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Modeling hybrid rough set-based classification procedures to identify hemodialysis adequacy for end-stage renal disease patients

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ABSTRACT

Healthcare problems observed in the majority of end-stage renal disease (ESRD) patients regarding hemodialysis (HD) treatment are serious issues for the Taiwanese healthcare services, and an interesting topic is thus the adequacy of HD therapy. This study successfully models a hybrid procedure to measure HD adequacy to assess therapeutic effects and to explore the relationship between accuracy and coverage for interested parties. The proposed model has better accuracy, a lower standard deviation, and fewer attributes than the listed methods under various evaluation criteria. The study results are useful to subsequent researchers to develop suitable applications, and to ESRD patients and their doctors to ensure satisfactory medical quality.

1. Introduction

Taiwan has the highest prevalence in the world of end-stage renal disease (ESRD). ESRD patients thus provide an interesting and important research topic. Chronic kidney disease (CKD) generally undergoes five stages, and CKD patients progressively lose renal function over months or years until they reach stage five—renal failure. The renal failure stage is thus a well-known uremia, also known as ESRD [1]. ESRD requires special curative treatment. Regarding the optimal choice of therapeutic method for ESRD patients, conservative therapies involving simple medical management are feasible, but such patients eventually require dialysis or renal transplantation. Although renal transplantation may significantly alleviate the cost of dialysis, obtaining a healthy kidney from a living donor is difficult. The shortage of donated organs available for transplantation has recently become a universal phenomenon; therefore, dialysis has become the only practical alternative to renal transplantation and is a widely performed and relatively safe healthcare procedure. Dialysis removes waste materials (e.g., potassium and urea) and free water from the blood. Practically, two categories of dialysis exist, hemodialysis (HD) and peritoneal dialysis. Although both can decrease potential kidney trauma and damage, HD is the most commonly used treatment in hospitals and clinics or at home because it achieves a good quality of life (QOL) and quality of service (QOS) for ESRD patients and their doctors, respectively. The above statement clarifies that the healthcare problems faced by ESRD patients receiving HD therapy are academically interesting. Research on HD adequacy and associated therapeutic effects is useful for all interested parties wishing to analyze HD performance.

Measuring HD performance definitely requires an effective method of evaluating HD adequacy. The literature [2] has identified four indicators associated with HD adequacy, including the urea reduction ratio (URR), clearance rate per volume (named Kt/V), albumin levels, and hematocrit. Furthermore, numerous studies [2–5] have further demonstrated that URR is commonly used to determine HD dose and has been used to assess HD adequacy in different diseases. Consequently, this study considers URR an effective principle for measuring HD adequacy. Although methods to address the adequacy problems associated with HD therapy have considerably improved recently, information on classification (also called forecasting) models based on statistical methods and artificial intelligence (AI) techniques to classify URR measurements remains insufficient. This insufficiency is perceived to be the main barrier to more extensive valuation and includes: (1) the lack of decision rules to explain the experimental data, (2) the lack of effective methods for identifying determinant attributes, and (3) the knowledge gap associated with rough set theory (RST) on AI techniques. In particular, RST methods have emerged as an alternative to conventional statistical methods for classification and have achieved great progress when applied to real-world problems in various domains, such as energy [6], finance [7], and medicine [8], as have inspired both practitioners and researchers. In fact, it has been observed that a direct trend in the generalization of knowledge is to build a rule-based model to explain the data and provide logical and powerful explanations

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based on literature review [9,10]. Importantly, there is increased interest within healthcare services in using RST to develop reliable alternates to classification problems in the context of HD therapy, and various interested parties are conducting trials.

This study attempts to develop a hybrid classification model based on rough set (RS) classifiers to address HD adequacy measurements to promote doctor–patient relationships and communication between ESRD patients and their doctors. This study has the following objectives: (1) to develop a reliable model for effectively predicting HD adequacy for healthcare services; (2) to identify the key determinants used to classify URR and influence HD adequacy; (3) to generate comprehensible decision rules that interested parties can apply in knowledge-based healthcare services; (4) to examine various AI models to further assess the performance of rough set classifiers under evaluation criteria; and (5) to explore the relationship between coverage and accuracy, and coverage and rule number.

The remainder of this paper is organized as follows. Section 2 introduces the related literature. Next, Section 3 describes the proposed model and presents an empirical case study, and Section 4 discusses the findings. Finally, Section 5 draws conclusions and recommends future research directions.

2. Related literature

This section reviews the issues related to HD adequacy for uremia patients, including the urea reduction ratio, feature selection methods, rough set theory, rule induction methods, rule filter, and AI algorithms used for classification.

2.1. Urea reduction ratio

Generally, the kidneys are major organs located within the abdominal cavity in the human body and produce liquid waste from urine by filtering it from the blood. In medicine, kidney function and kidney disease are classified into five stages, each with corresponding treatment plans based on the decrease in the glomerular filtration rate (GFR). Qualitatively, Stages 1 and 2 involve kidney damage and mildly reduced kidney function, respectively. Meanwhile, Stages 3 and 4 involve moderately and severely reduced kidney function, respectively. Finally, Stage 5 is kidney failure, which is usually characterized by signs and symptoms of uremia requiring kidney replacement therapies, such as dialysis or transplantation [11], and this stage is best known as uremia or ESRD. During the uremia stage, dialysis is the only method of filtering toxins to avoid damage to the body and eventual death or extension of life other than through receiving kidney transplantation. HD treatment is the major form of dialysis therapy and is the most widely used renal replacement therapy (RRT) for ESRD patients. A good approach to understand the outcome of HD treatment is to measure the adequacy of HD.

Professional nephrology groups have established four criteria to measure HD adequacy, including URR, Kt/V, albumin, and hematocrit [4], in the form of clinical practice guidelines. First, in research fields, measurement of the relative reduction of the blood urea nitrogen (BUN) concentration caused by dialysis is associated with a specific indicator of HD adequacy for the URR [4,12]. The efficiency of the dialysis membrane is measured by whether it adequately removes waste products from ESRD patients [13]. Thus, the outcome of HD therapy is focused on achieving a URR of 65% or higher, or on reducing the BUN to 35% or less of its pre-dialysis level [4]. Furthermore, Szczech et al. [5] stated that URR is the main determinant of a HD dose in the United States. Second, in practice, the Renal Physicians Association and the National Kidney Foundation recommended that the minimum level of HD adequacy for ESRD patients is equivalent to a URR of 65% [4]. Consequently, using URR alone to measure HD adequacy may be appropriate for both academics and practitioners. The following formulated expression represents URR: $\mathrm{URR}=(1-\text{post-dialysis BUN/pre-dialysis BUN})\times 100\%$.

2.2. Feature selection methods

A key aspect of the knowledge discovery process used to mine knowledge rules from data is feature selection, which has been a fertile field of research in statistical pattern recognition [14], machine learning [15], and data mining since the 1970s [16]. Feature selection is used to select the most useful and valuable information from large volumes of data [17] and has the following potential benefits: (1) model simplification (feature selection reduces data dimensionality, facilitates data visualization, and decreases search costs (time and money)), (2) faster model induction and structural knowledge (feature selection reduces storage requirements, accelerating the learning algorithm and increasing its effectiveness as the amount of data decreases), and (3) ease of interpretation (feature selection improves data mining efficiency during the final data interpretation stage). Thus, feature selection is necessary and can evaluate attribute usefulness, remove redundant or irrelevant attributes, and select the most relevant attribute.

In applied techniques, feature selection algorithms are broadly categorized into three types: filter model, wrapper model, and hybrid model [15,17], each with different evaluation criteria. First, the filter model relies on general training data characteristics to determine feature relevance based on data alone, independent of classifiers [15], using measures of distance, information, dependency, and consistency. Second, the wrapper model requires a single predetermined learning algorithm and uses the performance of that algorithm for attribute evaluation and selection. The wrapper model performs well but is computationally costly. Finally, the hybrid model uses an independent measure to identify the best subsets for a given cardinality and applies a mining algorithm to select the best subset across various cardinalities [17]; thus, it enjoys advantages compared with the two previous models. In real-life field experiences, various feature selection methods—for example, Cfs, Chi-square, Consistency, Gain Ratio, and InfoGain—are well known and are applied to study domains to obtain highly satisfactory solutions. Thus, this study experiments with five methods of feature selection as follows: (1) for Chi-squared value attributes: calculating the value of the chi-squared statistic compared with the class; (2) for GainRatio value attributes: measuring the gain ratio relative to the class; (3) for InfoGain value attributes: measuring the information gain relative to the class; (4) for OneR: using the training data to value attributes using the OneR classifier rather than cross validation; and (5) for ReliefF value attributes: repeated sampling and considering the value of the given attribute for the nearest example of the same and different classes.

2.3. Rough set theory

Traditional computational techniques such as statistical methods require a strict assumption of linear separability or normality but lack explanatory and interpretative power to the given datasets. Thus, many studies have used soft computing architectures to construct models to process qualitative and quantitative problems in the medical field more recently than statistical methods, and offer superior performance to both practitioners and scholars. In particular, traditional computational techniques used in knowledge discovery and data mining strive to achieve absolute accuracy; however, RST is a soft computing technique