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A Study on the Assessment of Prosthetic Infection after Total Knee Replacement Surgery

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Abstract**—**This study, for its research subjects, uses patients who had undergone total knee replacement surgery from the database of the National Health Insurance Administration. Through the review of literatures and the interviews with physicians, important factors are selected after careful screening. Then using Cross Entropy Method, Genetic Algorithm Logistic Regression, and Particle Swarm Optimization, the weight of each factor is calculated and obtained. In the meantime, Excel VBA and Case Based Reasoning are combined and adopted to evaluate the system. Results show no significant difference found through Genetic Algorithm Logistic Regression and Particle Swarm Optimization with over 97% accuracy in both methods. Both ROC areas are above 0.87. This study can provide critical reference to medical personnel as clinical assessment to effectively enhance medical care quality and efficiency, prevent unnecessary waste, and provide practical advantages to resource allocation to medical institutes.

Keywords**—**Total knee replacement, Case Based Reasoning, Cross Entropy Method, Genetic Algorithm Logistic Regression, Particle Swarm Optimization.

I. Introduction

AGEING of population has become a prominent problem in Taiwan. According to the statistics conducted by Ministry of the Interior of Taiwan in 2012, the ageing population has reached 2,600,000, accounting for 11.15% of the total population. With the rapid advent of technology and medical care, people's average lifespan is increasing and the birth rate is decreasing, causing a steady increase on the ageing population percentage in Taiwan. Lin pointed out that population in Taiwan has indicated and shown a significant ageing trend [1]. As public health education is becoming widely common and popular and medical care techniques are continuously advancing, the average lifespan of citizens in Taiwan increases relatively, contributing to the growing elderly population and the increasing number of patients in illnesses and conditions associated with natural degeneration of the human body. Many among the elderly population are at high risk of knee osteoarthritis. Total Knee Replacement (TKR) can effectively alleviate symptoms, correct knee destructions, and improve the joint functions. Based on the statistics provided by National Health Insurance Administration Bureau, the patients in need of total knee replacement surgery exceed 12,000 every year in Taiwan. Hsu maintained in his 2003 study that among all cases of total knee replacement, osteoarthritis accounts for roughly 90% and its causes generally include natural degeneration, past injuries, and chronic overuse of the knee joints [2]. Treatments for arthritis consist primarily of more conservative approaches such as reducing weight, taking glucosamine supplement, and etc. If such treatment plan doesn't alleviate conditions or diminish pains, a surgery will be recommended. According to National Health Insurance's Amount Information Website, about 10,000 patients receiving TKR and the number is on the rise every year [3]. Among all, the majority of knee osteoarthritis patients improve their pains significantly following the procedure, and the success rate is as high as over 90%. However, there are several risks following a total knee replacement, the highest risk factor is postoperative infection. Once complications occur in total knee replacement surgery, the infections are the most destructive and disastrous, causing removal of the artificial joint and reconstruction of the procedure, which can cost much more money and energy [4].

Haleem stated that antibiotics are required to treat patients with minor infections, whereas complete removal and clearing of artificial joint materials is a must for those with severe infections. Only when infections are under control will new artificial joints be re-implanted, resulting in extra surgical costs, longer hospital stays, and inflictive sufferings on patients [4].

Statistics data provided by the National Health Insurance Administration show that on average there are about 20,000 patients in Taiwan having TKR during 2009 to 2011, increasing at additional 1,000 or more surgical cases annually. The health insurance provisions on total knee replacement materials are at about 11 billion New Taiwan dollars. Additionally, the costs for the surgeries are roughly 26 billion dollars. If the procedure were not covered by the insurance, the out-of-pocket cost for individual TKR patient would have been NT$130,000 to NT$140,000, which enlists the surgery as high cost [3]. This study attempts to construct an evaluation system on postoperative deep infection in TKR through case base reasoning to provide information used for preoperative diagnosis by patients and medical institutes, with the objective to eliminate waste in healthcare resources on postoperative deep infections, alleviate and reduce risks of infections, and simultaneously effectively enhance medical care quality in Taiwan's current health insurance system.

II. Literature Review

A. Total Knee Replacement

Tsai stated that arthritis, at as high as 20% prevalence rate, is the most common disease causing pains and dysfunction of

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knee joints [5]. When symptoms cannot be greatly alleviated or improved regardless of treatments such as pain-relieving drugs, lifestyle modification, and assistance of clutches, etc., physicians will recommend arthritis patients to undergo total knee replacement surgery. The procedure involves replacing the damaged or diseased joint surfaces of the knee and cartilage with metal and plastic artificial components. In general, artificial joint comprises of the thighbone, lower leg bone, and knee cap. The knee joint of human body consists of tibia (shin bone) and fibula. Normally, the lower leg bone (tibia) will be replaced in TKR procedure. Depending on the condition of the kneecap portion of the knee joint, primary doctors of the patients might decide to replace knee cap surfaces.

TKR is one of the most common and important orthopedic surgeries in the century. The first case of TKR was conducted in 1968. As the advancement of surgical materials and techniques, the procedure is getting better and safer. Till now, TKR is a surgery that is very safe and highly accepted in patients; however, risks and complications, as illustrated in Table I, are still inevitable following the procedure.

TABLE I
SPECIFIC SURGERY-RELATED RISKS AND COMPLICATIONS

Complication	Explanation
Bacterial Infection	Possible infections are likely to occur after TKR. Severe cases of bacterial infection require replanting artificial joints.
Revision Surgery	Artificial knee joints (prosthetics) might become loose, break, or fall out and thus revision operation is required in patients who have initial TKR long ago.
Joint Dislocation	Recipients of the surgery often have dislocated joints due to misalignment of implanted joint devices and components.
Damaged Nerves	Nerves are subjective to damages during the surgery. Patients will feel numb and their activity functions might be affected.
Artilery Damages	Blood loss resulting from arterial damages during the operation is very common; however, removal of the lower limbs will be needed in severe cases.
Bone Fracture	Since bones are very fragile, fractures can occur during or after the operation.
Wound Healing	Wounds continue bleeding and tissue necrosis happens around the edges of the wounds. In severe cases, revision surgery is needed.
Deep Vein Thrombosis& Pulmonary Thrombosis	It is not rare to have deep vein thrombosis after the operation, and it is uncommon to cause pulmonary thrombosis on the contrary. Though pulmonary thrombosis is rare, it can lead death in severe cases.
Joint Stiffness (Arthrofibrosis)	It is not very common to have stiffness after the operation. However, patients in severe cases will require receiving of other treatments.

B. Particle Swarm Optimization

Particle Swarm Optimization (PSO), is brought to the table and presented by Kennedy and Eberhart, in which the computational concept was originally derived from the swarm behavior theory, as observing the movement of a flock of birds or a school of fish, each would move toward the optimal, or the best known, position through specific message transmitting methods between individuals [6]. The initial particle of PSO is generated randomly and the search for the optimal solution is done through continuous iterative searching. During each iterative process, the particle swarm changes its search direction using two different kinds of memory: the optimal solution of individuals (pbest) and the optimal variant memory (gbest). After the computation of PSO based on the above two methods, the typical particle's velocity and position is as shown in Fig. 1.

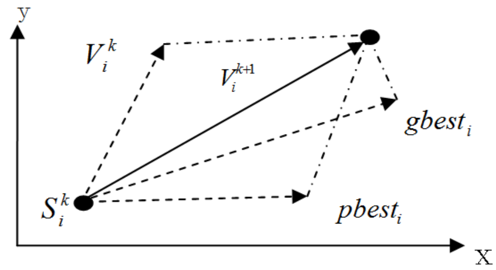

Fig. 1 Particle's velocity and position

Yen mentioned that particle swarm optimization has characteristics such that it can search distributively, has memory, required less components and has less variables, is easy to be used along with other algorithms, etc. [7]. Therefore, it has great potential in finding the optimal solutions.

C. Genetic Algorithm Logistic Regression

Lin stated that genetic algorithm logistic regression is developed from linear regression models, in which the critical value of p must be determined [8]. Generally, the critical value is 0.5; however, to determine whether or not one thing is successful, the most commonly used statistic approach is genetic algorithm logistic regression (GALR).

Chang and Hsu constructed three differentiable models using artificial neural network, logistic regression, and genetic algorithm logistic regression and adopted them to differentiate pancreatic cancer from acute pancreatic cancer and the results indicated that GALR has outperformed the other two models [9]. Aci et al. applied a new approach using a combination of K nearest neighbor algorithm, GALR, and Bayesian network to the classification of the five databases in UCI, and obtained better results [10]. The overall testing results are better than those in the past years.

D. Cross Entropy

Cross entropy (CE) algorithm is the Stochastic optimization technique proposed by Rubinstein, which was mainly used to estimate rare random incidents. It's also called Kullback Leibler divergence [11]. CE algorithm has the basic characteristic of maintaining the parameter probability distribution of solutions. Comparing to other randomizing techniques, such as GA or PSO, CE can be directly operated onto the samples of candidate groups.

In retrospect, CE algorithm can locate the optimal solution from the distribution of samples. To achieve such an objective, therefore, it generated new random variables using iterative method to update the parameters of the probability distribution before processing them to find the optimal solution.

E. Case-Based Reasoning

Case-Based Reasoning (CBR) is a new theory and research approach derived from the artificial intelligence field attributed to Schank and Abelson [12]. Tseng maintained that the main feature of CBR is its attempt to simulate the way people solve new problems based on their past experiences in similar situations [13]. CBR systems store past data, statistics, and problem-solving experiences in the case-base database, and when encountering new problems, CBR paradigm, by conducting a search to match the similar experiences about similar situations in the database and to prioritize these findings based on similarities, provides users a reference aiming to assist in the decision-making process.

F. Receiving-Operating Characteristic (ROC) Curves

Clinically more and more new evaluation techniques are coming out, and if the new technique is to use numbers to present diagnostic results, a "normal range" is required to be used as a basis to interpret the results. ROC curves are a perfect tool for many researchers to determine the "normal range". Schein maintained that the area under the curves can be adopted to assess the accuracy [14]. In 1973, Simpson and Fitter proposed that "area under ROC curve (AURC)" as an indicator to determine the distinguishment ability of diagnostic tools [15]. Based on this theory, to understand whether a model is good or bad, the accuracy of the model (ACC) or area under ROC curve (AURC) need to be compared as illustrated in Fig. 2.

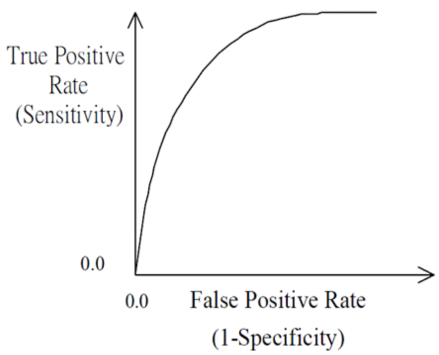

Fig. 2 ROC curve

G. K-Fold Cross Validation

K-fold cross validation is mostly implemented for the validation of auxiliary medical systems constructed by artificial intelligence. Dursun Delen pointed out that the advantages are to effectively reduce deviations and differences resulted from random sampling, especially when the sampling space is smaller, K-fold cross validation will not result in worse accuracy due to insufficient training sample selections [16]. Its disadvantages, however, is that it will take more time to process because to classify all samples into K clusters will require K models. Yeh mentioned that K-fold cross validation separates collected data into K clusters of equal size, of which sub-cluster is used as testing data, while the remaining K-1 clusters as training data [17]. After K times of testing, the average error of total K testing data is computed and obtained. This validation method aims to conduct testing on all data which can become testing and training clusters. This study also adopted such method to validate and evaluate the ability of the model.

III. Research Method and Approach

This study, through interviewing the specialists, used algorithms to compute the weight and to evaluate and verify system accuracy.

A. Data Collection and Pre-Processing

This study used authentic medical history data from the reporting library of each hospital in Taiwan that is stored in the health insurance database. Focusing on patients receiving TKR surgery as its research subjects, this study attempts to find the possible variable factors that might lead to deep infection following TKR procedure. After discussing with orthopedic surgeons and exploring the available literatures, main potential influencing factors are selected.

B. Computation of Significant Factor Weight

With the emphasis on postoperative deep infection after TKR, this study utilized PSO, GALR, and CE algorithms and used different parameter settings to compute the weight.

C. Model Construction and Evaluation of Postoperative Deep Infection after TKR

Regarding research method and design, three approaches of artificial intelligence such as PSO, GALR, and CE are adopted to build the assessment model of postoperative deep infection.

Combining case-based reasoning steps proposed by Anmodt, a cycling concept is constructed [18]. The following procedures are taken in accordance with the use of VBA verification program in Excel, use the overall data of which 80% is randomly selected as training model while 20% for testing purpose: (1) input patient information, (2) analyze patient information, (3) apply each algorithm to determine the weight, (4) select patient information, (5) apply similarity rule, (6) modify patient information, and finally, (7) save patient information.

D. TKR Postoperative Deep Infection Model Validation and Efficiency Assessment

After performing ten-fold cross-validation algorithm, ten sub-clusters are generated to evaluate system accuracy. Then the testing accuracy and ROC curves assessment model efficiency value of the artificial intelligence are entered into the model and differences statistical methods are implemented to analyze, validate, and determine whether the model is strong or weak or if there's any difference. Finally, paired sample T test is utilized to test the differences between the three algorithms of PSO, GALR, and CE.

IV. Research Results

A. Data-Mining Analysis Results

After consulting related literatures and discussing with professional healthcare personnel on factors influencing TKR postoperative deep infections, the variables which are based on patient gender, age, complications, physicians' operation volume, hospital service volume, hierarchical levels of medical institutions, and regions are selected to use in this study.

B. PSO Algorithm Analysis

1. PSO Algorithm Parameter Combination Setting

This study uses TKR postoperative deep infections to construct a model, and select the cycle times that minimized the objective function values after undergoing different cycling times and PSO experiment analysis as the basis. Its analytical results show that the number of initial particles for TKR postoperative deep infections is 20 and convergence times as 156 times can make goal of minimizing the overall total of output solutions and assessment solution errors.

2. PSO Results Analysis

In this study, the focus is on observing TKR postoperative deep infections, through literatures and professional team discussions, factors affecting TKR postoperative deep infections are selected. Then PSO algorithm is implemented to analyze the weight values to be used to set the related weight of case-based reasoning construction, as shown in Table II.

C. GALR Analysis

Using GALR to build TKR postoperative deep infection model, after algebra test, there are 200 chromosomes with coding ranges from -15~15 and loop algebra as 5000. With French Roulette, mating rate is 0.3, mutation rate is 0.1, and converges to the optimal solution can be obtained at 620 generation, as illustrated in Table II.

D. CE Analysis

CE is implemented to conduct weight analysis of TKR postoperative deep infection model. With the more outstanding cross entropy convergence capabilities, optimal solution is guaranteed. Among all, total number of samples, iteration times, percentage of elite selection, smoothing motion parameters, dynamic smoothing constants s and β are 56, 50, 0.01, 0.8. 0.95. and 10 respectively. This research uses iterations times of 2 as its convergence point to obtain the weight values as illustrated in Table II.

TABLE II
PSO, GALR AND CE WEIGHT VALUES

Factors	Weight		
	PSO	GALR	CE
Hospital volume	0.272946	0.419355	0.007275
Surgeon volume	0.399162	0.483871	0.005494
Gender	0.594119	0.741935	0.831694
Age	0.001288	0.677419	0.195632
Complications	0.747226	0.967741	0.990528
Hospital level	0.216785	0.612903	0.83264
Region	0.127875	0.290323	0.390662

E. Case-Based Reasoning (CBR) Auxiliary System

In accordance with "Excel VBA" program as the auxiliary tool to design system interface, this study selects TKR surgery from the health insurance research database as its subject to conduct analysis of case factors. Mainly the system is to apply case-based reasoning in evaluation of postoperative deep infection after TKR. By inputting the key factor of health insurance database in this case and conducting computation using similarity formulas, top ten pieces of data which has the highest similarities in the database is ranked. Users can refer to any of the ten data and its detailed information is available for viewing. If there's a special case, users can note it in the remark column to provide references for future diagnosis. The following shows the user interface of the system program. Data shows gender of males and females with age ranging from 1 to 99 years of age, doctors and surgical volume of the hospital, hierarchical level of medical institutes including medical center, regional hospital and local hospital, regional distribution covering four areas of north, central, south, and east, and complications.

F. Model Efficiency Evaluation and Validation

Table III provides the accuracy and the corresponding ROC curves of the evaluation results focusing on postoperative deep infection following TKR.

TABLE III
SYSTEM ACCURACY ASSESSMENT OF INDIVIDUAL WEIGHT VALUES

	Accuracy	10-fold Average Accuracy	AURC
PSO	96.29%	97.77%	0.9315
GALR	95.76%	97.35%	0.8754
CE	93.65%	94.49%	0.8359

Whether a model is good or bad can be determined by comparing the accuracy (ACC) or area under the ROC curves (AURC); however, Li stated that the means possess significant variability and thus it cannot be used to determine the quality of the model easily or if there's any difference [19]. Tsai maintained that paired T-test should be used to examine the difference between models [20]. This study found no significant difference between PSO and GALR results and the weight values produced from both algorithms are both suitable to be used as a basis to evaluate the TKR postoperative deep infection system.

V. CONCLUSIONS

With the increasing aging population, patients who undertook total knee replacement are increasing and health insurance for the elderly has become a critical issue for improvement in 2^{nd} generation national health insurance plan. This study constructed a system to evaluate the deep infection after total knee replacement procedure. The results mainly provide physicians preoperative patient evaluations to prevent any waste in patients, medical resources, and national health insurance. In the postoperative deep infection after TKR model, no significant difference is found in gene logistic regression and particle swarm optimization algorithms using the paired T test. A set of evaluation systematic interface, which has over 90% accuracy in its testing data after test validations, is developed implementing PSO in combination with case-based reasoning tool. In addition, since the area under the ROC curves is as high as 0.93, this particular system can reduce the error generated during the process of evaluation and assist doctors and other professional medical personnel in performing preoperative assessment to provide critical and important referencing basis in postoperative recovery education to patients and their families.

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