Orthopaedic Implant Selector Expert

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Abstract—**Choosing the best orthopaedic implant for a patient can be complicated and needs experience and comprehensive knowledge of the characteristics of both the patient and the implant itself. An incorrect selection of an implant can lead to early failure and revision surgery. As a result of increasing demands for orthopaedic implants during the last decades, this paper investigates a method which would potentially help to select the optimum implant for the human hip joint. From this concept, the aim of this paper is to develop an expert system application (Orthopaedic Implant Selector Expert System, OISES), for selecting the best hip implant type for an individual patient. The software EXSYS Corvid is used to develop the application based on research and data collection of previous both successful and failed surgery for total hip replacement, in order to act as consultation point when choosing the best implant.**

***Index Terms*—human hip joint; expert system; implant**

I. INTRODUCTION

This project describes the development of an orthopaedic implant selector, using a knowledge-based expert system. This comprises a computer program to solve a diverse choice of decision-making problems pertaining to difficulties or uncertainties where there is a need to consult and check with human experts or specialists [1].

The development of an orthopaedic implant is the combination of both subject areas of medical and engineering therefore many of the issues that cause problems for orthopaedic implant selection are due to surgeons and patients not knowing the answers to certain medical or engineering technical questions. These issues can be regarded as lack of knowledge and can be solved by providing the appropriate knowledge.

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An expert system is able to provide an effective and scalable way to deliver this knowledge without the need and costs of other techniques by being able to capture and deliver expert knowledge via interactive sessions to provide precise reasoned advice and assistance which is equivalent to being able to ask an expert [2]. Surgeon involvement and support for systems that would evaluate patient needs more closely would go a long way towards choosing the best implant and therefore by maintaining a survey and data base on implants and analysing this data for selecting the next implant can greatly help in choosing the best implant [3].

From the concept of MYCIN application, (which is an expert system build to discover bacteria resulting infections and to advise such antibiotics for the individual patient) the main objective of this paper is to develop a similar expert system application which will give advice or will act as a consultant point in order to provide an answer/result or a guide for the surgeon who will be selecting the necessary implant for the given patient. Simultaneously, the development of this expert system application will increase the success rate of orthopaedic implant selection which will also reflect on future surgical operations positively.

Average THR lifetime expectancy is about 15 years but the average life time expectancy of a healthy person is six or seven times more than the lifetime of an implant with expectations to have active life and therefore there are high demands patients for THA. This high demands and expectancy raises the need for this project.

At the present, the choice of a suitable implant selection is complicated for an orthopaedic implant surgery due to continuous alteration by manufacturers. Different products offered by different manufacturers are subject to different criteria. An orthopaedic implant selector program (Expert System) will reduce the failures risk due to the incorrect implant selection and therefore associated risks and expenses also reduced. Main advantages of this application (OISES) are, being able to accomplish a better implant selection that allow surgeons to evaluate fast and safely, the type of implants and which configuration are the most best for each patient.

II. MATERIAL AND METHODS

Expert systems:

Expert systems have become an accepted method due to its ability to demonstrate knowledge and solve problems by using knowledge for a given field therefore, expert systems have the main role in the development of this project. The ability of expert systems in determining the requirements, knowledge gaining, applying result and formulating a data for presenting and reviewing the data to select the best implant type, makes it ideal for this projects application.

Experts system is an expertise, acting as a human consultation or human expert, giving advice using the data transferred previously from a human expert to a computer. The stored data in the computer is then ready for the users to call upon the computer to make inferences and arrive at a specific conclusion for specific advice or consultation as needed.

EXSYS Corvid® (Version 5.2.1):

EXSYS Corvid software is an expert system development tool and it has been used in this project to develop the OISES application. However there are many other software for expert system building tool and each have individual advantages and disadvantages.

Decision Theory:

This theory is the fundamental of probability theory extent of Pascal, Bernoulli and Fermat work. Bayes theorem relates the probability of the occurrence of an event to the occurrence or non-occurrence of an associated event. The occurrence probability of a hypothesis H given some evidence E is:

$$P(H|E) = \frac{P(H \cap E)}{P(E)}$$

And,

$$P(E|H) = \frac{P(H \cap E)}{P(H)}$$

Given this probability;

$$P(H \cap E) = P(H|E)P(E) = P(E|H)P(H)$$

By rearrangement we obtain Bayes theorem is given by;

$$P(H|E) = \frac{P(E\,|\,H)P(H)}{P(E)}$$

This theorem states that the conditional probability that a hypothesis H is true given an event E, $P(H|E)$, is the probability of E given H, $P(E|H)$, times the prior probability of H, $P(H)$, all divided by the probability of E, $P(E)$. To deal with more than one hypothesis, Bayes's theorem can be extended by:

$$P(E) = P(H \cap E) + P(\sim H \cap E)$$

And from this equation we get;

$$P(E) = P(H\,|\,E)PH + P(E|\sim H)P(\sim H)$$

Expanding the equation:

$$P(H|E) = \frac{P(E|H)P(H)}{P(H\,|\,E)PH + P(E|\sim H)P(\sim H)}$$

In order to formulate the problem of diagnostic inference, assuming that if E= (E_1,..., E_n) is a set of n pieces of evidence and H= (H_1,..., H_m) is a set of m mutually exclusive hypotheses under consideration, then Bayes' theorem can be further generalised as

$$P(H_j|E_i) = \frac{P(E_j|H_i)P(H_i)}{\sum_{k=1}^{m} P(E_j\,|\,H_k)P(H_k)}$$

With

$$P(E_J) = \sum_{k=1}^{m} P(E_j\,|\,H_k)P(H_k)$$

Where

$P(H_i)$ is prior probability of H_i
$P(H_i | E_j)$ is posterior probability of H_i
$P(E_j | H_{ij})$ is conditional probability of E_j.

Derived formula can be used as a means of inference in knowledge based expert system. If knowledge is stored in rules of the form if E_j then H_i and if E_j is true then Bayes theorem updates the belief in H_i from $P(H_i)$ to $P(H_i | E_j)$, provided that $P(E_j | H_{ij})$ and $P(E_j)$ are both known. This is shown more clearly in figure 1, in an inference net bellow:

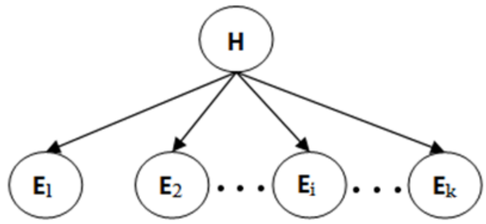


Fig 1. Inference net, relation between H and E parameters

Bayesian reasoning in expert systems:

In the simplest case, Bayesian network was shown, but for more complex structures the idea of recovery algorithm developed by Rebane and Pearl (1987) can be used. For demonstration using an example of Robert G. et al [4] can be adopted for this project. If an implant type is needed and to reason all possible implants choices, then let "I" be the variable for implant choices, allowing answer yes and no. Their define probabilities are age, "A" with P(A=yes)=0.1 and gender, G with P(G=yes)=0.2. Assuming that these possible precipitation events are independent so that there is no reason to "believe that occurrence of one should influence the occurrence of the other" Robert G.et al [4]. Therefore following conditional probabilities of implant choices are accepted:

P(I=yes | A= no, G=no) = 0
P(I=yes | A= no, G=yes) = 0.5
P(I=yes | A= yes, G=no) = 1
P(I=yes | A= yes, G=yes) = 1

This results in a graphical model of this system shown to the left of figure 2 with each variable labelled by its current probability of taking the value "yes" (the value P(I=yes)=0.19 is calculated below). If a patient is in need for an implant type, then the event "I=yes" has happened and therefore the need to find the conditional probabilities for A and G, given this implant selection problem [4]. From the above Bayes' theorem:

$$P(A, G|I = yes) = \frac{P(I = yes|A, G)P(A, G)}{P(I = yes)}$$

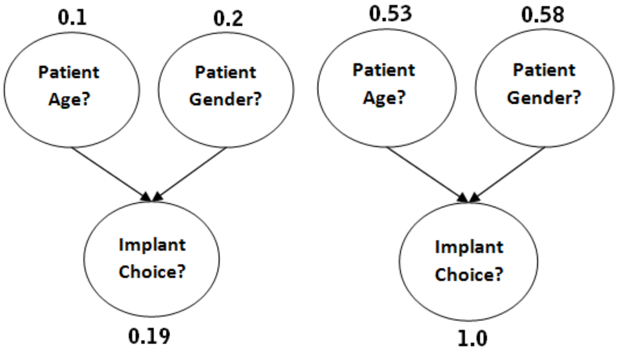


Fig 2. Certainty factor distribution

Figure 2 shows the graphical model representing two independent implant selection with probabilities of a "yes" response before and after observing implant choice. By summing over the relevant entries in the join posterior distribution of A and G we thus obtain,

$P(A=yes \mid I=yes)=0.42+0.11=0.53$ and

$P(G=yes \mid I=yes)=0.47+0.11=0.58$.

These values are displayed on to the right of figure 2.[4] Expert systems commonly determine the probabilities of interdependent events by weighting. Bayesian Belief Networks provide a method of weighting the property of results mathematically. The mathematics behind this shows which result is most accurate as demonstrated in diagram.

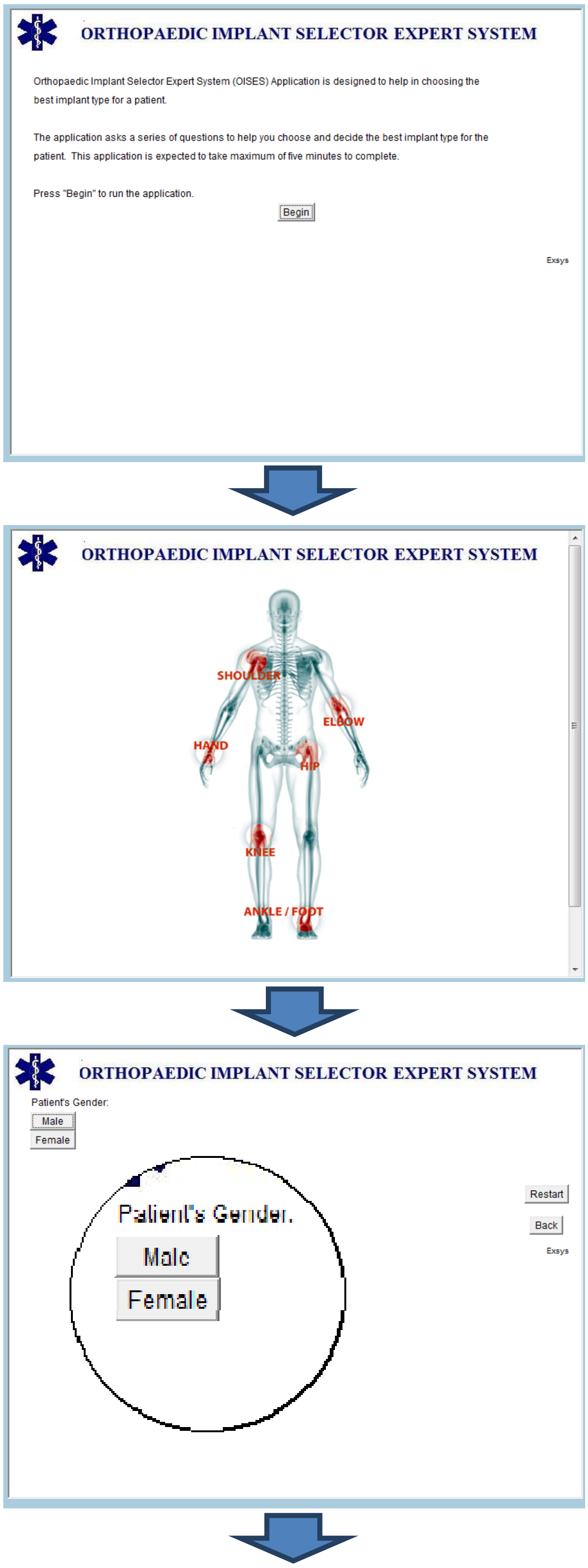
Application

The expert system application was built for this project as a result of several researches and data collected. Abbreviation of the project name "Orthopaedic Implant Selector Expert System", is given to the built expert system application, OISES. OISES is a new concept that is newly developing, which has been developed to overcome the inherent limitations of implant selection as explained in earlier sections. As the name suggests "Orthopaedic Implant Selector Expert System" it is designed to select and choose an implant type for any orthopaedic part of a human. So far the application is built only for selecting hip implants.

The program is developed to use patient information from the user of the application to acquire the anatomic information necessary to guide and to select the best implant and will finally recommend an implant type for the user. The application is initially designed for two types of users, for surgeons or patients but permitting anyone to have access.

The application uses an expert system technique which is expected to be safe, accurate, efficient, cost-effective, and adaptable for this application and purpose.

A presentation of the OISES application is shown by below figures in detail (Fig 3):



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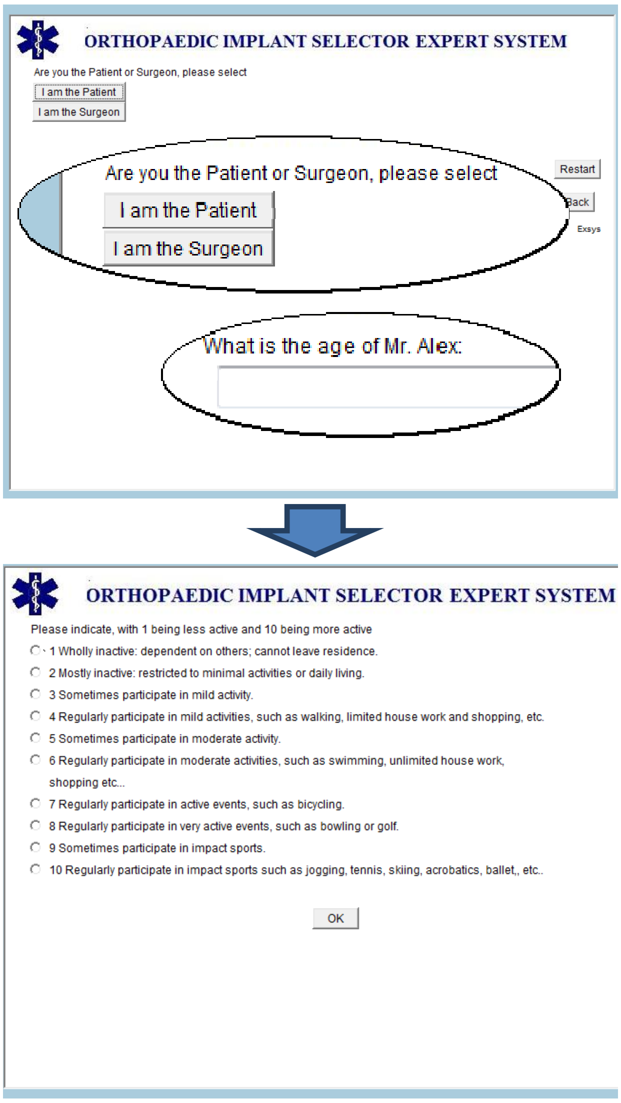

Fig 3. Detailed presentation of the OISES application

OISES consist of sets of variable rules. For example, a typical consultation of OISES application in the form of IF and THEN rules are demonstrated as bellow:

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IF: the age of the patient is “30
to 39”
AND: the gender is “male”
AND: the weight is “less than 49 kg”
AND: the activity level is “level 8 to 10”
AND: the bone quality is “Good bone quality”
THEN:

Wearing Type:
Ceramic / Ceramic (CF=0.55)
Metal/Metal (CF=0.26)
Fixation Type:
Press fitting, Porous ingrowths (CF=0.9)

Material Type:
Titanium Alloy (CF=0.4)
Cr/Co, Casted CoCr (CF=0.25)

Design Type:
With Collar (CF=0.5)
Stem Shape: Monobloc (CF=0.25)
Stem surface: Polished(CF=0.40)
****

The above rule presents a typical consultation and advice from OISES. Illustration and presentation of all the rules in the OISES application in this form can be difficult to specify therefore for simplicity the rules are transformed to a graphical demonstration where it is more presentable for understanding. This graphical representation of rules is shown in Fig 4.

III. CONCLUSION

In general the short-term object was achieved by building an expert system application for selecting or advising a hip implant type but however this dissertation was pioneer to the project of orthopaedic implant selector expert system which requires a long-term study. The long-term objective of the project was to build an expert system application that advices the best orthopaedic implant for a given patient, designed for the use of academic purpose. Previous studies showed that, such project required a long-term study for a complete compellability and reliability of the desired level of the expert system application. Therefore as this dissertation was a pioneer to this project, the objective and the aim of this dissertation was to investigate a particular area in orthopaedic implant area (hip) and built and propose an expert system application for implant selection within a particular area of orthopaedic implant.

For this dissertation the orthopaedic area of hip implants was focused and investigated in an attempt to build and propose expert system applications that will advice for selection of the best implant for the hip. The work involved a comprehensive investigation of both areas of expert system application development and hip implant analysing together with decision making probability theory. It was clear that ~~a~~ data linking patient data directly with the data of implant used could provide an accurate estimate for identifying which implant could be selected. Therefore in attempt to find ideal data and to consult an expert, patients, surgeons, and implant registers were necessary. However within a limited time, no ideal data was achievable due to patient privacy and therefore alternative data was used to make decisions. This data was based on research of previous investigations and data gained form ODEP website. Various data from previous research were collected, together with data containing a list of implants used, for analysing individual effects of parameters. For the analysis of hip implants, various research and data was collected in order to categorise different type of hip implants with additional research on understanding how patient parameters and implant parameters affects the implant choice.

The research was focused on experimental studies. Comprehensive decision based information were recorded and applied to the application. It was known that the implant life or the success rate of the orthopaedic implant affects the choice of implant selection. As a result of research, it was found that implant categorisation can be divided into four groups; design, wearing couple (bearing couple), material

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and fixation. This categorisation of implant was then compared against the most important patient parameters, which directly affected implant life; patient's age, weight, activity level, bone quality and diagnosis which were most important factors in effecting implant life. With most important factor being the age of the patient it had most affected the selection criteria of the implant for a particular patient. It was noted that BMI of the patients did not have any effect on implant life. This implant parameter with patient parameters was investigated and a decision probability was created in the application of expert system and OISES was built. The findings and decision probability were demonstrated in a graphical manner as shown in the appendix section.

The project was developed based on research and data collected only of patients and implant parameters but however as any other expert system application, such projects require ensuring with an expert and an advisor. The general purpose of this investigation was to demonstrate its ability of developing an expert system application that was based on the analysis of patients and implants only. The implant choices have vast effects on the success rate of a THA but the success rate of a THA does not purely depend on the implant and the patient itself. The experience of the surgeon and the surgical technique both have an impact on success rate of a THA, which ~~is~~ therefore adds complications and further work to the project.

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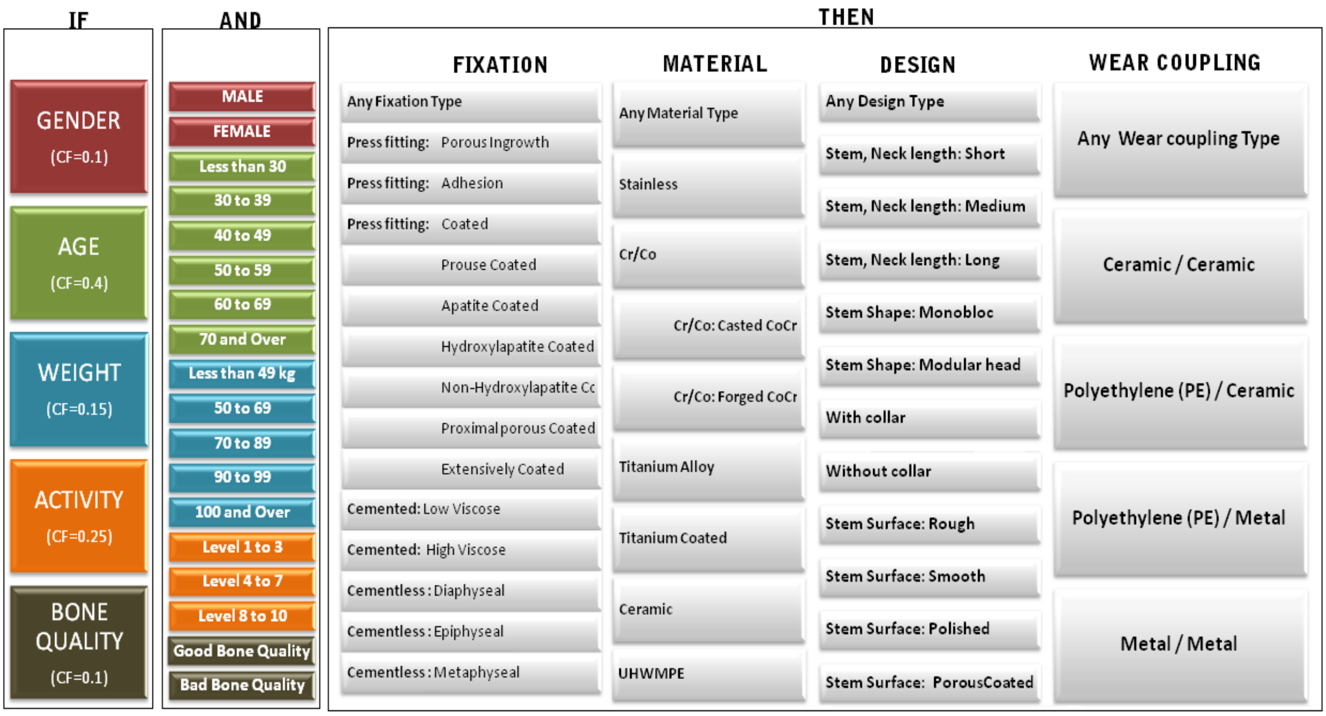

Fig 4. Typical consultation and advice from OISES

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