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Machine Learning for Prediction of Life of Arteriovenous Fistula

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***Abstract*—Millions of patients worldwide suffer from Kidney failure and require dialysis. In most cases, dialysis is started after the kidney function of the patient falls below a threshold. In this scenario the patients kidney is essentially non functional. In order to conduct dialysis, native arteriovenous fistulas are constructed to increase blood flow in the superficial vein, and hence facilitate dialysis. Over time, as dialysis continues, the patient may suffer from hypertension and reduced vein function leading to the collapse of the fistula. The ultrasound doppler test for checking the state of the fistula are expensive and doing it again and again is not feasible. We study work related to Chronic Kidney Disease which provides similar data points to those required for the health of the fistula and propose a mechanism to predict the life of a fistula.**

***Index Terms*—Dialysis, Machine Learning, Fistula, Chronic Kidney Disease**

I. Introduction

Kidney failure or renal insufficiency, is a condition which exhibits damaged kidney function where the kidneys lose their ability to excrete metabolic wastes from the blood stream [1]. The two main types include acute kidney injury(AKI), which may be reversed by timely remedies, and chronic kidney disease, which is unfortunately often irreversible.

Chronic kidney disease (CKD) is a gradual decrease in renal function over an extended period, sometimes months, generally years. When a patient is diagnosed as having CKD, he needs to be put on dialysis, for which a native arteriovenous fistula needs to be constructed [1], [2]. Dialysis is generally done for four hours three times a week to ensure acceptable Quality of life for the patient. Over time, as dialysis is conducted, some patients might suffer from hypertension and reduced vein function which may eventually lead to the fistula failing [3], [4]. Developing another fistula takes time and during this period, the patient is inconvenienced by dialysis via a catheter [3]. Constant ultrasound doppler scans[5] to check fistula health are not feasible. Currently, the very significant amount of data being output by the dialysis machines is view and go. I.e. It is not stored. It is not used except during dialysis. Therefore, in the current system, there is no prediction and most procedures follow a action response method where a new fistula is created once the old one fails catastrophically and hypertension is not treated proactively [5].

The focus of this paper is to utilise this data in order to predict fistula health, streamlining procedures carried out by nephrologists, allowing them to proactively treat patients to stop them from entering a hypertensive state and keeping them informed as to the state of the fistula, to allow for the creation of a new one before the current one fails so as to not inconvenience a patient with a catheter as a stopgap measure. Doing the same is likely to improve the quality of life of the patient allowing them to lead a mostly normal life even while they undergo dialysis. This paper is further divided into five more sections. Section II provides an overview of renal disease covering its types and types of dialysis possible. Section III discusses the work already done in this field and all our inferences. Section IV covers the work proposed, including all the modules to be included. Section V covers the modules and a brief description of each. Section VI shows a flow diagram for the work proposed. Section VII mentions evaluation details. Section VIII discusses the work done thus far. Section IX concludes the paper by discussing the problem at hand, its solution and implications.

II. Renal disease - An Overview

Patients suffering from renal impairment, generally present themselves with symptoms which seem to be mostly non specific or if a consultation with a medical professional has revealed elevated urea or creatinine. When such a patient consults a nephrologist, it is of paramount importance that he or she is able to identify the ailment of the patient and distinguish between AKI and ESKD [2].

AKI stands for Acute Kidney Injury. It is generally a sudden onset episode of kidney failure or damage which results in a severe imbalance of body fluids due to a build up of excretory products in the blood stream. It may also be caused by reduced blood flow to the kidneys or a blockage in the urinary tract. In most cases, this disease is treatable and kidney function may be recovered. ESKD stands for End Stage Kidney Disease. As the name suggests, this is a fatal disease and reversing the damage caused is no longer possible[6]. A patient can be said to have ESKD when his or her kidney function falls below 15%. This can be considered the last stage of Chronic Kidney Disease(CKD) and severely shortens life expectancy[2]. At this stage, it is almost certain that the patient has lost his kidneys. The patientis now

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presented with two options:

- Lifelong dialysis.
- Dialysis followed by Kidney transplant.

Patients and their relatives can add themselves to transplant list to enroll themselves for a domino transplant or relatives can donate a kidney if there is a match. While on the list, dialysis occurs regularly. In case the patient gets a transplant, it can be stopped, else it continues for life When it comes to undergoing dialysis, the patient has four options:

- Temporary catheter.
- Distal arteriovenous fistula.
- Proximal arteriovenous fistula.
- Permanent catheter.

A temporary catheter is a stopgap measure which allows a patient to undergo dialysis for the two weeks it takes for a fistula to develop. Of the two techniques for the arteriovenous fistula, the proximal method is preferred over the distal method. In the distal method the fistula is constructed near the wrist. The proximal method constructs it in the upper arm. If a fistula is no longer possible, a permanent catheter may be used. However, this inconveniences the patient and has a short lifespan of around one and a half year compared to fifteen to twenty years for a fistula.

III. Related Work

A lot of work has already been done in the field of dialysis on the whole. Much of the work done concerns the various methods and techniques involved in identifying Chronic Kidney Disease.

Paper[7] deals with the identification of Chronic Kidney Disease using machine learning techniques. This paper suggests trends in algorithms used. It does not specify the parameters considered and states that the training set did not have 100% observed parameter values. It specifies 6 different classification algorithms that were used to compare them. They include: logistic regression, decision tree, SVM with a linear kernel, SVM with a RBF kernel, Random Forest Classifier and Adaboost. Of these, SVM with linear kernel gives the highest accuracy of 98 percent.

Paper[8] looks to achieve the same goal but using Decision trees and SVM. In this scenario, Decision trees give an accuracy of 97%-100% whereas SVM gives an accuracy of 97%. The results are based on the population of 250 patients with CKD and 150 healthy patients. Sequential minimal optimization and J48 was used for decision tree using WEKA and the dataset considered had 25 distinct parameters.

Paper[9] tries to find significant parameters in kidney dialysis sets using the K-means algorithm. It relies on classifying parameters into ranges such as medium, low and high to further aid with clustering. This paper mainly focused on identifying survival period of patient undergoing dialysis using clustering techniques. Making classes helps with making the prediction. In this scenario, creatinine plays an important part and it is found that patients with a level of creatinine which is either high or low are likely to suffer from adverse effects.

Paper[10] deals with the effects of dialysis to the quality of life of a patient. It shows the results of a survey of patients undergoing hemodialysis. Starting hemodialysis involves a significant lifestyle change and can have a lot of effects on a patients physical and mental health. Care needs to be taken that changes are not averse. The paper was restricted to specific region and results cannot be generalized.

Interactive sessions with nephrologists have furthered our understanding of the dialysis process and its subprocesses. These interactions have also helped us come up with relevant factors to be considered in relation to health of the fistula.

Looking at the manual of the Fresenius 4008s, a common dialysis machine, we see that it shows a variety of factors on its display, updating second on second. Most of this data is considered in the present and not stored.

Looking at all the related work it was identified that identification and classification is an important aspect of work in the field of dialysis. However there is a need to provide for forecasting and prediction of life of arteriovenous fistula by making use of state of the art techniques such as Machine Learning and big data.

IV. Proposed Work

This paper presents the various blocks that need to be implemented in a system to predict life of arteriovenous fistulas. The modules in the system are as follows:

- Personal and Clinical Factors
- Analysis of information
- Prediction
- Reports

V. Modules to be developed

The proposed system was envisioned after considering the data set of 200 patients. Firstly, normalcy was defined in the dataset and then the resulting data set was compared. Of the 200 patients 35 had normal functioning of arteriovenous fistula while the remaining had reduced function. 5 dialysis sessions were included for each patient to avoid any case of operator error.

The dataset comprises of over 30 values reported by the machine. Some of them are:

- Dialysis flow
- Blood flow
- Arterial Pressure
- Venous Pressure
- Ultrafiltration speed
- Heart rate
- Trans membrane pressure
- Total Ultrafiltration speed
- Blood pressure

- Target kT/V

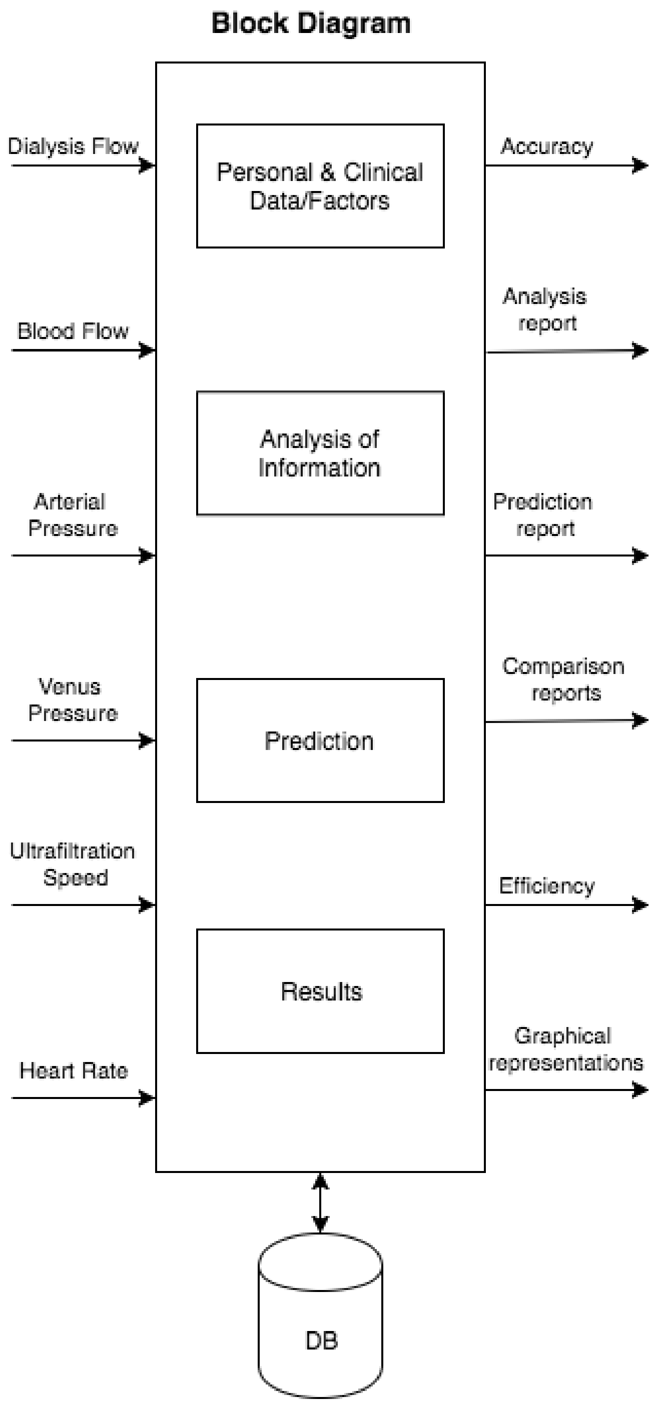

Fig. 1. Block diagram of proposed system

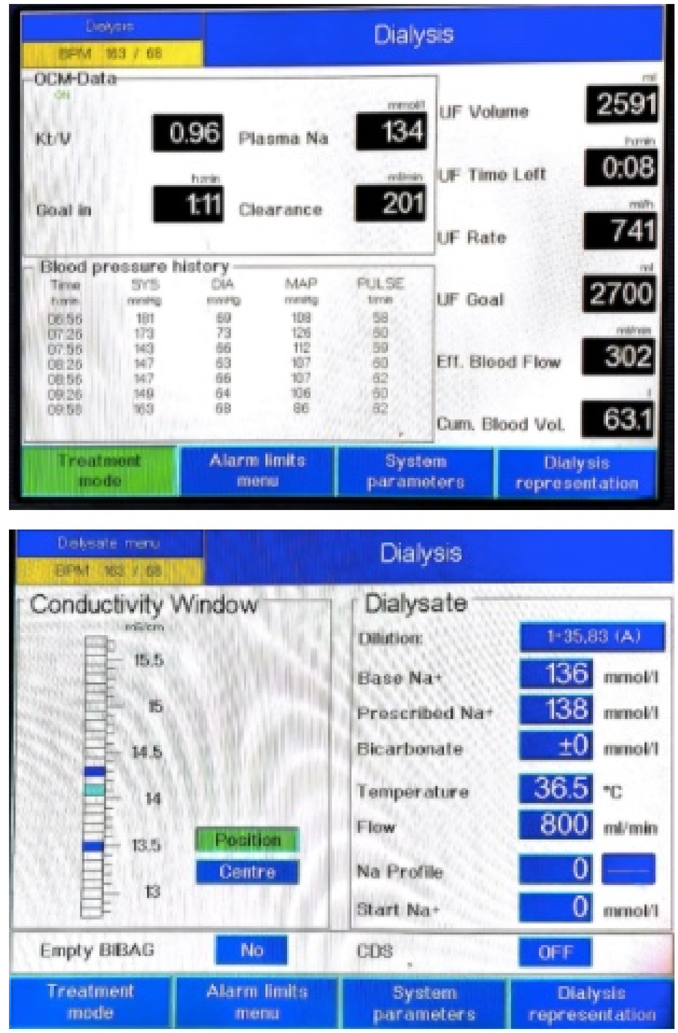

Fig. 2. Fresenius 4008s screengrab

In Fig 2 we see two screen grabs from the Fresenius 4008s dialysis machine. The device has a default treatment mode which is shown in the first image and others for modifying the levels of alarms to ring, system parameters as well as dialysis representation which is shown in the second image.
There are four distinct modules need to be developed in the system in order to effectively predict the life of arteriovenous fistula The first module is Personal Clinical data. This module will take in data which is being output from the dialysis machine and store it within a database after segregating it based on the type of data. Data may be divided into the categories - personal, clinical or miscellaneous.
The second module is Analysis of Information. This module will take in data from the database and process it according to rules to group it into classes by performing segmentation. Alongside segmentation, the data will also be rendered into multiple combinations which will make for clear pattern analysis.
The next module in our system is Prediction. This module will

consider the algorithms we have seen used with hemodialysis and check their efficacy on the data at hand. Based on the efficiency new algorithms may be developed to improve accuracy of the system.
The last module is Results. In this module, we will compare the predicted value with the actual condition to calculate the accuracy of the system and generate reports to track performance of the system.
The hardware required for satisfactory performance of the system consists of a minimum of:

- 2 Intel E5-2670v3 12 Core/24 Thread 2.3Ghz 30Mb Cache
- Processors
- 64 GB RAM
- Nvidia Quadro P600 - 4 units
- Internal drives - 1024GB Samsung 960 Pro NVMe SSD
- External storage - Distributed Ceph Storage with SSD Caching Tier using 800GB Intel SSD DC S3610 Series Drives
- Fresenius 4008s dialysis machine

VI. Implementation of Proposed System

The flow of the system is as follows(Fig 3):

- Technician logs into the system.
- Download of data output by the dialysis machine.
- Upload of csv file to server.
- Shell script to convert csv file to database entries.
- Running script to add to database.
- Add data to training set.
- Use data to train model.
- Test prediction against known patient condition. Optimise algorithms if necessary.
- Generate reports.

Fig 4 shows the the level 1 DFD of the system showing flow of data between the modules.
Once data has been output by the machine, the technician will download it and upload it to the server in csv format.
The data available will be trained in TensorFlow[11] using multiple Machine Learning algorithms including SVM with different kernels, random forest classifiers, logistic regression, adaboost, decision trees and the K-means algorithm [7], [8], [9], [12].
After finding the accuracy for each of these, an algorithm can be developed to increase accuracy of the system. Each parameter will be divided into at least three segments which will aid in clustering in the case of K-means algorithm and should provide clear trends. Also based on the classes of each parameter, we can generate possible combinations and their effects, similar to a decision tree. A hybrid application framework[13] like Ionic will be used for the application using generated model.

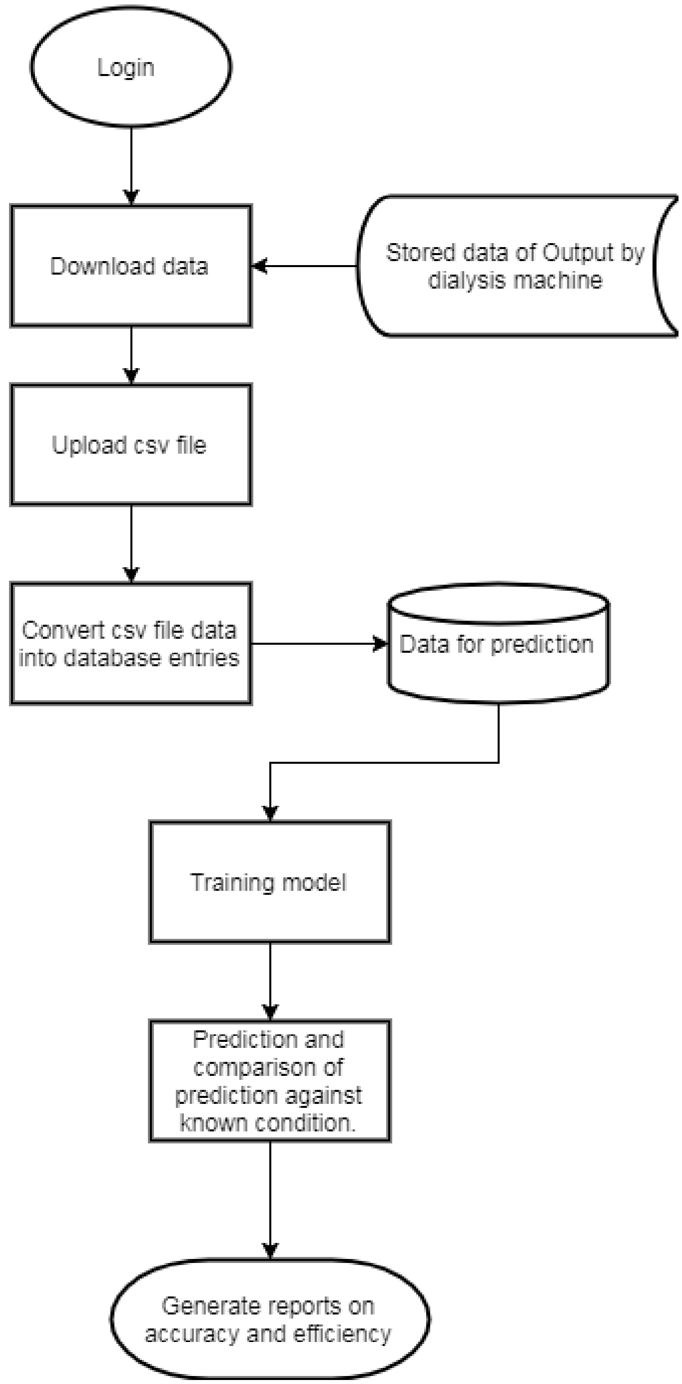

Fig. 3. Flow of system

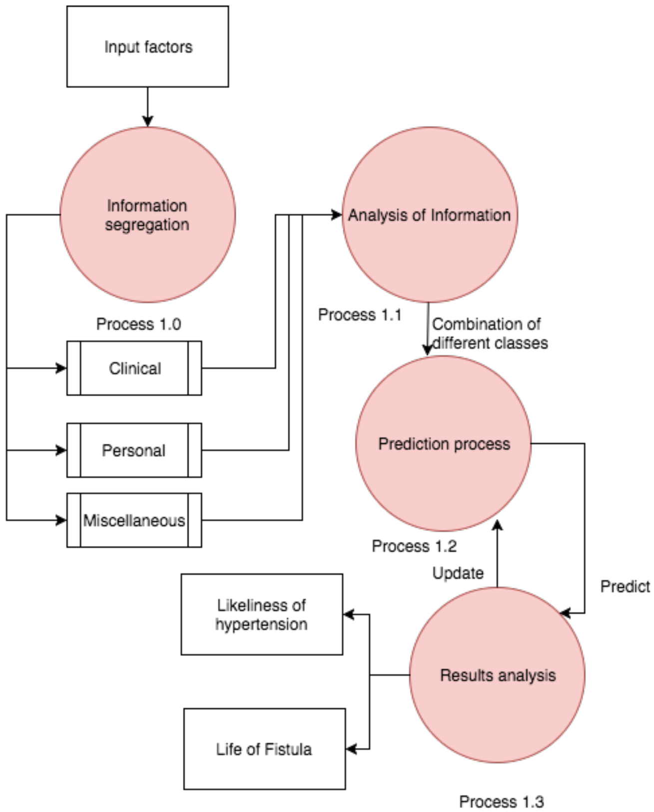

Fig. 4. Level 1 DFD

VII. Evaluation Details

All initial predictions made by the system must be compared with ultrasound doppler scans[5] to ensure that the system is generating accurate results.
Ai= 1 if result matches.
= 0 if no match
Accuracy = Summation(Ai)/ Count(A)
Where A is a matrix of comparison of output

VIII. Work done thus far

We have successfully identified important factors to be considered for the prediction system, modules that will be present in the system, flow between the modules and considered multiple algorithms for inclusion in the system. We have looked at the data of a failing fistula and a healthy one and used the same to understand the parameters better.
The results of the same are as follows:
The session 1 stats show an AVF which is failing. In Fig 5, the Session 1 blood flow is much under the recommended 300ml/min. Session 2 shows an acceptable blood flow, slightly above 300 ml/min.
The venous pressure in a healthy AVF should be increasing with duration of dialysis. In Fig 6, this is the case in Session 2, but not in Session 1 where it is dropping with time.
The UF speed should be as close to 1 as possible. In Fig 7, the low speed in Session 1 indicates that ultrafiltration is not

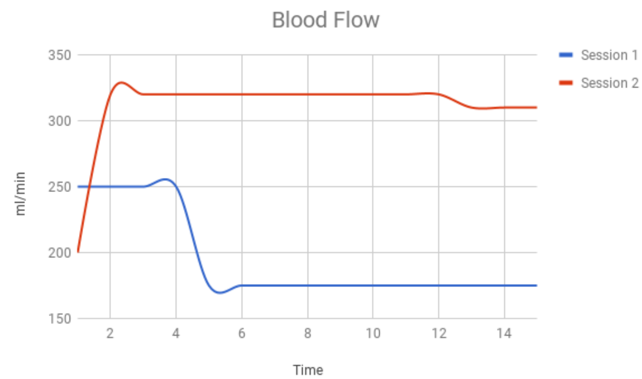

Fig. 5. Blood Flow

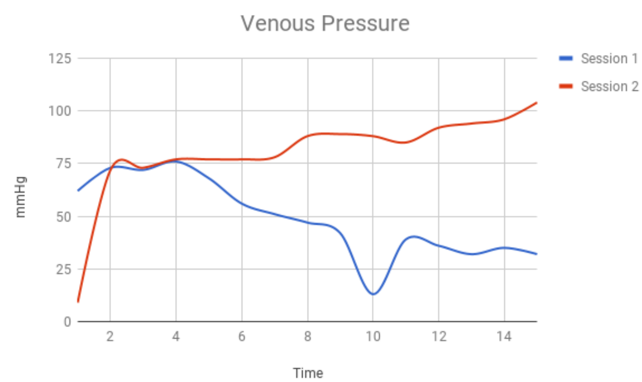

Fig. 6. Venous Pressure

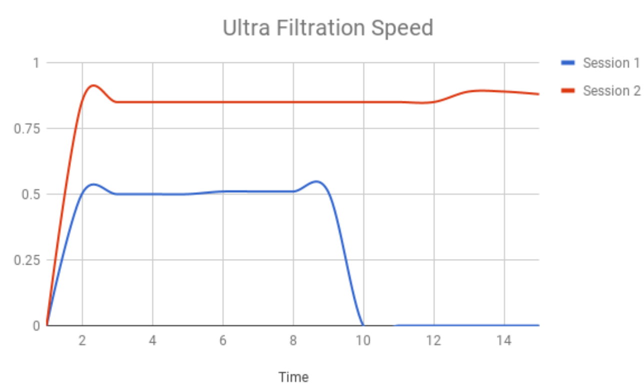

Fig. 7. Ultrafiltration Speed

going at an acceptable rate.

The convection current in the artificial kidney creates a

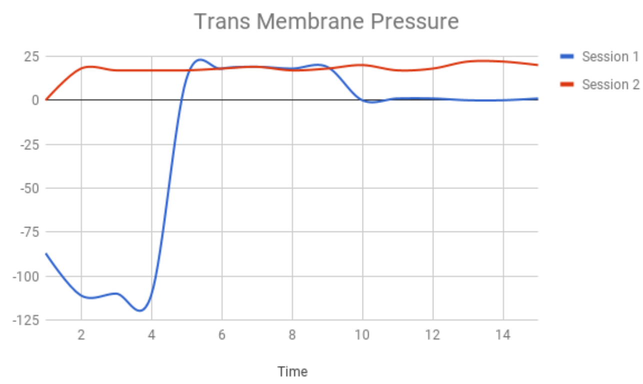

Fig. 8. Trans Membrane Pressure

positive pressure difference allowing wastes to be filtered out. In Fig 8, this is not the case in Session 1. It is the case in Session 2.

The final kT/V value at the end of a dialysis session should

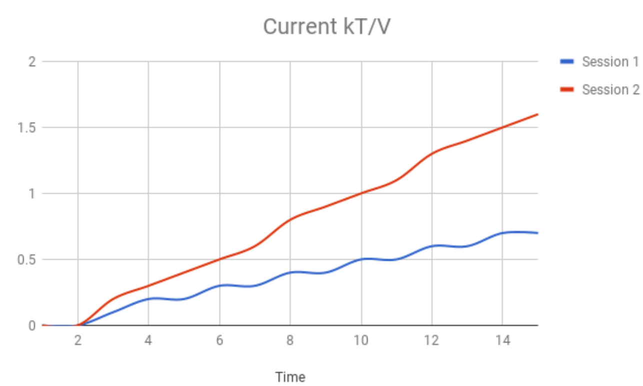

Fig. 9. Current kT/V

be at least 1.2, preferably higher. Fig 9 shows that in Session 1, the kT/V value is an ineffective 0.7. In Session 2 it is an effective 1.6.

IX. Conclusion

With the passage of time, the arteriovenous fistula is likely to fail. If or when this happens, the patient will be inconvenienced with having a catheter while a new fistula can be developed. This is extremely unfortunate because using the ultrasound doppler test [5] to check health of fistula is not feasible. Since dialysis is a continuous process, the dialysis machine is a treasure trove of information which can be used by our system to predict the health of the fistula without any expensive tests. Having this data declared at every dialysis session allows for continuous monitoring of the fistula over time. Thus if it is likely to fail, a new fistula can be created at another location and the current one can be used till it fails. In the meantime, the new fistula develops and dialysis can shift to it. This system when developed will improve quality of life of the patient due to foregoing the catheter while also reducing medical costs of scans like the ultrasound doppler[5].

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