events. This is the reason why for a number of patients, the numerical differences were in excess of +10. For these patients, a higher dose of insulin may reduce the chances of these events and increase the quality of life. However, it is important to realize that if the insulin dosage is too high, then hypoglycemic events may start to exude. For example, Rubin et al. conducted a study on insulin related hypoglycemic events on 1990 hospital patients and concluded that chances of these events were low at a threshold below 0.6 units/kg [13]. Table 15 shows the values of units/kg for each patient for the daily insulin doses calculated by the fuzzy system. The fact that all of these values were below 0.6 units/kg may be a key factor in reducing hypoglycemic events for the patient population used in this study.

Table 15. Units/kg values for predicted dose using fuzzy system of daily insulin units for 39 patients

Patient Number	Predicted insulin dose by the fuzzy system	Units/kg
1	40.0	0.47
2	33.0	0.45
3	46.5	0.57
4	40.0	0.42
5	46.5	0.53
6	52.6	0.58
7	39.5	0.51
8	40.0	0.53
9	40.0	0.53
10	40.0	0.45
11	40.0	0.50
12	33.0	0.46
13	39.5	0.50
14	33.0	0.40
15	40.0	0.51
16	46.5	0.53
17	40.0	0.44
18	33.0	0.40
19	39.5	0.50
20	46.5	0.54
21	46.5	0.57
22	40.0	0.50
23	39.5	0.51
24	46.5	0.50
25	39.5	0.51
26	46.5	0.61
27	39.5	0.45
28	33.0	0.40
29	52.5	0.55
30	40.0	0.47
31	33.0	0.42
32	33.0	0.39
33	40.0	0.53
34	46.5	0.54
35	46.5	0.51
36	46.5	0.53
37	39.5	0.52
38	40.0	0.50
39	39.5	0.51

Conclusion

Since the fuzzy based system provides a more personalized calculation for daily insulin doses, it may create better regulation for blood glucose levels for type 2 diabetes patients. This fact should eventuate once the patient blood glucose levels are monitored over long periods of time. For patient 6 in particular, the benefits were apparent after a week of observation. For this one case, the fuzzy-based system was able to predict a more accurate dose leading to better blood glucose control. It is conceivable that these adjusted doses might translate to better glucose control for other patients as well but further observations need to be made in order for that claim to be conclusive.

References

1. The top 10 causes of death. (2017, January). Retrieved August 11, 2017, from http://www.who.int/
2. Mendenhall, E, Norris, SA, Shidhaye, R, & Prabhakaran, D: Depression and Type 2 Diabetes in Low and Middle Income Countries: A Systematic Review. Diabetes Research and Clinical Practice 2014; 103(2), 276–285.
3. Patient Care & Health Information: Type 2 Diabetes. (2017, January). Retrieved August 11, 2017, from http://www.mayoclinic.org/
4. Albisser, AM, Schiffrin A, Schulz M, Tiran J and Leibel BS: Insulin dosage adjustment using manual methods and computer algorithms: A comparative study. Med. Biol. Eng. Computing 1986; 24: 577-584.
5. Fabietti, PG and V Canonico: Control oriented model of insulin and glucose dynamics in type 1 diabetics. Med. Biol. Eng. Computing 2006; 44: 66-78.
6. Garber AJ, Moghissi ES, Bransome ED, *et al.* American College of Endocrinology position statement on inpatient diabetes and metabolic control. Endocr Pract. 2004; 10(1):77-82.
7. Jayaraj, N, Cherian CM and Vaidyanathan SG: Intelligent Insulin Infuser. Proceedings of the Third UKSim European Symposium on Computer Modeling and Simulation 2009; 74-78.
8. Xu, Z, Liu S, Gan Z, Ma B and Liu G *et al*: An integrated intelligent insulin pump. Proceeding of the 7th International Conference on Electronic Packaging Technology, Shanghai 2009; 1-5.
9. Yang, R, Zhang M and Tarn TJ: Adaptive backstepping control of a micro-needle micro-pump integrated insulin delivery system for diabetes care. Proceedings of the 7th IEEE Conference on Nanotechnology Hong Kong 2007; 448-453.
10. Goh, W, Pasquier M and Quek C: Adaptive control of infusion pump for type-i diabetes control using a self-tuning regulator. Proceeding of the 10th International Conference on Control, Automation, Robotics and Vision 2008; 1379- 1384.
11. Zelin, S, Jun GH and Norwich KH: The glucose control mechanism viewed as a regulator. Med. Biol. Eng. Computing 1975; 13: 503-508.
12. Moghissi E, et al: ACE / ADA Inpatient Diabetes and Glycemic Control Consensus Statement: Garber A. American College of Endocrinology and American Diabetes Association Consensus statement on inpatient diabetes and glycemic control: a call to action. Diabetes Care 2006; 29(8):1955-62.
13. Clement S, Braithwaite SS, Magee MF *et al*: American Diabetes Association Diabetes in Hospitals Writing Committee. Management of diabetes and hyperglycemia in hospitals. Diabetes Care 2004; 27: 553-91.
14. Rubin, DJ, Rybin, D, Doros, G, & McDonnell, ME: Weight-Based, Insulin Dose–Related Hypoglycemia in Hospitalized Patients with Diabetes. Diabetes Care 2011; 34(8): 1723–1728.
15. Elaine C and Phillip G: Use of U-500 insulin in the treatment of severe insulin resistance. Insulin 2008; 3(4): 211-218.