Algorithm for the Infusion Rate of Glucose During an Insulin Clamp

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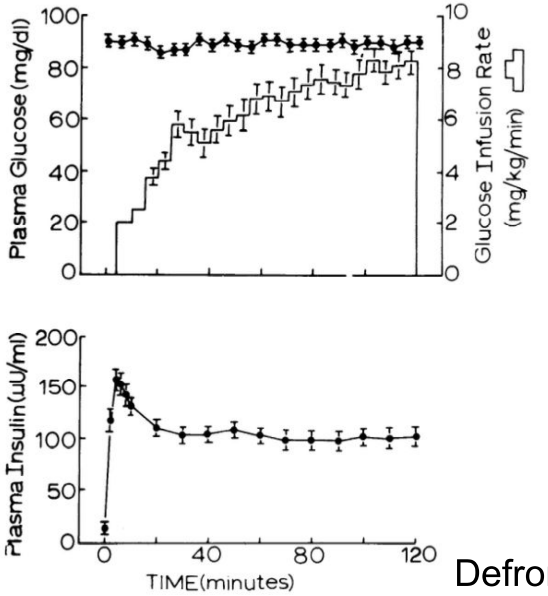
GlucoReg

Background: Hyperinsulinemic clamp

- Plasma insulin rate is raised and held at 120 μU/mL via constant insulin infusion
- Glucose is infused and blood glucose levels are measured; GIR adjusted
- Measures <u>insulin sensitivity</u> in patient
- Patients: Pre-diabetics, diabetics, those with endocrine & metabolic disorders



Defronzo et al., 1979

Refresher: Problem Statement

- In hyperinsulinemic clamp studies, Dr. Luther adjusts GIR on the fly based on his clinical judgment
- This can lead to inaccurate adjustments which can affect subject safety and data validity
- Some people claim that an algorithmic approach works, but no one Dr. Luther has talked to has been successful
- We will develop an algorithm that allows researchers to perform these studies in a more controlled manner

Refresher: Needs Assessment → Provider

Interface

1. Should be simple to understand
2. Should include inputs for all possible variables the physician may want to change: target glucose level, insulin clamp level, demographic data, time of experiment
3. Given patient demographics and history, should simulate the glucose level over time, prior to clinical testing

Refresher: Needs Assessment → Provider

Algorithm

1. Should calculate the amount of glucose uptake based on the constant insulin infusion rate the physician specifies
2. Depends on actual glucose infusion rate (not suggested)
3. Should output a recommended glucose infusion rate that accounts for the time delay in measuring glucose level from blood sample (t-1)

Refresher: Needs Assessment → Provider

Timing

1. Runtime -- should provide physician with proper glucose infusion rate (GIR) within 10 seconds of inputting the current glucose level
2. Should include an easy to navigate UI for immediate data entry

Refresher: Needs Assessment → Patient

Safety

1. Ensure that glucose levels do not exceed or drop below safe levels, as determined by the physician
2. Measurements need to be taken every 5 minutes to ensure glucose levels are where they should be. If not, the program should alert the physician (future iteration)
3. Must run smoothly so that no bugs interrupt the program

Refresher: Needs Assessment → System

Applicability and cost

1. Should be applicable to different physicians and different hospitals performing the same studies
2. Should be open source
3. Results from these studies should lower healthcare costs in the future

Progress: Multiple Regression Analysis

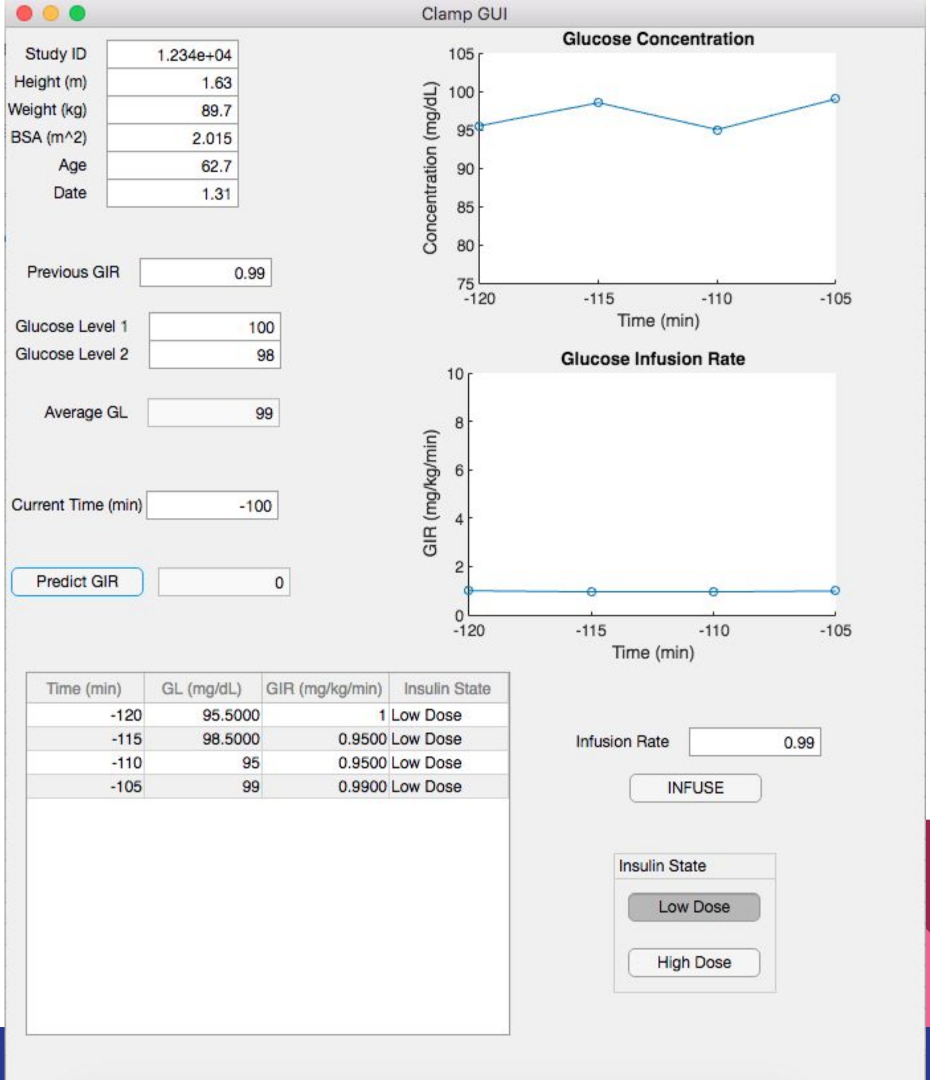
```
Linear regression model:
    GIR ~ 1 + Height + Weight + BSA + Age + Gender + Race
```

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	3.2236	2.011	1.603	0.11325
Height	15.35	5.7597	2.6651	0.0094679
Weight	0.19485	0.083456	2.3348	0.022309
BSA	-20.895	8.0997	-2.5797	0.0119
Age	-0.014226	0.0054871	-2.5927	0.011498
Gender	0.14254	0.16286	0.87521	0.38433
Race	-0.32696	0.22619	-1.4455	0.15261

Progress: GUI

- Will take inputs and generate a predicted GIR
- Once closed, file will save to MATLAB workspace and an excel file



Code: GUI

```
time = cell2mat(app.UITable.Data(:,1));
gl = cell2mat(app.UITable.Data(:,2));
gir = cell2mat(app.UITable.Data(:,3));
%              x1 = linspace(-120,120,1000);

% Plot the GIR and GL

plot(app.glucoseinfus, time, gir,'-o');
plot(app.glucoseconc, time, gl,'-o');


    app.glucoseinfus.YLim = [0 10];
    app.glucoseconc.YLim = [75 105];

% Update the time
app.CurrentTime.Value = curtime + 5;

% Update the Infusion Rate
app.InfusionRate.Value = prevgir;
```

```
% Button pushed function: Button
function ButtonButtonPushed(app, event)

    % Update number of button pushes
    app.buttonpush.Value = app.buttonpush.Value +1;
     butpush = app.buttonpush.Value;

     % initialize variables
   studyid = app.StudyID.Value;
    height = app.Height.Value;
    bsa = app.BSA.Value;
    weight = app.Weight.Value;
    age = app.Age.Value;
    prevgir = app.PrevGIR.Value;
    gl_one = app.GlucoseLevel1.Value;
    gl_two = app.GlucoseLevel2.Value;
    avg_gl = mean([app.GlucoseLevel1.Value, app.GlucoseLevel2.Value]);
    app.AverageGL.Value = avg_gl;
    curtime = app.CurrentTime.Value;
    LD = app.LowDose.Value;


    % Calculate the future GIR
    if prevgir==0 && curgl==0
        app.PredictGIR.Value = 1+ 15.35*height + .19485*weight - 20.895*bsa - age*.014226;
    else
        % This is where we will put in the algorithm
        app.PredictGIR.Value = 0;
    end
    % Update table
    app.UITable.Data{butpush,1} = curtime;
    app.UITable.Data{butpush,2} = avg_gl;
    app.UITable.Data{butpush,3} = prevgir;
    if LD == 1
        app.UITable.Data{butpush,4} = 'Low Dose';
    else
        app.UITable.Data{butpush,4} = 'High Dose';
    end
```

Progress: Machine Learning

Support Vector Regression Kernels to build algorithm using scikit in Python

- Open Source
- One of the best coding languages for Machine Learning
- y0 as a function of demographics (initial infusion rate from multiple regression)
- Δy as a function ONLY of Δx — linearity, one independent variable
- cross validation

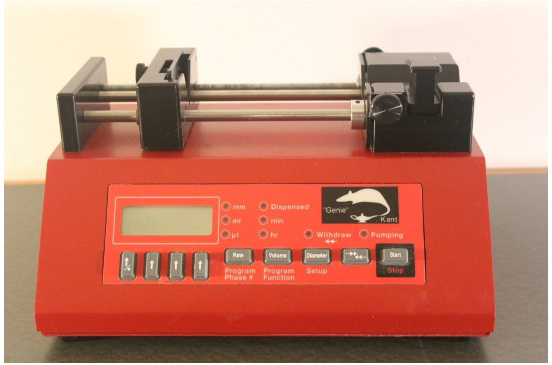
Our pump

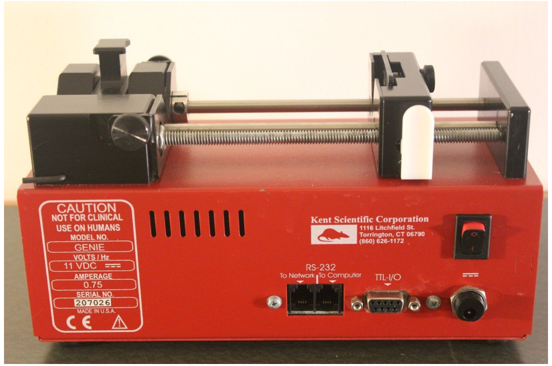
CareFusion BD Alaris Pump Module with Guardrails MX software suite

*Because of proprietary and safety concerns, we do not plan on trying to interface with this pump

Pump POC

- Syringe Pump POC
  - Kent Scientific Genie Syringe Pump
  - Glucose solution in syringe
  - Communicate from MATLAB to pump via serial communication
  - Monitor physiological signals
  - Monitor pump controls





Pump - Serial Communication

- Communicates via text-based dialogue
  - DIA → set diameter in mm
  - RAT → set rate
  - RUN → start infuse
  - STP → stop motor
- Wrote a C++ code with Dr. Diedrich

GenieControlDlg.cpp

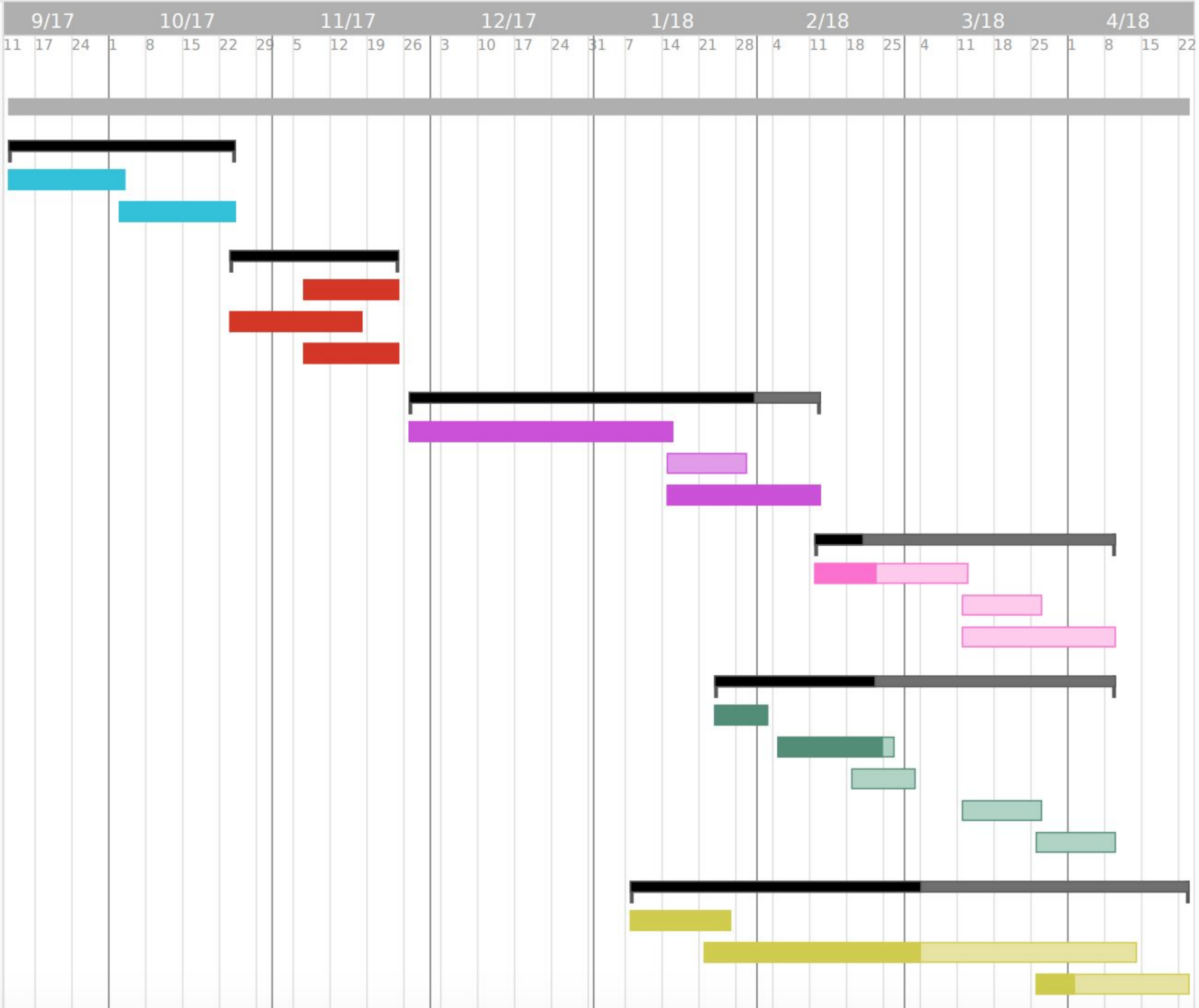
```cpp
/////////////////////////////////////////////////////////////////////////////
// CGenieControlDlg dialog

CGenieControlDlg::CGenieControlDlg(CWnd* pParent /*=NULL*/)
	: CDialog(CGenieControlDlg::IDD, pParent)
{
	//{{AFX_DATA_INIT(CGenieControlDlg)
	m_dia = _T("");
	m_rate = _T("");
	m_volume = _T("");
	m_dose = _T("");
	//}}AFX_DATA_INIT
	// Note that LoadIcon does not require a subsequent DestroyIcon in Win32
	m_hIcon = AfxGetApp()->LoadIcon(IDR_MAINFRAME);
}

void CGenieControlDlg::DoDataExchange(CDataExchange* pDX)
{
	CDialog::DoDataExchange(pDX);
	//{{AFX_DATA_MAP(CGenieControlDlg)
	DDX_Text(pDX, IDC_EDIT_DIA, m_dia);
	DDX_Text(pDX, IDC_EDIT_RAT, m_rate);
	DDX_Text(pDX, IDC_EDIT_VOL, m_volume);
	DDX_Text(pDX, IDC_EDIT_DOSE, m_dose);
	//}}AFX_DATA_MAP
}

BEGIN_MESSAGE_MAP(CGenieControlDlg, CDialog)
	//{{AFX_MSG_MAP(CGenieControlDlg)
	ON_WM_SYSCOMMAND()
	ON_WM_PAINT()
	ON_WM_QUERYDRAGICON()
	ON_BN_CLICKED(IDC_BTN_SEND, OnBtnSend)
	ON_BN_CLICKED(IDC_BTN_START, OnBtnStart)
	ON_BN_CLICKED(IDC_BTN_STOP, OnBtnStop)
	//}}AFX_MSG_MAP
END_MESSAGE_MAP()
```

Pump - Serial Communication

- Can check communication in Arduino before going to MATLAB
    - Useful to verify commands before running full code
- Next step is to implement C++ code into MATLAB
    - MATLAB Instrument Control Toolbox
    - Or, compile C code into MEX

Gantt Chart

Glucose Regulation Algorit...	**61%**
Preliminary Brainstorming	**100%**
Familiarization and meeting Dr. Luther	100%
Brainstorming	100%
Preliminary Data Analysis	**100%**
Data storage and sorting	100%
Database and demographic analysis	100%
Multiple regression analysis	100%
Algorithm - first round	**84%**
Development of algorithm - first draft	100%
Clinical testing (1)	0%
Algorithm iterations (1)	100%
Algorithm - second round	**16%**
Implementation of machine learning	40%
Clinical testing (2)	0%
Algorithm iterations (2)	0%
Pump interface	**40%**
Familiarization with pump/Brainstorm...	100%
Prototype	90%
First round of testing	0%
Prototype modification	0%
Finalization	0%
Algorithm + Pump Finalization	**52%**
Creation of user interface	100%
Finalization of algorithm, UI, and pum...	50%
Design day preparation	25%



BMES Grant Application

- Finalized aside from video of prototype and proof of design
- Will need a letter of support

Algorithm for the regulation of glucose infusion

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Next Steps

- Finalize first iteration of algorithm and use in clinical trial (not directly on patient, but side by side)
- Obtain new sources of data
- Continue working on machine learning
- Finish pump interface by implementing C++ code into MATLAB
- Continue to work on BMES grant application

Questions?