Assignment 2

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1. Introduction

Remote patient monitoring (RPM) has rapidly become a common approach for completing patients' data collection in the last decades. RPM is a telehealth technology that enables the collection of patients' data in an outside location instead of a medical center, such as at home or in a remote area. Vegesna (2017) reported that RPM enhances the ability of clinicians to monitor patients and make decisions in non-traditional settings by combing digital technologies like smartphones and computers. Implementation of RPM system realizes real-time monitoring and information storage ensure effective two-way communication between patients and health providers which could improve patients' experience. One of the biggest purposes of RPM is to promote and intervene in compliance behaviors in chronic treatment like hemodialysis (Lim, 2016; Hale, 2016), as patient compliance is essential to ensure high-quality treatment results (Saran, 2003; DiMatteo, 2004). Hale (2016) proved that, compared with usual care, RPM could significantly improve both self-report and medical adherence during therapy. DiMatteo (2004) also stated that non-compliance behavior (e.g., ignore medical recommendations, resist attending sessions, and rebellious mood) would waste resources and money for clinics. In the US, the cost of non-compliance patients in 2015 was up to $290 billion and most of them paid for unfollowing regulations (Haas, 2019).

In a traditional setting, non-compliance is always detected by demographics, lifestyle, mental status, and external support. Leggat (1998) tried to discover the relationship between nonadherence and demographics include age and race. Lifestyle (e.g., nutrition, smoking, and drinking) and mental status like depression have been proved to have a negative impact on compliance during treatment (Ibrahim, 2015; Kutner, 2002; BURMAN, 1997). Moreover, external support especially social support and patients' wellbeing have a positive correlation with compliance (Wang, 2020; Kimmel, 1998; Ibrahim, 2015).

Communication is not be emphasized or ignored by most research in the center-based treatment as it is difficult to be recorded or evaluated through standards. This problem has been addressed with the prevalence of RPM which means more methods and factors can be utilized to make a better prediction of non-compliance and take action in advance. By using the digital systems, patients are encouraged to write messages or send emotions after each session and all information would be stored automatically.

In this study, the aim was to resolve the ignorance of communication by analyzing the relationship between the frequency of text messages and the compliance with combined emotions. Several machine learning methods would be used to classify and calculate the accuracy of predictions. The result will prove whether the number of messages would affect compliance and the role of emotions in communication. More suggestions about how to improve health care services and more tips about communications can be proposed to increase patients' satisfaction and reduce nonadherence. The rest of paper contains introduction of hemodialysis to understand the background and gaps, followed by methods introduction to explain the algorithms of different machine learning methods.

2. Background

2.1 Hemodialysis

End-stage renal disease (ESRD) occurs when kidneys lose abilities that filter wastes and excess fluids from the blood to maintain the normal operation. Kidney transplant is one way to cure, but only 25% of ESRD patients can accept a functioning transplant instantly (Collins, 2005). For patients who are on a waiting list or unsuitable for kidney transplantation, hemodialysis is essential for them to survive (KRAUS, 2007; DE FIJTER, 2010). Hemodialysis is a renal replacement therapy that establish a connection between person and machine to filter the wastes in the blood and return blood finally. Normally, ESRD patients need to accept hemodialysis three times a week and each session takes 3 to 4 hours (Sockrider, 2017).

2.1.1 Non-compliance Behavior

In center-based hemodialysis, non-compliance definitions always relate to personal behaviors which are evident and able to be directly observed like skipping or shorting sessions (Kimmel, 1998; Ibrahim, 2015; Kutner, 2002; Leggat, 1998). This classic character is utilized in most research to analyze the relationship between risk factors and survival. In addition, the medical parameter is another aspect to be considered during identify non-compliance behavior. Although this aspect is impossible to straightly point out the unusual status, more accurate judgment can be achieved by combining personal behaviors. Both Leggat (1998) and Ibrahim (2015) regarded inter-dialytic weight gain (IDWG) as one of standard to assess non-compliance which is one of the medical parameters to measure the fluid taken between two hemodialysis sessions. A higher IDWG score would lead fluid overload which is associated with a high risk of hospitalizations and causes poor outcomes of treatment (Wong, 2016). Normally, the patients were considered non-compliance when IDWG exceed 5% of dry weight (DW) or more than 1.5kg. Therefore, non-compliance behavior definition in the traditional medical settings includes two aspects, personal behavior, and medical parameter respectively. Both could provide help to classify patients and analysis the key factors with nonadherence.

2.1.2 Factors

There are several factors that can be used to predict noncompliance behaviors in traditional medical settings, and they are grouped as internal (lifestyle and mental status), external (external support), and controversial (demographic).

Internal indexes are also known as psychological or behavior impact which means these are related to patients' mental status and lifestyle includes depression, alcoholism, and smoking. Depression is one of the classic mental statuses which would bring a negative impact on adherence. Both Somerset (2011) and Ibrahim (2015) indicated that patients who suffer from depression or stay in depression symptoms have more risk to appear nonadherence behavior. The depression score of non-compliant patients was significantly higher than others. In addition, lifestyle such as alcoholism, smoking, and malnutrition is another internal influence that can be regarded as the main antecedents of persistence. Research shows that alcoholism is one of the most important risk factors closely link with non-compliance (BURMAN, 1997). Meanwhile, Leggat (1998) and Kutner (2002) stated that smoking is another strong predictor which would reduce motivation and increase sensitivity. Moreover, Ibrahim (2015) and Ikizler (2013) observed that adherence is also associated with nutritional status, which is another factor to predict the patients' behaviors in advance.

External impact always come from outside resources include social support and patients' wellbeing which would improve the quality of life and bring a positive influence on patient. Several studies have proved the significant relationships between compliance and social support or quality of life. Lower levels of social support and poor quality of life would directly increase the negative perceptions and possibility of skip the session in therapy (Wang, 2020; Kimmel, 1998; Ibrahim, 2015). To minimize the number of compliance and refine outcomes of therapy through clinic, homelessness also needs to be solved as homelessness is strongly related to the failure of treatment in many countries like New York, England, Ireland, and Denmark (BURMAN, 1997).

Therefore, both internal and external indicators are essential to predict nonadherence during traditional treatment in clinics or medical centers. However, controversial factors exist which means the elements have arguments, and hard to ensure the impacts and relationships with compliance. Demographic that includes age and race is one of most common controversial parts of the prediction. Many researchers like Leggat (1998) and Shamaskin (2012) believed that age is vital in prediction as younger patients are more likely to appear non-compliant behavior than older patients. Ibrahim (2015) reported a contrary conclusion which is no significant impact has been observed between age and compliance. A similar situation occurs on the education level which is another classic factor. Both Leggat (1998) and Ibrahim (2015) stated that educational level does not obviously contribute to compliance, but Wang (2020) and Bland (2008) emphasized the importance of helping lower education patients understand the progress and content of the therapy to increase their positivity. More studies may focus on finding the relationships between different factors and observe whether these controversial factors are associated with other direct factors and can be group as one element.

2.2 Home Hemodialysis (HHD)

In traditional hemodialysis sessions, patients need to go to the clinics by themselves, which generates lots of transportation expenses. Meanwhile, it also takes many public resources as the clinic has to arrange stuff for operation and supervision. The processes would occupy huge time and cost for both patients and health care providers that is one of the main reasons for home hemodialysis (HHD) became the prior choice and the global trend. HHD is a cost-effective treatment method that started in the early 1960s. It allows patients to undertake three weekly sessions of treatment at home by themselves. In Australia, the cost of achieve dialysis at home was about 30% lower than in center which means more budget can be utilized to supply a better service (Agar, 2019). Patients are also enjoying the freedom, flexibility and better quality of life which could help them re-establish self-identity and improve compliance in HHD (Cases, 2011). Although a big difference exists between two types of treatment, the definition of non-compliance behavior is similar and remote settings are more biased to personal behavior judgments like frequency of attendance and duration of sessions. More effort is spent on

analyzing the barriers and how to reduce the impact.

2.2.1 Home Hemodialysis System

Compared with the clinic environment, remote therapy is established through online software like apps to help health centers and patients to monitor in time. Data recorded by patients themselves were stored and conveyed to health professionals. Professionals would review the data and give some responses if there are some issues in sessions (Liu, 2017). Implementation of RPM system which realize real time monitoring and information storage ensure an effective communication between patients and health providers and refine patients' experience (Ong, 2016).

There are three main components included in the HHD system (Liu, 2017), application, cloud server, and Web app respectively. The first component is conducted on the mobile device, which means patients have to install the HHD app on their own phones. Basic functions display on the dashboard to help patients record their sessions like recording weights or blood pressures data and providing feedback. Data of sessions would be uploaded instantly with an internet connection. The cloud server which builds on Window Azure services is the second component. It provides a safe platform place to store patients' data in the database. This information can be analyzed at any time through the website which is the last component hosted by Azure to ensure privacy and security. Health professionals can know the status of patients with different parameters on the website to decide future therapy schemes and send feedback.

2.2.2 Barriers

In the remote monitoring context, more factors have been considered which are not emphasized in the traditional setting but are essential in remote monitoring. Part of the factors could bring benefits and strength to prohibit nonadherence, others are barriers to patient acceptance and adoption of the digital environment.

The strength of remote monitoring can be divided into two parts based on different stakeholders, patients, and clinics respectively. From the perspective of the patient, the biggest benefits are freedom and flexibility. Cases (2011) confirmed that patients enjoy the freedom and flexibility which could help them re-establish self-identity and improve compliance of therapy. Plummer (2017) also highlighted the importance and necessary of flexibility in the unsupervised treatment which could increase the attendance rate in each session. Implement of remote patient monitoring systems could also bring benefits for health care providers like saving money and resources. One of the most important reasons about home hemodialysis is encouraged is lower costs and resources occupy (Agar, 2019; Walker, 2014). By reducing costs and resource utilization, more attention can be paid to the quality of service to enhance patient motivation and reduce mortality.

Simultaneously, many factors with negative influence also appeared which could aggravate noncompliance. For example, social isolation, self-operation, and family burden are the main obstacles patients need to confront. Cafazzo (2009) proved self-cannulation and family burden are primary barriers for patients to adopt home hemodialysis. Lack of confidence and fear of frequent needles themselves conquer the perception of pain and become one of the most important inhibitors of compliance behavior. Complex dialysis therapy is also hard for family members which would increase the burden and fear to bear responsibility which would be completed by care providers in traditional treatment. This opinion is confirmed again by Walker and Hanson in 2015. In addition, they highlighted another important obstacle, social isolation. Many patients mentioned that being alone is the reason why they refused to choose home hemodialysis.

Although many passive indicators exist in the digital environment, compared with center hemodialysis, the implementation of remote patient monitoring systems displayed better adherence, and the global trends in home hemodialysis will not change (Agar, 2019; Berman, 2011). More research can focus on improving services to increase satisfaction and acceptability to reach a better outcome and adherence.

2.3 Prediction Method

Logistic Regression method is one of the most popular machine learning algorithms during analyzing the relationships or independent of different factors with compliance (Leggat, 1998; Saran, 2003; BURMAN, 1997; Cafazzo, 2009; Kutner, 2002). Logistic regression given in Cramer (2002) is widely used in classification or prediction in the medical field and provides easier implementation with effective training ("Logistic regression," n.d.). Saran (2003) utilized logistic regression to identify predictors of non-compliance (e.g., race, age, gender, and depression) and discover the associations between facility practice patterns and compliance. Logistic Regression was also mentioned by Kutner (2002) which was implemented to prove the influence of non-compliance by smoking and successfully ensure the negative impact of smoking after comparing and analyzing the results.

Cox proportional hazards models (Cox, 1972) is another common method that is also suitable in medical statistics. The model is always used to justify the correlations between the survival time of patients and factors which have been identified to predict. Both Saran (2003) and Leggat (1998) utilized cox proportional hazards models in survival analysis which focus on estimate death and hospitalization risk associated with different measures of non-compliance like race and country. The result showed that black is more likely to drop out a session compared with white which has 88% of compliance.

2.4 Current Problem

Compared with traditional settings, remote treatment collects more digital and accurate information from patients like medical parameters, emotional records, and messages. With the popularity of HHD, the electronic communication service has been implemented in most applications to replace face-to-face consultation. Bauer (2021) stated that communication could improve understanding of treatment and assessing symptoms by patients' behaviors to support monitoring. The importance of analyzing patient-provider communication has also been emphasized by many researchers but there is little evidence that communication can refine self-management and clinic interventions to affect adherence (Roter, 2009; de Jong,

2014). Most research just cites patients' messages to prove and justify points (Walker, 2015; Cases, 2011; Diefenbach-Elstob, 2017). Message content usually regards as an argument or example to increase the persuasiveness of opinions. However, communication can be considered as a new factor to discover the impact to adherence. Although Roter (2009) proposed a general pattern to classify communication as a symbol of different levels of compliance to better understanding the relationship between adherence, few studies focus on analyzing a specific aspect of communication like message frequency to discover whether these messages imply patients' emotions and attribute changes that would impact compliance. In addition, communication factor analysis may also help solve the controversial indicators and provide a new direction to upgrade clinic services and patient's satisfaction as messages information grouped variables like education levels and emotions together which allow considering and analyzing more factors at the same time.

2.5 Multi-modal Communication Theory

Multimodality is a basic feature of human language which means multiple signal channels are used simultaneously when communication (Taglialatela, 2015). Louwerse (2012) proved the synchronized behavior in multimodal communication. The relevance evidence of this opinion like unintentional synchronization behavior (e.g., body posture, gesture, and movement) has been found by Richardson (2005) and Schockley (2003) which means person's behavior can be impacted by another one during communication. In addition, much research emphasized the influence of emotional expression and interaction (Knutson, 1996; van Kleef, 2009, Mehu, 2015). They mentioned that emotion should also be regarded as a communication signal as both emotional expressions and reactions could change people's perceptions and behaviors. The combine of emotional and symbolic components can effectively increase the transformation of information to help people better understand the content and make appropriate responses in conversations.

Communication is significant for patients and health providers. A suitable communication strategy can improve effectiveness of consultations which would impact patients' satisfactions

and adherence (Farquharson, 2011). Roter (2009) and Bauer (2012) mentioned that patient compliance is also related to several factors in communication, such as the frequency of questioning, positive or negative status, and the amount of information. Moreover, in digital environment, the impact of text-messaging on patients' perceptions has been confirmed by several researchers (Nsagha, 2020, Välimäki, 2012). Therefore, communication is an important aspect that affects patient compliance, and it is necessary to conduct more research on communication factors such as the amount of information and emotions.

Combined with the multimodal communication mentioned before, there are two hypotheses are proposed in the study to better access the relationship between communication factors and patients' compliance. Both number of messages and emotions factors would be evaluated by different methods.

Hypothesis 1: The number of text messages can be used to predict remote monitoring patients' non-compliance behavior.

Hypothesis 2: The emotion conveyed by messages imply remote monitoring patients' compliance.

3. Method

3.1 Data source

My Home Hemodialysis is a mobile application that has been implemented in several hospitals like Black hospital for ESRD patients to achieve better remote treatment. About 15 years of data came from 338 remote monitoring patients have been collected. From 2014 May to 2021 March, 49804 sessions were recorded and available for further analysis. To increase the reliability and accuracy of results, incorrect data has been removed after data cleaning, include inactive users and unusual durations. Inactive users would be considered as virtual users who are researchers or clinical nurses. This situation always occurs as researchers and nursers would also create accounts on the app and simply played around for a few days to better understand or test some functions on the app. This part of users is not included in our research area, so the users with less than ten sessions would be deleted. The second condition is unusual duration which means too long or too less time in sessions. Normally, a dialysis session lasts 6 to 7 hours, but parts of durations in the data are not in this period. It usually caused by patients forgetting to click "End Session" after starting a session entry. Therefore, unusual duration data would be treated as a normal session (6-7 hours) and for patients who has a low entry would be removed.

3.2 Non-compliance Behavior Definition

Skipping session is a classic character that has been utilized in most of research to distinguish con-compliance behavior and majority of patients take three session per week (Kimmel, 1998; Ibrahim, 2015; Kutner, 2002; Leggat, 1998). In this study, the definition of non-compliance behavior is attendance time less than three in a week. The number of weekly sessions would be counted and mark the weeks with less sessions. The data would be divided into two groups after calculating, normal group and nonadherence group respectively. Several methods include logistic regression and Neuro-linguistic programming would be implemented to analyze the relationship between number of messages and non-compliance in hemodialysis.

3.3 Statistical Analysis

Logistic regression is suitable for proving the relationships between categorical variables by testing the hypotheses (Peng, 2002). To discover the impact of communication to patients' compliance, two hypotheses have been proposed:

Hypothesis 1: The number of text messages can be used to predict remote monitoring patients' non-compliance behavior.

Hypothesis 2: The emotion conveyed by messages imply remote monitoring patients' compliance.

Independent variables are the number of messages and emotional changes. Compliance is a dependent variable that has two values (Yes or No) depending on the number of weekly sessions. The logistic regression would be implemented to confirm the correlation between independent and dependent variables and Nature-Language Processing (NLP) would be applied to evaluate and identify the emotions in the text messages.

The dataset would be divided into three group, train, validation, and test respectively ("Training, validation, and test sets," n.d.). Training data contains 60% of random data used to fit parameters of logistic regression model and both validation and test data occupy 20% of randomly defined data from dataset. However, validation data focus on unbiased access the performance of models by tuning hyperparameters and test data is to evaluate the final model which have a good performance on training data.

The cross-validation (CV) method would be implemented to access the performance of final prediction methods. CV is a widespread strategy for algorithm selection that split data into k groups and runs k times. Each time just one group would be used to evaluate, and others are applied to training. Finally, the cross-validation accuracy is the mean of results from k times. Compared with other evaluation algorithms, CV ensures the greatest possible amount of data for training and reduces the risk of overfitting as the training sample is independent (Arlot, 2010).

3.4 Contribution

In this study, the impact of two communication factors (the number of text messages and emotion changes) can be confirmed by fitting machine learning methods and analyzing the accuracy results. This is future research based on previous studies which proved that communication between patients and health professionals is important and it is necessary to have more studies on communication factors and patients' compliance. The result of this study might solve part of problems and provide a new direction to improve quality of life, isolation, and compliance. In addition, more suggestions about how to upgrade health service and recommendations about communication strategies can be proposed to help health providers establish a better environment for patients to accept HHD, increase their satisfaction and reduce nonadherence.

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