

Simulation TMJ clinic by Using Intelligence Techniques

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ABSTRACT

The research aims is structuring the TMJ clinic; it is a computerized system that diagnoses and treats the clinical cases through a computing statistical basis for the serious cases.

This system helps to take broad decisions broad in dentistry and in diagnosis.

Artificial networks have been used to find first the major exponents of the TMJ diseases, in order to exploit a training basis (**Hebbians Network**) to help to shed light on the affecting variance as to get almost less variance with a large amount of information. second to show how the variables under discussion interact and cause specific outcomes. We use BBN and we have some conclusions about this .

The current system has a proper of being quick storage and restoration, and updating the information for each patient, as well as new items benefit & inhgate all patients.

The system includes a general and specific statistics for individual patients or clinics, and it is interchangeable spontaneously according to the case. There are several queries and reports.

This system has been followed on (80) patients from the outpatient dept. of Al-Salaam university Hospital/Dentistry college / TMJ unit at Mosul University.

The possibility of application has been suggested to the private and general clinics.

Database has been designed by Microsoft Access and programmed by visual Basic **V.6.0.**

الخلاصة

يهدف البحث إلى بناء نظام لعيادة مفصل الفك وهو نظام حاسوبي يقوم بفحص وتشخيص وعلاج الحالات السريرية

لمرضى العيادة من خلال بناء قاعدة بيانات حاسوبية متكاملة لمتابعة الحالة الصحية للمرضى الذين يراجعون العيادة .

اعد هذا النظام للمساعدة في اتخاذ القرارات الواسعة في علم طب الأسنان ومساعدة طبيب الأسنان في تشخيص الحالة

فضلا عن استنتاج خطوات العلاج المقترحة لغرض تنفيذها في هذه العيادة

تم استخدام الشبكات الاصطناعية **أولاً**: لإيجاد المكونات الأساسية لأمراض مفصل الفك وذلك بتوظيف قاعدة تديب -

مناسبة (شبكة هيب) التي تساعد على توجيه الاهتمام بالمتغير المؤثر معنويا أي الحصول على أقل ما يمكن من

المتغيرات بأكثر ما يمكن من المعلومات ، **ثانياً**: تم استخدام BBN لرؤية كيفية تأثير ومسببات المتغيرات وهناك بعض

الاستنتاجات حول ذلك .

يتصف النظام بسرعة الخزن والاسترجاع، وتحديث المعلومات الخاصة بكل مريض ، وإضافة قيود جديدة بما يقدم

صفحة متكاملة عن كل مريض .

يشتمل النظام على عمل إحصائيات عامة وخاصة سواء كانت على مستوى الفرد (المرض) أو العيادة (المرضى

المراجعين) والتي تتغير تلقائيا مع تغير الحالة المرضية ، كما يوفر النظام العديد من الاستعلامات والتقارير المختلفة .

- Lecture – Administration & Economic College
- **Lecture – Dentistry College
- ***Asst.-prof— Dentistry College

تم تطبيق هذا النظام على (80) مريض من المرضى المراجعين لمستشفى السلام الجامعي -كلية طب الأسنان - قسم جراحة الفم - عيادة مفصل الفك - جامعة الموصل ، وقد أثبت إمكانية اعتماده في جميع عيادات طب الأسنان العامة والخاصة .

تم تصميم قاعدة بيانات النظام باستخدام (Microsoft Access) وتمت برمجة النظام باستخدام لغة فيجوال بيسك بإصدارها السادس .

INTRUCTION

Knowledge and data used are considered to be one of the most important, impairment that have been taken seriously by the decision – making process in the patients and treatment managements.

According to the excessive development , new systems have been born, they depend on the human simulation on the basis of daily decision – making process or the mechanism of human members , and artificial intelligence this can be done by the association of mathematics and statistics , these sciences are the most highly – discovered sciences during the 20th century that scientists try to provide machines with the ability to make conclusions to be like specialists who can be doctors , economists or planners .As for the lack of a complete system by the oral clinics -TMJ- (Galdonm j. ,et.al. 2006, p5).

Research aims

1. Improving the medical care via dentist to take the relevant decisions in diagnosis and treatment.
2. Identifying the major exponents to the TMJ diseases through the structure of nets on the basis of the association of training .
3. The application of the programs with real data for patients of TMJ and providing the best requirements of information such as reports and statistics .
4. The applicability of data to the research studies in various academies in TMJ.

1- TMJ (Temporomandibular joint diseases and disorders)

Temporomandibular joint diseases and disorders, commonly called **TMJ**, are a collection of poorly understood conditions characterized by pain in the jaw and surrounding tissues and limitations in jaw movements. Injury and conditions that routinely affect other joints in the body, such as Grthritis, also affect the temporomandibular joint. The National Institute of Dental and Craniofacial Research (NIDCR) of the National Institutes of Health (NIH) states that over 10 million people in the United States suffer from TMJ problems at any given time. While both men and women experience TMJ problems, the majority of those seeking treatment are women in their childbearing years. (Grant, 2007, p1)

The TMJ Association (**TMJA**) is a national, non-profit, 501(c)3 tax exempt organization whose mission is to improve the diagnosis, care and treatment of everyone affected by TMJ diseases and disorders through fostering research, education and other activities with the ultimate goal of preventing TMJ problems. (Sandra & Addym,2003,p1)

The TMJA was founded in 1986 by two TMJ patients because of their own experiences with severe TMJ pain and complications as a result of unsuccessful treatments. Over time, it became clear to them that there were a multitude of problems in this field, with very little consensus on anything and much controversy on everything. It became apparent that a solution was not readily available for patients, and we needed more information founded on valid scientific studies.

The TMJA's scientific meetings and continuous advocacy for multidisciplinary research have resulted in several institutes of the National Institutes of Health (NIH) proposing initiatives which will lead to multi-disciplinary research specifically focused on TMJ diseases and disorders. In recent years, there has been unprecedented action at the NIH, which now appears to be committed to expanding the scope and improving the quality of research on TMJ diseases and disorders.

The TMJ Association presents the following solely as an information guide to provide TMJ patients with direction in making health care decisions. (Edward, 2006, p25)

2- Artificial Intelligence (AI)

AI may be defined as the branch of computer science that is concerned with the automation of intelligent behavior. (Luger & William, 1998, p1)

It is used for many fields and it has many utilities, one of them is neural network

2-1 Neural Network

A neural network (NN) is a group of processing elements where typically one subgroup makes independent computations and passes the results to a second subgroup. Each subgroup may, in turn, make its independent computations and pass on the results to another subgroup. Finally, a subgroup of one or more processing elements determines the output from the network. Each-processing element makes its computation based upon a weighted sum of its inputs. A subgroup of processing elements is called a layer in the network. The first layer is the input layer and the last is the output layer. The layers that are placed between the first and the last layers are the hidden layers. The processing elements are seen as units that are similar to the neurons in a human brain, and hence, they are referred to as cells, neuron nodes, or artificial neurons. Threshold function is sometimes used to determine the output of a neuron in the

output layer. The value outputted from the threshold function characterizes the neuron to have fired or not. Synapses between neurons are referred to as connections, which are represented by edges of a directed graph in which the nodes are the artificial neurons. (Rao, 2000, p2)

Processing in neural networks is done in parallel, rather than sequentially, as would be necessary in computing on digital computers. Computing on digital computers also requires precise information and algorithms.

NN techniques have many applications, one of them is used for compression (reduction) data, such as those which are used to obtain principal component. (Dvavlo E., & Patrick Naim,1991)

2-2 Principal Component Neural Network

To construct (PCNN) we can write the Generalized Hebbians Algorithm (GHA) in following form :

$$\Delta w_{ji}(n) = \eta y_j(n) \left[x_i(n) - \sum_{k=0}^{j-1} w_{ki}(n) y_k(n) - w_{ji}(n) y_j(n) \right], \quad \dots (1)$$

$$i = 1, 2, \dots, p - 1 \quad , \quad j = 0, 1, \dots, m - 1$$

Where $W_{ji}(n)$ is a change applied to the synaptic weight $W_{ji}(n)$, Y_j is an output and X_i is input. N is a learning-rate parameter. The last part of equation is a forgetting factor.

For a single output neuron (a special case), $j = 0$, It can show that this neuron will discover the first principle component (Ojas rule). The second neuron sees an input vector $x(n) - w_{0i}(n)y_0(n)$ from which first Eigen vector of the correlation matrix R has been removed. The second neuron therefore extracts the first principle component of $x(n) - w_{0i}(n)y_0(n)$, which is equivalent to the second principle component and so on. (Hannu Pitkänen,1998,ch10)

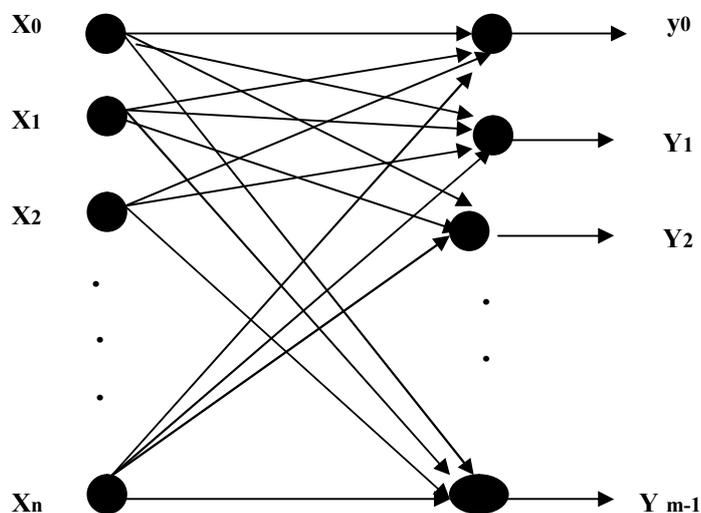


Figure (1) Feed forward Network with Single Layer of computational nodes

2-3 Bayesian belief networks

Bayesian belief networks are powerful tools for modeling causes and effects in a wide variety of domains. They are compact networks of probabilities that capture the probabilistic relationship between variables, as well as historical information about their relationships. BBN are based on Bayes' rule, which simply can be expressed as:-

$$P(b|a) = \frac{P(a|b) \cdot P(b)}{P(a)} \dots \dots \dots (2)$$

where $P(a)$ is the probability of a , and $P(a|b)$ is the probability of a given that b has occurred.

For building a BBN, there are steps that must be done, which are:-

- 1- Constructing the Graphical Model ,2- Constructing the Probability Tables. (Ankush & Ashraf,2007, p344)

The general algorithm of BBN is:-

$$P(X|E) = P(X|E_X^+, E_X^-) = \frac{P(E_X^-|X, E_X^+) \cdot P(X|E_X^+)}{P(E_X^-|E_X^+)} = \alpha P(E_X^-|X) \cdot P(X|E_X^+) \dots \dots (3)$$

Let U be the vector of parents $U_1 \dots U_m$, let u be an assignment of value of them, also ,let Y be the vector of children's $Y_1 \dots Y_n$ and let y an assignment of value of them, then

$$P(X|E_X^+) = \sum_u P(X|U) \prod_i P(U_i|E_{U_i \setminus X}) \dots \dots (4 - a)$$

$$P(E_X^-|X) = \prod_i P(E_{Y_i \setminus X}|X) \dots \dots (4 - b)$$

There for:

$$p(X|E) = \alpha \sum_u P(X|U) \prod_i P(U_i|E_{U_i \setminus X}) \cdot \prod_i P(E_{Y_i \setminus X}|X) \dots \dots (5)$$

(Jae k.,2009: 259-269),(Scott,2009: 68-69)

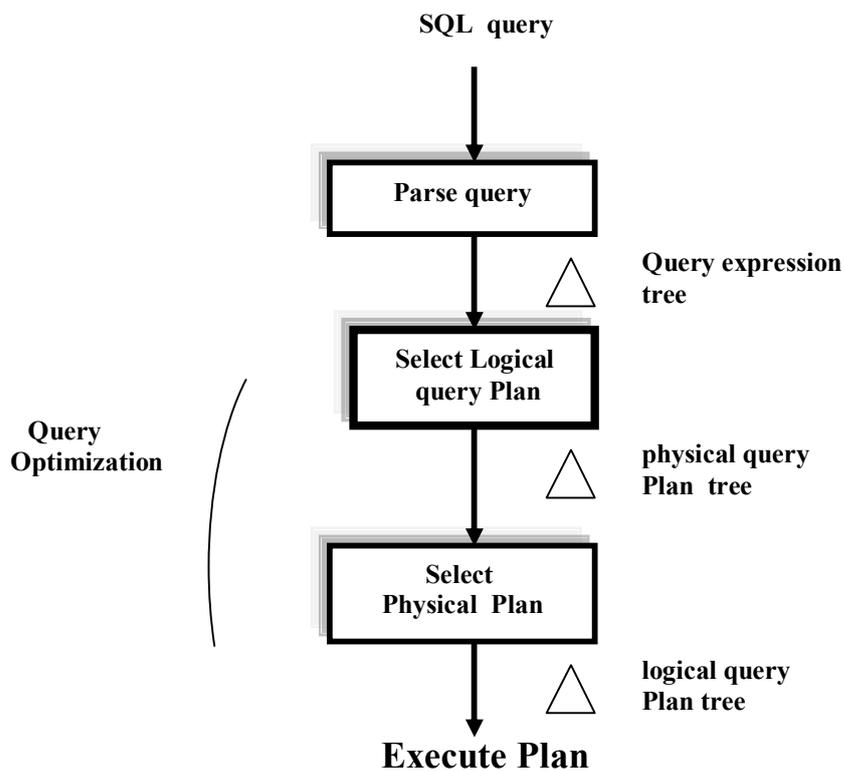
3-Query Compilation

Query compilation is divided into three major steps which are

- a) Parsing. A parse tree for the query is constructed.

- b) Query Rewrite. The parse tree is converted to an initial query plan, which is usually an algebraic representation of the query. This initial plan is then transformed into an equivalent plan that is expected to require less time to execute.
- c) Physical Plan Generation. The abstract query plan from(b), often called a logical query plan, is turned into a physical query plan by selecting algorithms to implement each of the operators of the logical plan, and by selecting an order of executing for operators. The physical plan, like the result of parsing and the logical plan, is represented by an expression tree. The physical plan also includes details such as how the queried relations are accessed, and when and if a relation should be sorted.

Parts (b) and (c) are often called the query optimizer, and these are the hard parts of query compilation. figure (2) illustrate these steps (Garcia-oliva, D.et.al., 2009, pp 701-703)



Figure(2): query compilation

4- System Component

The designed system consists of a group of programs by using (Visual Basic V.6.0) and permanent data file according to (Access), that requires data taken from the patient, figure (3) refers to the major components of program.

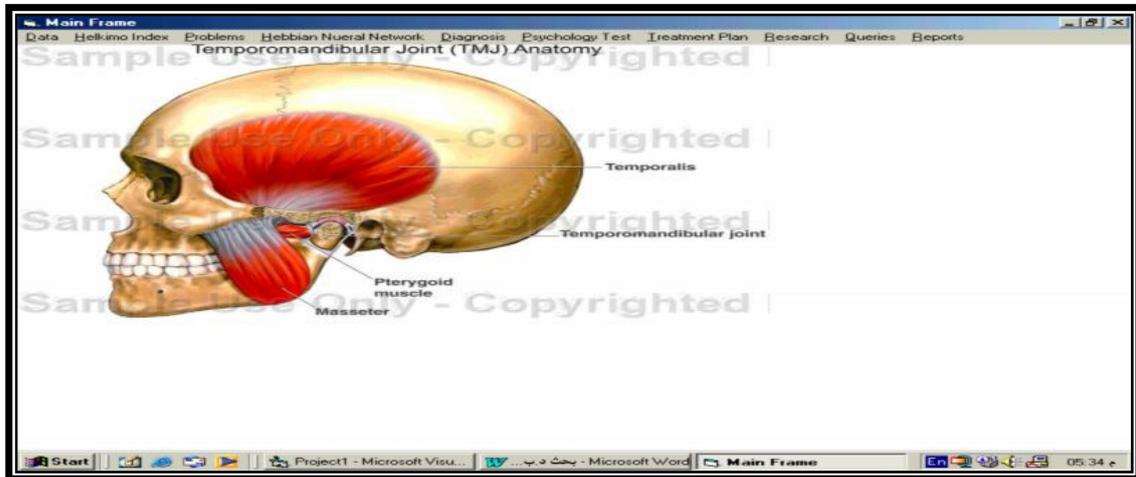


Figure (3) Main Form System

1- Data Input Unit: -

This unit is characterized by providing the basic data to (Helkimo Index). On this, covers the process of required input unit and distributed into two forms. There is a consecutive appearance according to Score as well as forms for missing dental case, carries....etc.) , With the possibility of

Transferring among data in the form or among the different forms with flexibility to update the data, See figure (4) (5).



Figure (4) Personal Information Form

Figure(5) Different Pain Form

2- Helkimo Index Unit: -

The data has been input collected to the indicated helkimo index in the input unit according to the Symptoms and pains that the patient is suffering. It can be:

- Calculate Score, figure (6)
- Animistic disfunctions., figure(7)

This would need in role to: -

- Impaired TMJ functions (I.T.F. Score).
- Mobility Index (M.I. Score).
- Muscular pains (M.P. Score).
- Pain on movement (P.M. Score).
- TMJ pains (T.P. Score).

Figure (7) Animistic disfunction index

Figure(6) Clinical disfunction index

3- Temporary classification for the disease: -

In this unit, Clinical disfunction can be calculated depending on the sum of input data within the same unit in order to get benefit of specifying the severity of the disease:

- Normal if the sum equal (0)
- Mid if the sum equal (1-4)
- Moderate if the sum equal(5-9)
- Severe if the sum more than or equal(10)

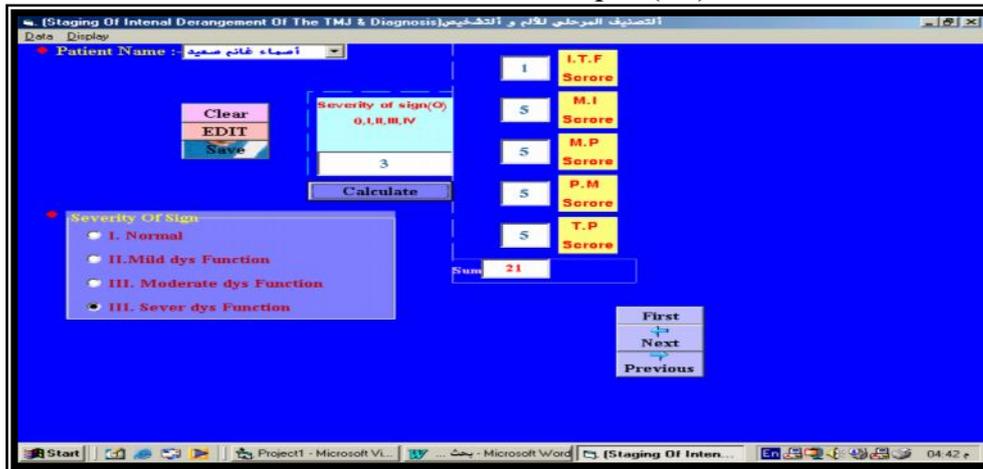


Figure (8) Temporary Classification form

4- Health Problem Unit: -

After specifying the problem that the patients suffering, the medical resources are given through programming the leading reasons of these problems, these problems are limited to two axes:

Disk displacement with reduction, Disk displacement without reduction. See figure (9).



Figure (9) Health Problems form

5 Networks

5-1 Hebbian Neural Network

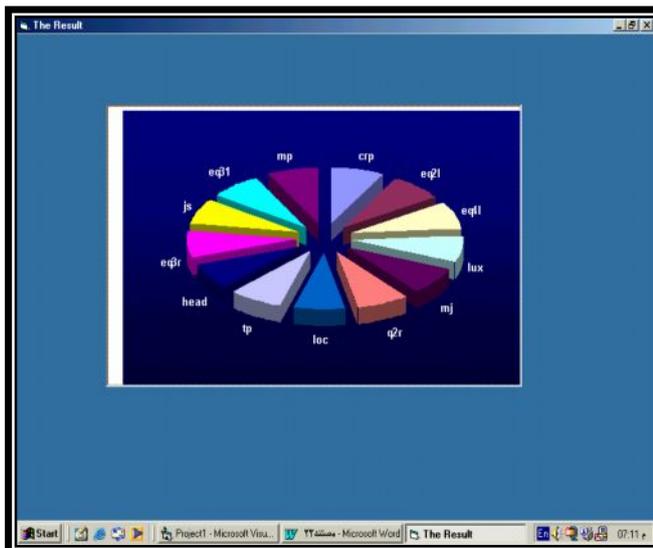
The Principle component neural network feed – forward (PCNN) as in equation (1) in paragraph (2-2) was used, it was consisted of: *input layer*, with (20) nodes (Which equal to the number of variables under study), *Output layer*, with (19) nodes, reduced to (13) nodes at later.

Depending on (0.5) learning rate & iteration number equal (200) we obtained (13) component with the value of Error (0.0604), Table (1) show Learning rate, iteration number , the value of error for each attempt from endeavors of the training.

Table(1) Training Hebbian Network

Series	Rotate Number	Training Rate	Error Value
1	150	0.25	0.184
2	200	0.5	0.0604
3	250	0.75	0.092
4	150	0.5	0.176
5	200	0.75	0.061
6	250	0.25	0.0735
7	150	0.75	0.19
8	200	0.25	0.0616
9	250	0.5	0.0962

By using an algorithm of PCNN, we obtain the cut point and know the principle components which are the most importance. These components as explained in Figure (10), (11) are (crp):creptation , and Next , (eq2L):Ear pain2l,(eq4L): Ear pain4l,(lux):luxation & so on until the last one , which is (mp):muscle pain score.



Figure(10) the result rotate



Figure(11) the result rotate

5-2 Bayesian belief Network(BBN)

To construct a Bayesian network, we first determine the hypothesis variables -which they are under our **entrusts**- Secondly, evidence variables are added, Finally, intermediate, or mediating, variables are added . These variables are Crp: Crepitation ,Head: Headache, Js: joint Sounds , Loc: Locking , Lux: Luxtation . Fig (12) shows the relationship between these variables

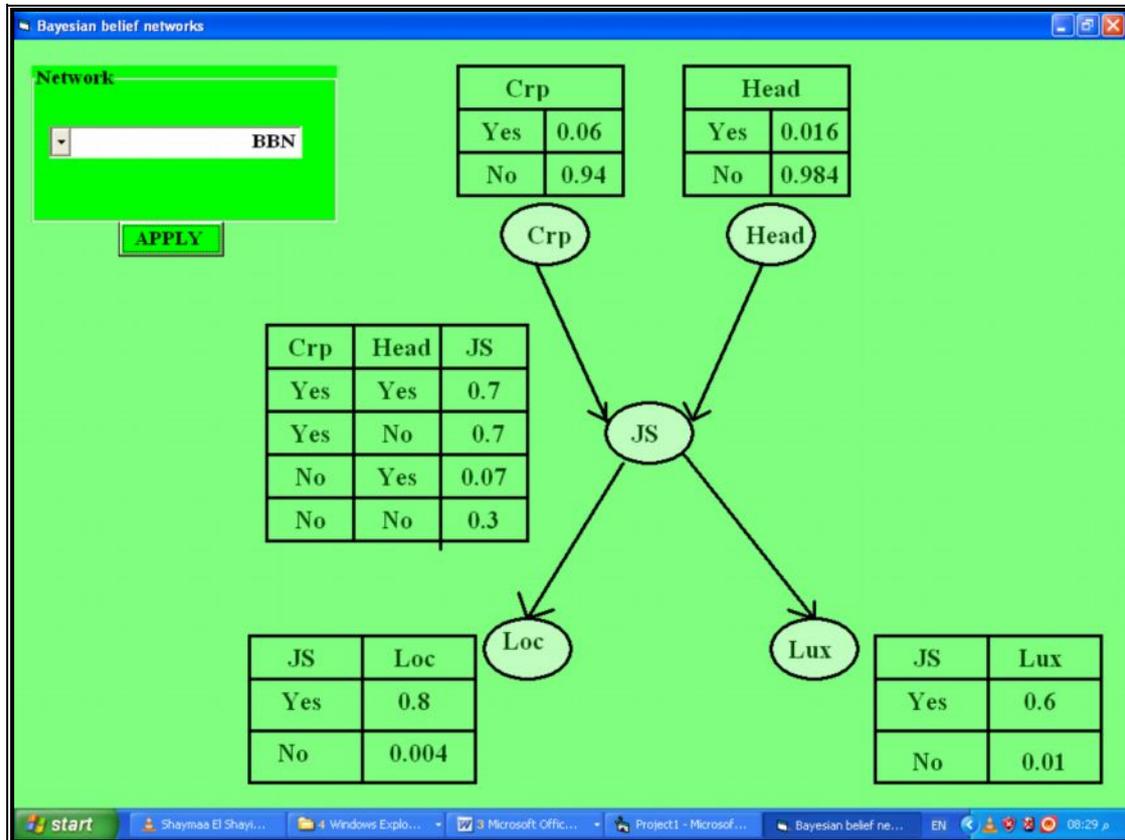


Figure (12): BBN For Discovery about (Locking),(Luxtation) in patients

by using an equation (5) in paragraph (2-3) we have :-

- 1- Probability of the patient has a (Js) but neither (Crp) nor (Head) has occurred, and both (Loc),(Lux):

$$P(loc \wedge lux \wedge js \wedge crp^- \wedge head^-) = 0.15539$$

- 2- Probability of the patient may be suffered from (Js),(Loc),(Lux) are:

$$\begin{aligned} A) P(js) &= P(js \wedge crp \wedge head) + P(js \wedge crp \wedge head^-) \\ &\quad + P(js \wedge crp^- \wedge head) + P(js \wedge crp^- \wedge head^-) \\ &= 0.3205408 \end{aligned}$$

$$\begin{aligned} B) P(loc) &= P(loc \wedge js) + P(loc \wedge js^-) \\ &= 0.2591504 \end{aligned}$$

$$\begin{aligned} C) P(lux) &= P(lux \wedge js) + P(lux \wedge js^-) \\ &= 0.2020394 \end{aligned}$$

4–A) If the patient suffered from (Loc), we can diagnos about (js) by using posterior probability as:

$$P(js|loc) = \frac{P(loc|js).P(js)}{P(loc)}$$

$$= 0.9895126$$

4-B) If the patient suffered from (Lux), we can diagnos about (js) by using posterior probability as:

$$P(js|lux) = \frac{P(lux|js).P(js)}{P(loux)}$$

$$= 0.951957$$

5-we entrusted about probability of effect Crepitation (Crp) & causes as below:

A) Crepitation (Crp)effect & locking (Loc) cause

$$P(crp|loc) = \frac{P(crp,loc)}{p(loc)}$$

$$= 0.1721447$$

B) Crepitation (Crp) effect and luxation (Lux) cause

$$P(crp|lux) = \frac{P(crp,lux)}{p(lux)}$$

$$= 0.1444412$$

6-Finally we entrusted about probability of both couse, locking (Loc), luxation (Lux) & Crepitation (Crp) effect as below:

A) locking (Loc) cause &Crepitation (Crp)effect

$$P(loc|crp) = \frac{P(crp,loc)}{p(crp)}$$

$$=0.62386$$

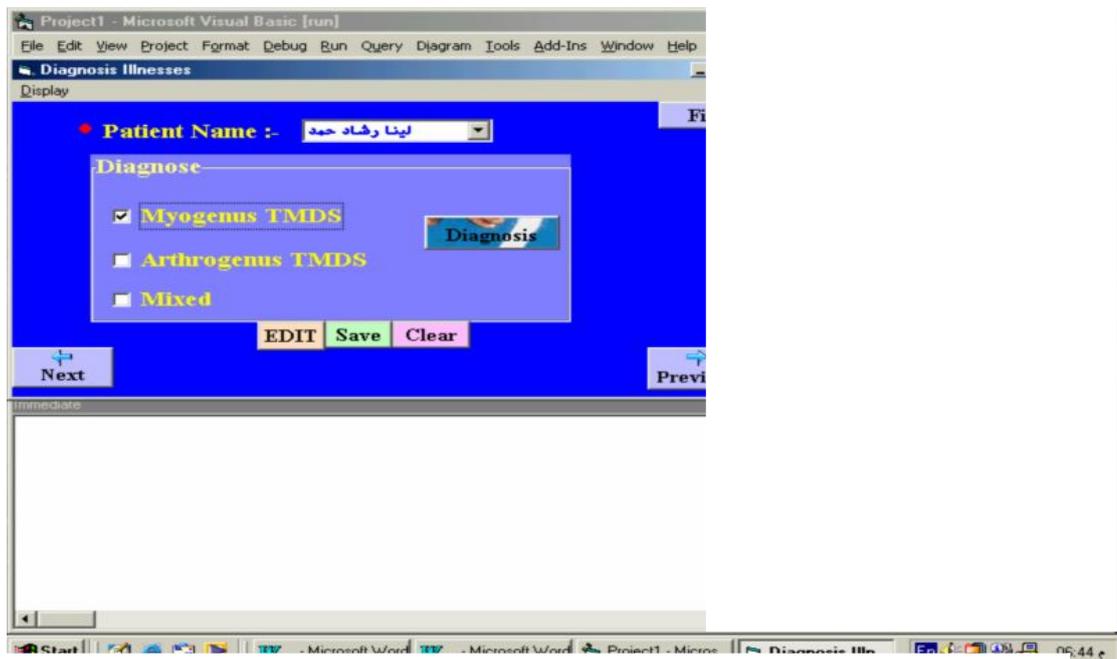
B) luxation (Lux) cause &Crepitation (Crp) effect

$$P(lux|crp) = \frac{P(crp,lux)}{p(crp)}$$

$$= 0.579666$$

6- Diagnosis Unit: -

Specifying the diseases that could cause the patients. This can be seen through the application of resources that benefit the diagnosis process as scores.... etc. The disease diagnosis has been programmed.



Figure(13) Diagnosis Unit

7- Treatment Unit (TMJs Treatment plan Unit)

In this case it is possible to put a plan for the treatment for each patient.

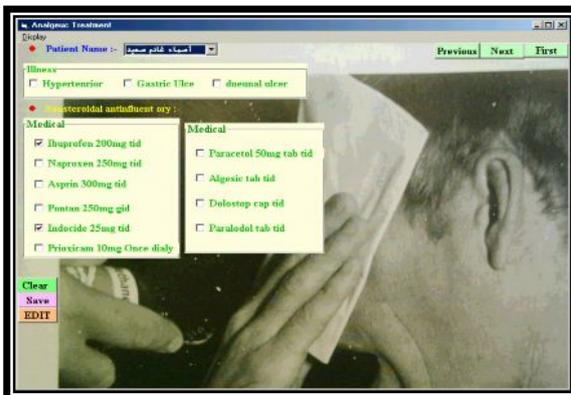


Figure (14) Analgesic Treatment form

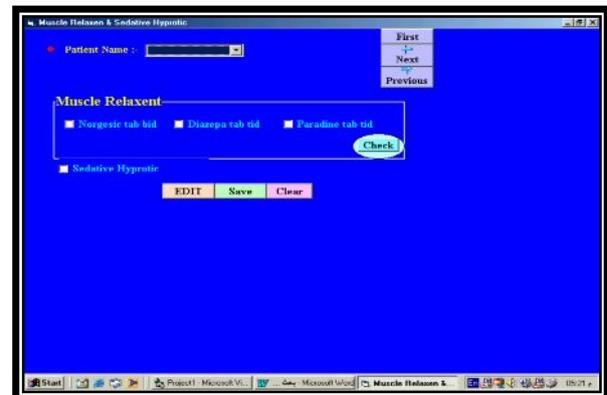


Figure (15) Muscle Relaxant & Sedative Hypnotic Form



Figure (16) Splint form

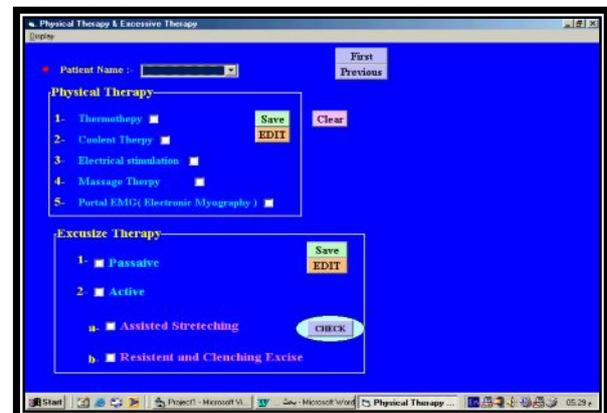


Figure (17) Physical & Exercise Therapy form

8-Statistic Unit

The efficiency of the activity of the programmed information system, in computer depends on the degree of the accuracy, clarity and totality of reports and, statistics issued by that system. On this basis, the designed software included the following:

1-statistics on the level of individual patient, it includes:

- Number and percentage (%) of Missing teeth of the patient.
- Number and percentage (%) of the Carried teeth of the patient.

Pat Name	Age	Sex	AM.U.L.	AM.U.R.	AM.L.L.	AM.L.R.	Co.U.L.	Co.U.R.	Co.L.L.	Co.L.R.
الشيخ محمد	55	M	0	0	0	0	0	0	0	0
المرأة محمد	30	F	0	0	0	0	0	0	0	0

Figure(18) static Of Missing & Carried Teeth

2-General Statistics on the Clinical Level includes :-

- Statistics associated with problems.
- Statistics associated with head diseases according to disease intensity and direction.
- Statistics associated with Tests.
- Statistics associated with Helkimo Index.
- Statistics associated with Diagnosis.
- Statistics associated with number and percentage (%) of inpatients within a limited period for certain year this also according to sex.
- Statistics associated with head pain according to pain intensity and location.
- Statistics associated with Disk interference.
- Statistics associated with ontological symptoms.
- Special statistics of the occlusion cases according to sex and age.
- Statistics associated with ear pains according to the side of pain on.

9-TMJ's Queries Unit

This unit includes a group of queries of inpatients according to sex and certain date and a certain age as in the as figure (19) below

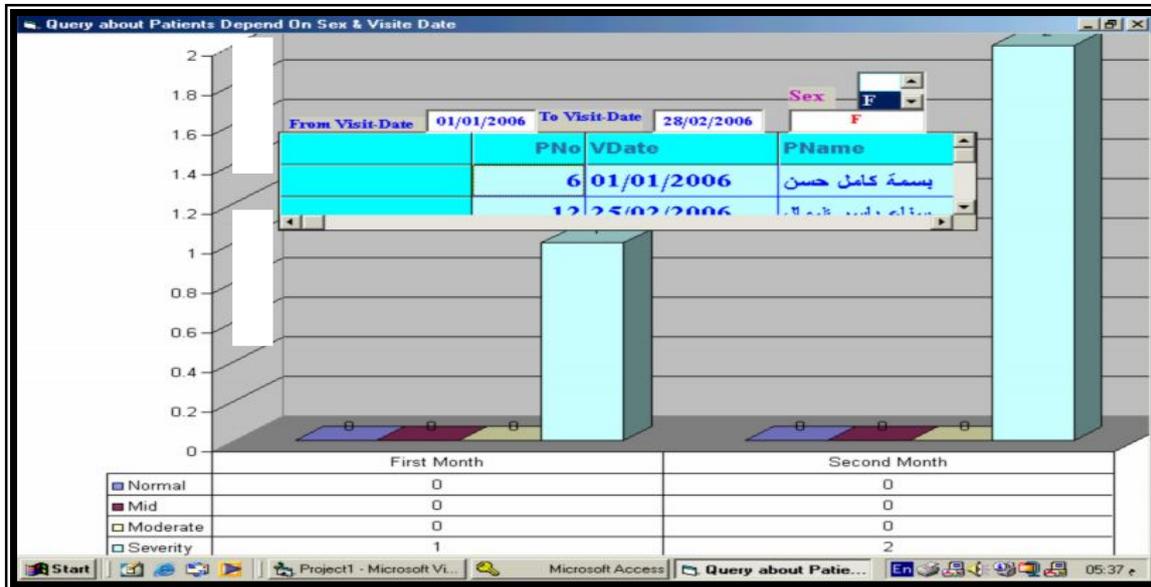
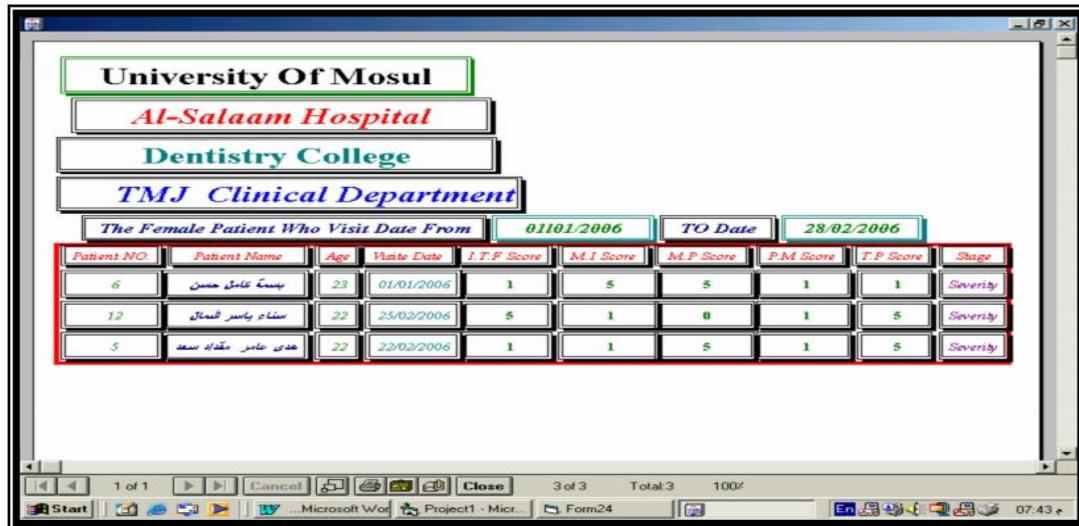


Figure (19) Query form on Sex, Age and certain Age

10-TMJ's Reports Unit :-

The system gives the reader a report on :-

- Helkimo Index. For each patient Depend on Age & Sex .& Visit Date, or for All Patient (Ascending By Patient Name & Visit-Date & Age, See Figure(20)) .
- The main causes of the disease.
- The Diagnosis. for each patient Depend on Age & Sex .& Visit Date
- The Treatment plan. for each patient Depend on Age & Sex .& Visit Date
- All Queries .
- All Static.
- All Health Problem for each patient Depend on Visit Date.
- Missing Teeth & Classification Angle. For each patient Depend on Sex .& Visit Date, or for All Patient . (See Figure(21))
- Habit History For each patient Depend on Age & Sex .& Visit Date, or for All Patient.



Figure(20) Report form for Helkimo Index

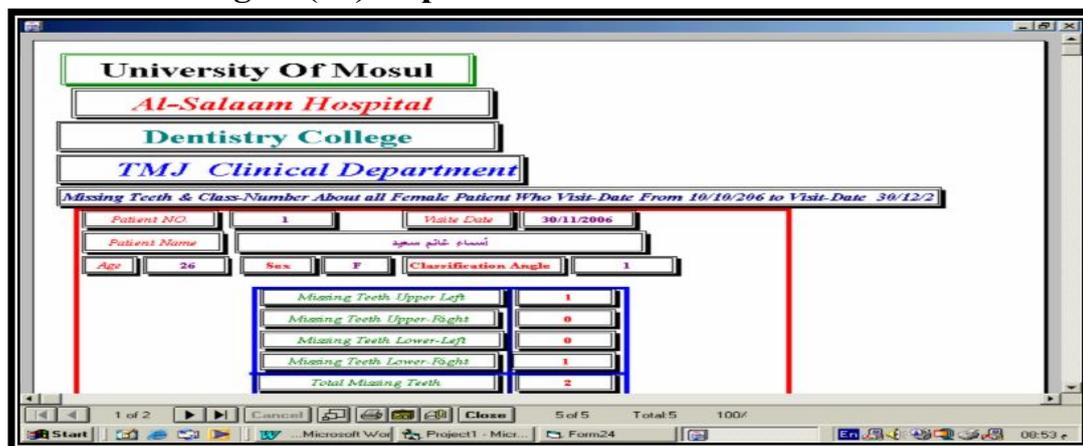


Figure (21) Report Form for Teeth

8-Conclusion

1. Practical results application have researched that the system designed characterized by a higher ability delicateness in calculating Helkimo Index. This consequently promoting the doctor's confidence in the criteria efficiency and dependence.
2. By using PCNN we could reduce the data dimension from(20 features –variables- to (13).
3. The benefits of automatic system provide a large amount of data; such as reports and statistics that may be used in scientific research projects.
4. By using posterior probability, we find that:
The patient may suffere from Locking with probability (0.259) more than from (Luxation) with probability (0.2020).

The probability of diagnoses Joint sound case given that Locking appeared is(0.989) greater than the probability of diagnoses Joint sound case given that Luxtation appeared (0.959).

5. BBN define probabilistic (dependencies & independencies) among the variables as well as they may reflect causality.
6. By using BBN we could diagnosis if someone suffer from Joint Sound with many cenarios.
7. Practical results application demonstrated that the adoption of designed programs in TMJs clinic would achieve very time and effort saving procedure paid by doctor.

9- Recommendation

1. Connecting this clinic with other clinics within a network that contains a system framework for all dental clinics, this is because the outputs of this clinic are benefited in other dentistry clinical framework.
2. This system is considered to be a developed beak through in the fields of oral surgery & TMJ.
3. The expansion of networks for the matter of use in the statistical methods for flexibility that may recognize the artificial networks .
4. The Use of BBN to obtain Diagnostic inference about (from Cause to effect and from effect to Cause) is most benefit for medical research .

Reference

المصادر العربية:

1. الهاشمي، أحمد (2005) ، " مبادئ قواعد البيانات العلائقية وطرق تصميمها " ، الاتحاد العربي للمبرمجين والمطورين والمصممين العرب .
2. المشكوري ،سعاد خلف سليمان (2001)، " مقارنة أسلوبى المركبات الأساسية و التحليل العاملي لمعالجة مشكلة التعدد الخطي في السيطرة النوعية مع تطبيق عملي " ، أطروحة دكتوراه ، كلية الإدارة والاقتصاد ، جامعة بغداد .

المصادر الأجنبية:

- 3- Ankush Mittal & Ashraf Kassim,(2007),"Bayesian Network Technologies Application and Graphical Models", Idea Group Inc,PP:135-136 .
- 4- Dvavlo E., & Patrick Naim,(1991) "Neural Networks" , Macmillan , HongKong.
- 5- Edward K. Reiman (2006),"The ABCS of TMJ/TMD Diagnosis & Treatment",. Rutland .

- 6- Galdonmj, Dura E .,Andreu, Y. ,Ferrando, M. ,Poveda, R.,Began JV,(2006),"*Multidimensional approach to the differences between muscular and auricular temporomandibular patients :coping ,distress ,and pain*" , Department of personality, assessment, and psychological treatment, University of Valencia, Valencia, Spain
- 7- Garcia-Molina, Hector , Ullman, Jeffrey & Widom, Jennifer , (2009) , "DATABASE SYSTEMS",2ndEdition, Pearson Prentice Hall, P703 .
- 8- Grant,O.(2007),"*About TMJ Disease/Disorders*" ,The TMJ Association,P1 .
- 9- Hannu, Pitkänen (1998), "*Multivariate Statistical Methods in Systems Engineering*", John Wiley and Sons, Inc., ch.10.
- 10- Hyvarinen, et al (2001)."*Independent Component Analysis*", John Wiley and sons, Inc., ch.6.
- 11- Jacek M. Zurada (1996), "*introduction to Artificial Neural System*", 2nd Edition., West P.C. New York .
- 12- Jae K.,Lee,(2009),"statistical bio-informatics: for life and biomedical science researches", *John Wiley and Sons, chapter(11),PP:259-269* .
- 13- Jose C.P., et al(2000), "*Neural and Adaptive systems: Fundamental through Simulation*", John Wiley and Sons, Inc.
- 14- Luger, George F. & Stubblefield, William A.(1998),"*Artificial Intelligence*", 3rd Edition , Addison Wesley Longman , Inc ,P1
- 15- Ozcelik TB,Erosy AE(2006),"*Temporomandibular joint clicking noises caused by a multilocular bone cyst: a case report*" ,J contempt Dent.pract,7(3),PP:99-105
- 16- Sandra R. Gordon, Addy M. Kujawa(2003):"*About TMJ Disease/Disorders*", The TMJ Association,P1.
- 17- Scott Evic, Coull,(2009):"*Methods For Evaluation The Privacy of A nony Mized Network*" .PP:68-69.
- 18- Simon Haykin(1999):"*Neural Network :A Comprehensive Foundation*",2nd edition, Prentice Hall, London .
- 19- Rao H.& Rao V.(2000):"*C++ Neural Network And Fuzzy Logic*" ,PP: 2- 4.
- 20- Vwani P., etal. (1998):"On relative convergence properties of principal component Analysis", IEEE Trans on Neural network, vol.9, No.2.