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University of Alberta

A Computer-Based Decision Support System for Orthodontic Diagnosis and Treatment Planning

by

C. Lesley Williams 

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the Degree of
Masters of Science
in Orthodontics

Department of Oral Health Sciences

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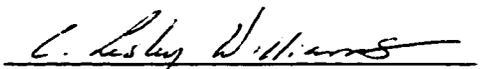

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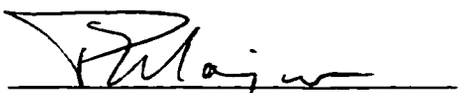

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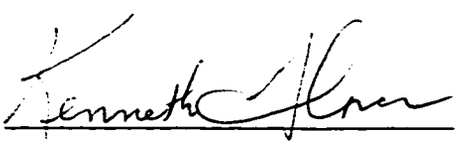

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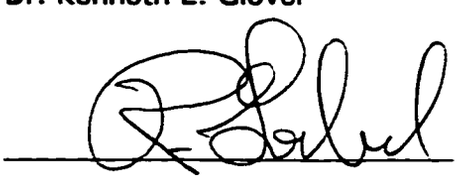

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Date: February 10, 1999

DEDICATION

This thesis is dedicated to my father, Charles Williams, who is not here to celebrate its completion. I know he would be very proud. It is also dedicated to my friend Sherre Friberg whose strength, courage and grace continue to inspire and amaze me.

ABSTRACT

The purpose of this project was to develop a prototype computer-based decision support system which focused on decision making in orthodontic diagnosis and treatment planning. More specifically, the decision support system was designed to help novice orthodontists work with and analyze a complicated database. In addition, the system was designed to help novice orthodontists critically evaluate their diagnosis and treatment planning decisions through using a knowledge base comprising expert feedback and structured literature reviews.

The system, named ORTHO1, was designed in modules set up for expert and novice input, case comparison and learning. A set of 10 clinical cases were analyzed independently by 3 expert orthodontists, 1 expert oral surgeon, and 4 novice orthodontists. In conjunction with relevant scholarly literature, the information provided by the experts was used to construct a system knowledge base. The novice orthodontist's input related to the clinical cases comprise the system's clinical database.

The system was tested by the novice orthodontists. Each novice case analysis was compared to the stored set of expert case analyses. By selecting the expert case which best matched the novice case, the novice orthodontist analyzed his or her decision making relative to that of the experts.

The ORTHO1 system provided the novice orthodontist with an opportunity to learn from the knowledge base. Such feedback provided an opportunity for the novice orthodontists to critically evaluate their diagnosis and treatment planning decisions. The ORTHO1 system also provided novice users with opportunities to change their input, thereby reflecting the learning which occurred during the use of the system.

The ORTHO1 prototype is the product of the initial stages of overall system development. Extensive system testing and evaluation are the next important steps in the development process. Following this, system implementation is possible.

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CHAPTER 1

CHAPTER 1

GENERAL INTRODUCTION

1.01 Introduction

The specialty of orthodontics has its formal origins in the late nineteenth century. Over the last 100 years, scientific research and technological advances have contributed greatly to the related body of knowledge. More recently, new scientific findings and improved technology have placed significant demands on the orthodontist. The need to apply proven principles, new scientific information, and new technology to clinical practice means the orthodontist must assimilate large amounts of information. This information must then be integrated with a complex clinical database in the process of establishing the best treatment for each patient.

Historically, orthodontists did diagnosis and treatment planning manually. Since the 1970's, orthodontists have used computer software programs designed to perform specific tasks which support the diagnosis and treatment planning process.[1] Stheeman reported that the majority of expert systems in dentistry were designed to support diagnosis and few were designed to support treatment planning.[2] Recent advances in computer hardware and software technology, and the near universal use of high powered personal computers means affordable and accessible tools now exist, which can be used to develop a computer-based decision support system.[3] A decision support system is not simply task oriented, but is designed to support and enhance the decision making process. Systems have been developed to support decision making in medicine; however, to date few systems have been developed in the specialized area of orthodontics.

Even the most experienced clinician finds the process of diagnosing and treatment planning an orthodontic case challenging. Specialized academic training and clinical experience have long been the clinician's tools. The challenge is even greater for the novice orthodontist armed with current knowledge and limited clinical experience.

The purpose of this project was to develop a prototype computer-based decision support system which focused on decision making in orthodontic diagnosis and treatment planning. More specifically, the decision support system was designed to help novice orthodontists work with and analyze a complicated database. In addition, the system allows novice orthodontists to critically evaluate their diagnosis and treatment planning decisions

through using a knowledge base comprising expert feedback and structured literature reviews.

Given the specialized nature of the practice of orthodontics, and the unique diagnosis and treatment planning process which is typically used, a very limited amount of background dental or orthodontic literature was found related to decision support systems. As a result, much of the related literature comes from medicine. The following sections contain a selected review of literature which pertains to the computer-based decision support system developed for this project. The areas of unaided decision making, dental and medical informatics, knowledge based systems, expert systems, literature support for decision making, and orthodontic diagnosis and treatment planning are reviewed.

1.02 Problems With Unaided Decision Making

Weed wrote that "the current practice of medicine relies far too heavily on the uncontrolled and unsupported exercise of human judgment extemporaneously applied at the time of decision making". [4] Weed noted that difficulties in making sound clinical judgments follow from "the limitations of unaided human minds in applying a very large body of knowledge ". [4] Huth stated that a professional's "capacity for knowing is sharply limited by the brain's capacity for the storage of information and processing of it". [5]

Weed suggests that too much emphasis is focused on the educated expert, or specialist, placing a confidence in the expert which leads one to "trust the unaided human mind in the face of many variables at the time of problem solving". [6] He suggested that this notion can lead one to believe that education enables the specialist to readily integrate the best available knowledge into clinical decision making. Weed indicated that little emphasis is placed on the difference between "what the educated expert knows and what the problem really requires". [6] This notion is supported by Arnette who, with reference to diagnosis and treatment planning in orthodontics, suggested a need to view a clinical problem from a broader perspective. He stated that "we treat what we are educated to see. The more we see, the better the treatment we render our patients". [7] Proffit noted that "the natural bias of any specialist is to characterize problems in terms of his or her own special interest". [8]

Rowsell, and Adams et al, demonstrated that the quality of decision making improves by simply organizing the clinical data in a logical manner. [9, 10] Weed stated that "effective coupling of medical knowledge to action can be greatly facilitated by simple associative mechanisms" and suggested that medical content be stored in an efficient database structure.[11] Although orthodontists have done this manually for over a century, using computers can speed up the process and allow the orthodontist to manage significantly

larger, more complex, and hopefully more comprehensive databases. As noted earlier, computer software programs have typically been designed to support the diagnosis and treatment planning process, rather than to improve or enhance it.

In addition to the organizing the clinical database, a decision support system has a knowledge base. This can include pertinent literature and expert opinion. Integrating these components of knowledge is essential in clinical practice today, but is difficult for the clinician to do without the support of a computer system. Although the value of clinical experience cannot be underestimated, the value of this clinical experience is enhanced when combined with and supported by scholarly scientific literature. Weed noted that the unaided human mind is often unable to recall all the relevant patient data and the related opinions from the literature, "and is often unable to take those two bodies of information and integrate them systematically to come up with the best course of action". [11] This clearly indicates the need for a decision support system. The background information needed to support the development of a decision support system is in the area of informatics.

1.03 Dental Informatics and Selected Medical Informatics

Medical informatics is defined by Shortliffe " the rapidly developing scientific field that deals with the storage, retrieval, and optimal use of biomedical information, data, and knowledge for problem solving and decision making." [12] Dental informatics refers to the specialized field of dentistry.

The use of computers in medicine and dentistry began in the 1960's. About a decade later, computer systems were developed in medicine which were designed to improve diagnostic accuracy and help improve decision making performance.[13] Further developments in computer technology in the 1980's resulted in some significant advances in the field of clinical medicine.

Computer-aided decision support, a subspecialty of informatics, is defined by deDombal as a system "whereby the doctor feeds data (which he or she has elicited from an individual patient). The computer then performs some kind of comparative analysis on the new data and produces a prediction which the doctor then uses in order to assist in diagnosis and/or patient management." [14]

Siever noted that "the ultimate goal of medical computer systems is to help clinicians make good decisions." [15] He stated that systems which provide clinical decision assistance will significantly affect clinical practice.

It is with the understanding that a limited amount of work has been done in the field of dental informatics specifically related to decision support in orthodontics that this project was chosen.

The following section provides some background information on the informatics concepts which have been used to help design the decision support prototype for this project.

1.04 Knowledge Based Systems, Expert Systems, and Literature Support

Knowledge Based Systems

Knowledge-based systems are computer systems designed to help generate quality solutions to problems. In the context of the system, knowledge refers to organized information that conveys concepts to help improve the efficiency and effectiveness of the problem solver. The knowledge based system is a means by which the knowledge can be used by a problem solver to reach an acceptable solution.

Hayes-Roth concluded that knowledge based systems have attained a "permanent and secure role in industry."[16] One of the assets of the knowledge based system is its interactive nature. It can interact with individuals and with other computer systems such as MEDLINE or on-line library systems or databases. Hayes-Roth noted that knowledge based systems are presently "leading the charge towards a new generation of cooperative systems".

Two examples of knowledge which can be incorporated into a knowledge based system are expert opinion and supporting literature. A specialized form of a knowledge based system is an expert system.

Expert Systems

An expert system is a computer-based decision support system which uses expertise as a knowledge base. The purpose of an expert system is to capture and use knowledge from high level experts and use that knowledge to assist the less proficient or experienced system users." [17] Expert systems can also store and process significantly larger amounts of information than can the human brain.[18] Therefore, expert systems can provide an individual with large amounts of knowledge relevant to his or her clinical area. The system can also be used as a tool for manipulation and storage of large amounts of patient information.

An expert is defined by Siever as a source of information. [15] This source of information can be applied by humans or machines and, in medicine or dentistry, can be in the form of an expert clinician's opinion or scholarly literature. Hayes-Roth noted that expert clinicians

are "distinguished by the quantity and quality of knowledge they posses". [19] He suggests that the experts' knowledge makes them more efficient and effective.

Research has shown that diagnostic accuracy can be improved with the use of a well designed expert system. The expert knowledge contained within the system can be used to help system users as follows: 1) by marshaling relevant facts; 2) by helping to avoid common errors; 3) by helping to eliminate redundancy; 4) by helping to reduce ambiguities; 5) by exploiting knowledge from complementary disciplines; 6) by analyzing problems from different perspectives or levels of abstraction. [19]

Two important factors in the quality of an expert system include the clinical experts, and the quality of the literature support. The clinical expert must be able to articulate the reasoning process or rationale related to the problem domain and must be willing to participate openly in the knowledge acquisition process. The literature used in the knowledge base must be scholarly and of high quality. The following section addresses the main issues related to literature support.

Literature Support

The explosion of scientific literature during the last two decades forced the National Library of Medicine to create a new computerized method of cataloging information sources or searching for scientific literature.[20] The resulting system, MEDLINE, is now highly sophisticated and is considered to be the major source of biomedical information.[21] On-line and CD ROM versions of MEDLINE have resulted in increased accessibility to users.

Blythe reviewed literature on information seeking behaviors of health science professionals. Blythe noted that health professionals need "knowledge - specialized and relevant information - to enable them to make professional judgments."[22] Unfortunately, health science professionals do not utilize this information optimally, and even on-line access to MEDLINE is underutilized.

Gruppen analyzed information sources used by physicians and noted that younger physicians and specialists rely on journal publications while older physicians tend to rely on continuing education presentations for new information.[23] Similar data was not available for orthodontists, therefore a similar pattern is assumed to exist.

To be well informed on current topics in health sciences, current peer reviewed literature must be used by practitioners. Covell reported that typically these resources are not well utilized.[24] Gorman reported that physicians make little use of the medical literature to meet their information needs.[25] Journal literature, in print or electronic form, was rarely consulted. Huth noted that literature is not typically accessed by clinicians due to the time and cost associated with accessing the literature, the time required to synthesize the

literature, and the time and difficulty associated with judging the validity of the literature.[5] "Opinion leaders" or experts were reported to play a very important role in the dissemination of new ideas in medicine.[26] Oxman stated that clinicians who rely on community standards or opinion leaders tend to believe that they are receiving the "best available scientific information."[27] However, in comparing evidence-based practice with recommendations of clinical "experts", Stross found that expert opinion and standard practice "do not provide adequate mechanisms for the transfer of scientific information into clinical decision making."[28]

Connely noted that information sources were selected by physicians based on the greatest potential benefit related to cost, time, and effort required to use the source.[29] Huth suggests that critical or structured reviews of scholarly literature be collected in a database.[5] Given the American College of Physicians is aggressively promoting evidence-based medicine, which requires clinical decision making be supported by scholarly literature, the development of a knowledge base as suggested by Huth will be essential to clinical decision making in the future.[30]

The computer-based decision support system developed for this project includes structured literature reviews and expert opinion, clearly two very important components of the system's knowledge base. The structured reviews can be accessed by the user to help support the decision making process. Structured reviews are succinct one page summaries of literature. They are typically presented as an "expanded abstract" which outlines study objectives, study design, results, discussion, and conclusions. In addition, the related journal articles are available to the user and a list of related references is provided by the system. If the user does not have the time to read structured reviews or papers while using the system, he or she can refer to the reference list or papers at a convenient time. The objective for using this form of literature support was to provide a knowledge base which was relevant, readily accessible and convenient to use. A knowledge base which combines expert opinion and literature support is a powerful component of a decision support system. An example of a structured review and list of references relating to a specific parameter are shown in Appendix B, Figures B1 and B2.

Example of a Knowledge Based Computer System in Medicine

Adams reported that in 16,737 patients seen with acute abdominal pain in UK hospitals from 1988 to 1993: a 20 percent increase in accuracy in the diagnosis of acute abdominal pain followed the implementation of a knowledge-based computer system; improved decision making performance was noted, supported by a 50 percent reduction in negative

laporotomy findings; and over 5 million British pounds were saved.[31] Similar findings have been reported by Myren in the field of gasteroenterology.[32]

The computer-aided decision support to the diagnosis of abdominal pain project (CADAP) also used the knowledge based computer system as a teaching tool for junior surgeons. Following a one year trial, the diagnostic accuracy of the junior surgeons had improved by 24 percent (from 39 to 63 percent). This improved performance by junior surgeons was again shown in an additional one year trial of the CADAP project.[31] Interestingly, those hospitals that did not continue using the CADAP system reported a reduction of diagnostic accuracy to near base levels.[9]

As reported by Adams, deDomba, Myren, and others, the introduction of computer-aided decision support can help teach clinicians to improve their diagnostic accuracy and improve clinical performance. Rowsell stated that, given the "overwhelming evidence of world-wide studies", decision support using knowledge-based systems "has much to offer a wide medical audience".[9]

Some Expert Systems in Dentistry

Some expert systems have been developed in dentistry. Four examples are listed below. The first two, oral diagnosis and oral radiographic diagnosis, are systems which support diagnosis in the specified areas in clinical dentistry. The later two examples, expert system for orthodontic diagnosis and Jerimiah, support diagnosis related to simple orthodontic problems, provide some decision support for general practitioners, and help these practitioners determine if referral to an orthodontist for more detailed assessment is required. Note that none of these systems have a primary focus on the treatment planning process nor are they designed for use by orthodontic specialists.

a) Expert System for Oral Diagnosis

In the early 1980's, Weed and Hertzberg designed an expert system which was applied in the area of oral diagnosis. Given a specific clinical problem, the database contained lists of possible causes, findings, comments, literature references, and opinions regarding patient management.[33] The system displayed a list of generic comments pertaining to the clinical problem and related literature references.

b) Oral radiographic Diagnosis (ORAD)

Oral radiographic Diagnosis (ORAD) was designed to aid in differential diagnosis of radiographic findings.[34] The program used analytical decision making tools to calculate, given the patients reported symptoms, the most likely diagnosis. Analytical decision making

is based on Bayes Theorem, which incorporates a probabalistic algorithm. When applied in decision analysis, one can calculate the probability that a given patient is suffering from a specific disease. For this type of reasoning to be useful, the prevalence of disease and symptoms in the population must be known.[35] A significant amount of background data is needed for this type of algorithm to produce meaningful results.

c) Expert System for Orthodontic Advice

Sims-Williams developed an expert system to support decision making in orthodontic diagnosis and treatment planning by general practitioners.[36] The purpose of the project was for the expert system to provide an orthodontic consultative service for general practitioners. The dentist could get some limited diagnostic and treatment advice from the system and determine if a consult with an orthodontist was required.

d) Jeremiah - Expert System

This system is designed to support decision making in orthodontic diagnosis. It was developed for use by the general practitioner. The system assumes that the user has no knowledge of orthodontics. Jerimiah is reported to provide a "recommended " treatment plan or suggest the patient be referred to an orthodontist for assessment. [37]

1.05 Diagnosis and Treatment Planning in Orthodontics

The problem domain for this research project is specific to diagnosis and treatment planning in orthodontics. To highlight the complexity of this process and to outline the context in which this research project has been developed, this selected literature review on diagnosis and treatment planning has been included.

Diagnosis and treatment planning have been shown to be key to successful orthodontics. Proffit, and Proffit & Ackerman describe a contemporary approach to diagnosis and treatment planning which promotes the "problem oriented approach". [38, 39] Proffit makes a clear distinction between the functions of diagnosis and treatment planning, and suggests that both components must be used when determining the best treatment for a given patient.[38] The series of logical steps in diagnosis and treatment planning outlined by Proffit are as follows [40]:

Diagnosis

- development of an adequate diagnostic database,
- formulation of a problem list, which is the diagnosis derived from the database.

Treatment Planning

- prioritization of the items on the orthodontic problem list, so that the important problem receives highest priority for treatment,
- consideration of possible solutions to each problem, with each problem evaluated for the moment as if it were the only problem the patient had,
- evaluation of the interaction among possible solutions to the individual problems,
- synthesis of an optimum treatment plan calculated to maximize benefit to the patient and minimize risk, cost, and complexity,
- presentation of the plan to the patient in such a way that informed consent is obtained.

To assemble a comprehensive database, Proffit recommends three major sources of information. [40]

- patient questionnaire
  - chief complaint / medical and dental history / physical, growth evaluation / social and behavioral evaluation.
- clinical examination
  - evaluation of facial esthetics / oral health / jaw and occlusal function / assessment of requirements for diagnostic records.
- evaluation of diagnostic records
  - cast (model) analysis / cephalometric analysis.

Proffit, and Moorrees & Grφn emphasize the importance of comprehensive orthodontic treatment planning.[41]. [42] Moorrees & Grφn stated that "as in medicine, diagnosis is an analytical process that constitutes an essential link between clinical examination and all aspects of treatment". [43] The authors emphasize the need for comprehensive consideration of the patient in diagnosis and treatment planning, and stress the importance of data gathering. Important data includes a comprehensive examination of the head and neck, intra-oral structures, extra-oral structures, radiographs (intra-oral and cephalometric), and photographs (intra-oral and extra-oral).

Proffit refers to truth and wisdom as two components of the diagnosis and treatment planning process. Truth is required during the acquisition of a database and the establishment of a problem list. Wisdom is required to devise a "plan that a wise and prudent clinician would follow to maximize benefit for the patient".[41]

In the pursuit of wisdom, one cannot overlook history. Wisdom comes from the evaluation and synthesis of all we are exposed to. Alton Moore, in a critique stated that "orthodontic dogma based on truth provides an orderly approach to orthodontic problems; however, that based on fiction may lead to professional or intellectual chaos".[43] Dogma as defined by Webster is "a principle belief or idea, especially one considered to be absolute truth" .[44] The purpose of Moore's critique was to "discuss some of the principles, beliefs and opinions that have influenced the development of orthodontic science" during his time. In so doing, he outlined some significant factors in orthodontic history and echoed some ideas still carefully considered today. In particular, Moore emphasized the importance of careful diagnosis and treatment planning.

Arnette, in a recent article on facial keys to orthodontic diagnosis and treatment planning, noted that "we treat what we are educated to see. The more we see, the better the treatment we render our patients" .[45]

It is in the pursuit of wisdom, the desire to see more, and the need to understand the process of diagnosis and treatment planning, that this research has been developed.

As noted in the introduction, the orthodontist must develop what an adequate diagnostic database necessary to evaluate each case. Diagnostic aids such as study models, radiographs, photographs, diagnostic set-up, clinical exam, indices and formal analyses are used. Moore suggested that diagnostic aids can be divided into two categories and evaluated based on five criteria.[46]

Categories of Diagnostic Aids

- Objective - specific methods
- Subjective - subject to adjustment and evaluation by the orthodontist

Criteria For The Evaluation of Diagnostic Aids

- It must correlate or be compatible with other methods of assessment
- Standards should be based upon scientific knowledge and not on personal opinion
- To be useful clinically, the proposed standard must point to a therapeutic solution that is attainable through orthodontic therapy.
- It must be readily understandable and applicable by the clinician.
- Standards to be useful universally must allow for variability between clinical operators and the treatment methods employed.

In the late 1960's, computers were introduced into orthodontic diagnosis and treatment planning. To date, computers have been considered to be aids to orthodontic diagnosis and treatment planning. Faber, Burstone, & Solanche reflected on the introduction of this new

technology.[1] Advances in technology have contributed to the production of electronic aids to the orthodontist which can be used to organize and display information required for comprehensive diagnosis and treatment planning. The authors listed some advantages of computer systems (circa 1978).[1]

- the ability to integrate a more thorough data base when developing a treatment plan,
- the ability to establish a detailed treatment plan which includes all steps for evaluation,
- a graphic visualization of projected treatment changes,
- the development of a data storage and retrieval system specific for each step of the diagnosis and treatment planning process,
- the ability to benefit from improved efficiency.

Note that, presently, computer technology has rocketed beyond the imaginations of the forefathers of orthodontics such as Angle and Tweed, and probably outstretched the imaginations of Moore, Proffit and others.[46,47] However, the fundamental principles of diagnosis and treatment planning presented by these authors form the foundation of the diagnosis and treatment planning process used by orthodontic practitioners of the 1990's. It is hoped that computer based decision support systems will one day be a standard tool used in orthodontic diagnosis and treatment planning.

1.06 Objectives of the Project

The main purpose of this project was to develop a prototype computer based decision support system which focused on decision making in orthodontic diagnosis and treatment planning. The decision support system was designed to help novice orthodontists work with and analyze a complicated database, and to critically evaluate their diagnosis and treatment planning decisions. Specific objectives for this computer based decision support system include the following:

- identify areas within the diagnosis and treatment planning process where novice orthodontist's decisions vary significantly from a group of experts,
- categorize and analyze areas identified within the novice orthodontist's decision making process that differ from the experts and,
- provide structured feedback related to the identified variations in decision making between the group of experts and the novice orthodontist.

1.07 Research Questions

- Can expertise within the domain of orthodontic diagnosis and treatment planning be structured so that it can be represented within a computer system?
- Can expertise within the domain of orthodontic diagnosis and treatment planning be used to assist novice orthodontists in decision making?
- Can a computer system, when dealing with problem solving in orthodontic diagnosis and treatment planning, help identify areas of weakness for the purpose of learning?

1.08 Research Hypotheses

- Using novice analyses of clinical cases as a clinical database, and expert analyses of clinical cases plus scientific literature support as a knowledge database, a prototype of a computer based decision support system can be designed. The decision support system can be designed to show how structured feedback can be organized and used in the decision making and learning process related to orthodontic diagnosis and treatment planning.

- Orthodontic diagnosis and treatment planning expertise can be formalized and structured into a decision support system, to support and improve the decision making and learning process of novice orthodontists.

1.09 Summary

In the development of this project, two assumptions were made: 1) By developing a database structure to help organize and store clinical case data, an orthodontist can potentially access and utilize all the information available in an efficient manner; 2) By enhancing the database to include expert opinion and literature support, a knowledge base can be included. The system can then provide the user structured feedback to help him or her improve, or at least critically evaluate, his or her decision making.

This research project was developed with the following in mind: 1) unaided clinical judgment can be flawed; 2) a complex clinical database must be assembled and analyzed for use in orthodontic diagnosis and treatment planning; 3) expert clinical opinion combined with and supported by good scientific evidence is key to providing a knowledge base; 4) novice orthodontists can benefit greatly from structured feedback in the diagnosis and treatment planning process and ; 5) a computer based decision support system can be

developed to support and enhance the diagnosis and treatment planning process in orthodontics.

BIBLIOGRAPHY

UNAIDED DECISION MAKING

1. Tversky, A., Kahneman, P. Judgement Under Uncertainty: Heuristics and Biases in Medical Decision-Making. Science 1992;185:1124-1131.

2. Weed, L.L. Knowledge Coupling, New Premises and New Tools for Medical Care and Education. Ann Arbour, Springer-Verlag, 1991.

3. Weed C.C. Problem-Knowledge Coupling. Mt. Sinai Journal of Medicine 1982; 52,2:94-8.

4. Weed L.L. Knowledge Coupling, Medical Education and Patient Care: Mistaken Premises and Inadequate Tools. Critical Reviews in Medical Informatics 1986,1;1:55-79

5. Weed, L.L.. Medical Records, Medical Eduation, and Patient Care: the Problem Oriented Record as a Basic Tool. Cleveland, 1969, Case-Western Reserve Press.

DENTAL and RELATED MEDICAL INFORMATICS

6. Abbey L.M. An Expert System For Clinical Teaching In a School of Dentistry. In: Salamon R., Protti D., Moehr J. (eds) Medical Informatics & Education International Symposium Proceedings. British Columbia:1989, Queen's Printer: 364-366.

7. Abbey L.M. Informatics in Dental Education: A horizon of opportunity. In: Salamon R, Protti D, Moehr J (eds) Medical Informatics & Education International Symposium Proceedings. British Columbia: 1989, Queen's Printer: 359-363.

8. Adams, I.D., Chan, M., Clifford, P.C., et al. Computer Aided Diagnosis of Abdominal Pain: A Multi-centre Study. British Medical Journal. 1986, 293:800-804.

9. Babad, Y.M., Hoffer J.A. Even No Data Has Value, Commun ACM 1984; 27 :748-756.

10. Bankowitz, R.A., McNeil M.A., Challinor S.M., Praker R.C., Kapoor, W.N., Miller R.A. Computer Assisted Diagnostic Consultation Service: Implementation and Prospective. Ann Int Med 1989; 110,10:824-832.

11. Bankowitz, RA, Lave, JR, McNeil, MA. A Method of Assessing the Impact of A Computer-Based Support System on Health Care Outcomes. Methods of Information in Medicine 1992;31,1:3-10.

12. Benson, P.E., Stephens, C.D., O'Brien, K.D. Orthodontic Products Update - Current Software for Teaching Orthodontics. Br J Orthod 1991 ; 23,1:72-76.

13. Cook, Thomas; Russell, Robert A., Introduction to Management Science, 4th Edition. Prentice-Hall. New Jersey, 1989.

14. Council on Dental Practice. Computer Technology in Dental Practice. JAMA 1980;101:938-943.

15. Davis, D. N., Taylor, C. J.. A Blackboard Architecture for Automating Cephalometric Analysis, Med. Informat. 1991;16,2:137-149.

16. Dalrymple, P.W.. CD-ROM MEDLINE and Users: Infromation Transfer in the Clinical Setting. Bull Med Libr Assoc 1990;78, 3:224 - 232.

17. deDombal, F.T. Computer-Aided Decision Support in Clinical Medicine. Int J Biomed Comp 1989; 24,9:9-16.

18. deDombal, F.T., Dallos, V., McAdam, W.A.F.. Can Computer Aided Teaching Packages Improve Clinical Care in Patients with Acute Abdominal pain? Yearbook of Medical Informatics 1992:286-288.

19. deDombal, F.T.. The Develpoment of Knowledge-Based Decision Support from 1955 to 2005. Theoretical Surgery. 1993, 299:1-8.

20. Essin D.J.: Experimental Identification of Technical and Data Base Factors That Can Affect The Success of Clinical Computer Systems. Int J Clin Monitor Comput 1988;5: 207-215.

21. Evidence-Based Working Group. Evidence Based Medicine: A New Approach to Teaching the Practice of Medicine. JAMA. 1992;268:2420-2425.

22. Evaluation of A Prototype, Ann Int Med 1989; 110: 824-832.

23. Donabedian, As. The Quality of Care - How Can It Be Assessed? JAMA 1990;260,12: 1743 - 1748.

24. Finkelstein M.W., Johnson L.A., Lilly, G.E. Interactive Videodisc Patient Simulations of Oral Diseases. J Den Ed 1988;52:217-220.

25. Gardner RM. Computerized Management of Intensive Care Patients. MD Computing 1986;3: 36-51.

26. Howard, R.A.. Decision Analysis: Applied Decision Theory. In: Hertz, D.B.; Melese, J., eds. Proceeding of the Fourth International Conference on Operations Research. New York: Wiley- Interscience , 1986: 55-71.

27. Kaldenberg, D.O., Becker,B.W., Hallan, J.B. Dentisty in the Year 2000: Assessments from a Delphi Panel. J Am Coll Dent 1990; 57:20-28.

28. Lau, F., Hebert, M., Simpson, J.. A Scientific Approach to Evaluating Health Information Systems. Workshop Presented for EDM Management Systems, Edmonton, Alberta. July 22, 1995.

29. Levy-Maydell, A.D., Venetsanopoulos, A.N., Tsotsos, J. K.. Knowledge-based Landmarking of Cephalograms. Comput Biomed. Res.1986; 19: 282-309.

30. McAdam, W.A.F., Brock, B.M., Armitage, T., Davenport, P., Chan, M., deDombal, F.. Twelve Years' Experience of Computer-Aided Diagnosis in a District General Hospital. Annals of the Royal College of Surgeons of England 1990;72:140-146

31. Myren, J., Bouchier, I.A.D., Watkson, G., deDombal, F.T. Report of World Organisation of Gasteroenterology. Scand Journal of Gastero 1988, Supplement 23:144

32. Nathwani BN, Horvitz EJ. Heckerman DE and Lincoln TL: Integrated Expert Systems And Videodisc In Surgical Pathology: An Overview, Hum Pathol 21 (1990) 11-27.

33. Richardson, W.S., Detsky, A.S., User's Guide to the Medical Literature. How to Use a Clinical Decision Analysis. JAMA 1995;273,20:1610-1613.

34. Richards, D., Lawrence, A. Evidence Based Dentistry. Brit Dent J 1995;:270-273.

35. Richardson, W.S., Detsky, A.- For the Evidence -Based Working Group. User's Guide to Medical Literature. VII. How to Use a Clinical Decision Analysis. A. Are the Results of the Study Valid? JAMA 1995;273,16:1292-1295.

36. Richardson, W.S., Detsky, A.- For the Evidence -Based Working Group. User's Guide to Medical Literature. VII. How to Use a Clinical Decision Analysis. B.What Are the Results and Will They Help Me in Caring for My Patients? JAMA 1995;273,20:1610-1613.

37. Rowsell , K.V.The Application of Knowledge Based Decision Support: Computer-Aided Diagnosis of Abdominal Pain at Ormskirk & District General Hospital, 1988-1993. South Lancashire Health Authority. 1993:12-15.

38. Salley J.J., Abbey L.M. A University Based Diagnostic and Treatment Knowledge Base with Links to Community Dental Practice. In: Salamon R., Protti D., Moehr J. (eds) Medical Informatics & Education International Symposium Proceedings. British Columbia: Queen's Printer,1989: 371-373.

39. Salley, JJ.; Zimmerman, J.L.; Ball, M.J. (Eds.).Dental Informatics: Strategic Issues For The Dental Profession. New York, 1990,Springer-Verlage.

40. Shortliffe, E. H.,Perreault, L.E. (Eds.) Medical Informatics, Computer Applications in Health Care.1990. New York, Addison-Wesley Publishing Company.

41. Shortliffe, E.H.. Computer Programs to Support Clinical Decision Making. JAMA 1987;258:61-66.

42. Siever, Adam; Holtzman, Samuel. Decision Analysis: A Framework for Critical Care Decision Assistance. Int J Clinical Monitor Comp. Volume 6, 1989, pp.137 - 156.

43. Van Bemmel, J.H..The Structure of Medical Informatics. Medical Informatics. 1984; 3:175-180

44. vanGinneken, A.M..The Structure of Data in Medical Records. Yearbook of Medical Informatics 1995:61-70.

45. Wilson, P.D., J.C., Young, C.K., Lyndon, P.J., Page, R.E., deDombal, F.T.. Computer Aided Diagnosis of Abdominal Pain: a multi -centre Study. Brit Med J, 1986; 293:800-804.

46. Wilson P.D., Horrocks J.C., Young C.K., Lyndon P.J., Page R.E., deDombal F. Computer Aided Diagnosis of Acute Abdominal Pain Using Simple Inexpensive Equipment and "Untrained" Personnel. Brit Med J 1975, 11: 73-75.

47. Wyatt, J.; Spiegelhalter, D.. Evaluating Medical Expert Systems: What to Test and How? . Medical Informatics, 1990. Vol. 15, No. 3, pp. 205 - 217.

48. Yan C. K., Venetsanopoulos, A.N., Filleray, E.D. "An Expert System for Landmarking of Cephalograms." Proceedings of the Sixth International Workshop on Expert Systems and Applications, 1980: 337-356.

49. Yoon, Y., Guimaraes, T., O'Neal, Q..Exploring the Factors Associated With Expert Systems Success. MIS Quarterly. March 1995.

50. Zimmerman, J.L.; Ball, M.J.; Petroski, S.P. .(1982). Computers in Dentistry. The Dental 30:739-744.

KNOWLEDGE BASED SYSTEMS, EXPERT SYSTEMS AND LITERATURE SUPPORT

51. Brown, I.D., Adams, S.R., Stephens, C.D., Errit, S.J., Sims-Williams, J.H. The Initial Use of a Computer-Controlled Expert system in the Treatment Planning of Class II Division I Malocclusion. Br J Orthod 1991;18:1-7.

52. Blythe, J.M.. Information Seeking- Patterns of Health Science Professionals. Bibliotheca Medica Canadiana 1992;14, 2 : 82- 89.

53. Covell, D.G. Information Needs in Office Practice: Are They Being Met? Ann Intern Med 1985;103:596-599.

54. Connely, D.P., Rich, E.C., Curley, S.P., Kelley, J.T. Knowledge Resource Preferences of Family Physicians. J Fam Prac. 1990; 30: 355-359.

55. Curtis, K.L., Weller, A.C., Hurd, J.M.. Infromation Seeking Behavior: A Survey of Health Sciences Faculty Use of Indexes and Databases. Bull Med Libr Assoc 1993; 81, 14; 383-390.

56. Dalrymple, P.W.. CD-ROM MEDLINE and Users: Infromation Transfer in the Clinical Setting. Bull Med Libr Assoc 1990;78, 3:224 - 232.

56. Gorman, P.N., Ash, J., Wykoff, L.. Can Primary Care Physicians' Questions be asked Using the Medical Literature? Bull Med Libr Assoc 1994;82,2:140-146.

57. Gruppen, L.D.. Physician Information-Seeking: Improving Relevance Through Research. Bull Med Libr Assoc1990;78,2:165-171.

58. Huth, E.J., The Use of Medical Literature. Ann Int Med 1989;110,2: 99-100.

59. Haynes, B.R., Hayward, R.S.A., Lomas,J.. Bridges Between Health Care Research Evidence and Clinical Practice. JAMIA 1995;2,6:342-347.

60. Kinney L.E. Expert Systems. Who Needs Them? (editorial). Chest 1987;91:3-4.

61. Mackin, N., Sims-Williams, J.H., Stephens, C.D. Artificial Intelligence in the Dental Surgery: An Orthodontic Expert System, A Dental Tool of Tomorrow. Dental Update. 1991, 10:341-343.

62. Oxman, A.D., Cook, D.J., Guyatt, G.H.. User's Guide to the Medical Literature. JAMA 1995;272,17:1367-1371.

63. Sims-Williams, J.H., Brown, I.D., Matthewman, A., Stephens, C.D. A Computer Controlled Expert System for Orthodontic Advice. Brit Dent J 1987 163;5:161-166.

64. Stephens, C.D., Mackin, N., Sims-Williams, J.H. The Development and Validation of an Orthodontic Expert System. Brit J Orthod 1996;23 :1-9.

65. Stheeman,S.E., vanStelt,P.F., Mileman,P.A.. Expert Systems in Dentistry. Past Performance- Future Prospects. J. Dent. 1992;20:68-73.

66. Stinson, E.R., Meuller, D.R.. Survey of Health Professionals Information Habits and Needs Conducted Through Personal Interviews. JAMA 1982; 243,2:140-143.

67. Stross, J.K., Harlin, W.R. The Dissemination of New Medical Information. JAMA 1979;241:2622-2624.

68. Weinberg, A., Ullian, L., Richard, W.D., Cooper, P.. Informal Advice and Information-Seeking Between Physicians. J Med Ed. 1881; 56: 175-180.

69. Williamson,J.W., German, P.S., Weiss, R., Skinner, E.A., Bowes, F. Health Science Information Management and Continuing Education of Physicians; A Survey of U.S. Primary Care Practitioners and Their Opinion Leaders. Ann Intern Med 1989;110:151-160.

70. Wilson, M.C., Hayward, R.S., Tunis, S.R., Bass, E., Guyatt, G.. User's Guide to the Medical Literature. JAMA 1995;274,20:1630-1632.

DIAGNOSIS & TREATMENT PLANNING IN ORTHODONTICS

71. Ackerman, J.L., Proffit, W.R.. The Characteristics of Malocclusion: A Modern Approach to Classification and Diagnosis. Am J Orthod, 1969;56: 443-454.

72. Ackerman, J.L., Proffit, W.R.. Treatment Response as an Aid in Diagnosis and Treatment Planning, Am J Orthod,1970, 57, 5: 490-496.

73. Alexander, T. A. ,Gibbs, C. H., Thompson, W. J., (1984). Orthodontic Treatment, Am J Orthod, Vol. 85, No. 1, January 1984 ,pp .21-27.

74. Andrews, L.. The Six Keys to Occlusion. Am J Orthod 1972;62,3:296-309.

75. Angle, E.H.. Treatment of Malocclusion of the Teeth, ed 7, Philadelphia 1900, S.S. White Dental Manufacturing Co.

76. Arnette. W.G., Bergman, R T..(1993). Facial Keys to Orthodontic Diagnosis and Treatment Planning . Part I , Am J Orthod 1993;103,4: 229-313.

77. Bolton, W.A. Disharmony in Tooth Size and Its Relation to the Analysis and Treatment of Malocclusion. Angle Orthod 1958; 27,3:113-130.

78. Bolton, W.A..(1962). The Clinical Application of a Tooth-size Analysis. Am J Orthod . 1962;48,7:504-429.

79. Faber, R. D., Burstone, C.J., Solonche, D.J. Computerized Interactive Orthodontic Treatment Planning. Am J Orthod ,1978; 73, 1: 36-46.

80. Jackson, J.M. Orthodontics in Search of a Common Denominator for Diagnosis and Treatment. Am J Orthod,1964;50, 2:125-136.

81. Jarabak, J.R.. Development of a Treatment Plan in the Light of One's Concept of Treatment Objectives. Am J Orthod 1960;46,7:481-514.

82. Moore, A.W. A Critique of Orthodontic Dogma . Angle Orthod. 1969;9, 2,: 69-82.

83. Moorees, C.F.A., Grφn, A.M. Principles of Orthodontic Diagnosis. Angle Orthod 1969;36,3:258-262.

84. Profitt, W.R. (1993). Contemporary Orthodontics, 2nd Edition, Mosby Year Book, Section III, Diagnosis and Treatment Planning, pp. 137 -264.

85. Ricketts, R.M., Roth, R.H., Chaconas, S.J., Schulhof, R.J., Engel, G.A.. Orthodontic Diagnosis and Planning. Rocky Mountain Data Systems, Denver, 1982.

REFERENCES

[1] Faber, R.D., Burstone, C.J., Solonche, D.J.. (1978). Computerized Interactive Orthodontic Treatment Planning. American Journal of Orthodontics. 1978;73,1:36-46.

[2] Stheeman, P.F., vander Stelt, Mileman, P.A. Expert Systems in Dentistry. Past Performance - Future Prospects. J. Dent. 1992;20:68-73.

[3] Shortliffe, Edward H.; Perreault, Leslie E.. Ed.. Medical Informatics, Computer Applications in Health Care.1990. New York, Addison-Wesley Publishing Company. p.20.

[4] Weed, Lawrence L., (1991), Knowledge Coupling. New Premises and New Tools for Medical Care and Education. New York, Springer-Verlag.p.xvi.

[5] Huth, E.J.,The Use of Medical Literature. Ann Intern Med 1989;110,2:99-100.

[6] Weed, Lawrence L., (1991), Knowledge Coupling. New Premises and New Tools for Medical Care and Education. New York, Springer-Verlag.p.1-2.

[7] Arnette. W.G., Bergman, R T. Facial Keys to Orthodontic Diagnosis and Treatment Planning . Part I , Am J Orthod 1993;103,4: 229-313.

[8] Profitt, W.R. (1993). Baltimore, Contemporary Orthodontics, 2nd Edition, Mosby Year Book, Section III, Diagnosis and Treatment Planning, pp.139.

[9] Rowsell , K.V.. The Application of Knowledge Based Decision Support: Computer-Aided Diagnosis of Abdominal Pain at Ormskirk & District General Hospital, 1988-1993. South Lancashire Health Authority. 1993:12-15.

[10] Adams ID, Chan M, Clifford PC et al. Computer Aided Diagnosis of Abdominal Pain: A Multi-Centre Study. Brit Med J. 1986, 293:800-804.

[11] Weed, Lawrence L., (1991), Knowledge Coupling. New Premises and New Tools for Medical Care and Education. New York, Springer-Verlag.p1.

[12] Shortliffe, Edward H.; Perreault, Leslie E.. Ed.. Medical Informatics, Computer Applications in Health Care.1990. New York, Addison-Wesley Publishing Company. p.20.

[13] Wilson, M.C., Hayward, R.S., Tunis, S.R., Bass, E., Guyatt, G.. User's Guide to the Medical Literature. JAMA 1995;274,20:1630-1632.

[14] deDombal, F.T. Computer-Aided Decision Support in Clinical Medicine. Int. J. Biomedical Computing 1989;24,9:9-16.

[15] Siever, Adam; Holtzman, Samuel. Decision Analysis: A Framework for critical Care Decision Assistance. International J Clin Monitor Comp. 1989; 6: 137.

[16] Hayes-Roth, F., Jacobstein, N.. The State of Knowledge-Based Systems. Communication of the ACM 1994; 37, 3; 27-39.

[17] Yoon, Y., Guimaraes, T., O'Neal, Q..Exploring the Factors Associated With Expert Systems Success. MIS Quarterly. March 1995.

[18] Kinney. E.L. Expert Systems. Who Needs Them? (editorial). Chest 1987;91:3-4.

[19] Hayes-Roth, F., Jacobstein, N.. The State of Knowledge-Based Systems. Communication of the ACM 1994; 37, 3; 27-39.

[20] Stead, W.W., Haynes, R.B., Fuller, S., Travis, L.E., Beck, J.R., Fenichel, C.H. et al. Designing Medical Informatics Library and Research Projects to Increase What is Learned. Vanderbilt University , 1993 (unpublished).

[21] Dalrymple, P.W.. CD-ROM MEDLINE and Users: Infromation Transfer in the Clinical Setting. Bulletin of the Medical Librarians Association 1990;78, 3:224 - 232.

[22] Blythe, J.M.. Information Seeking- Patterns of Health Science Professionals. Bibliotheca Medica Canadiana 1992;14, 2:82- 89.

[23] Gruppen, L.D.. Physician Information-Seeking:Proving Relevance through Research. Bull Med Libr Assoc 1990;78,2:165-171.

[24] Covell, D.G. Infromation Needs in Office Practice: Are They Being Met? Ann Int Med 1985;103:596-599.

[25] Gorman, P.N., Ash, J., Wykoff, L.. Can Primary Care Physicians' Questions be asked Using the Medical Literature? Bull Med Libr Assoc 1994;82,2:140-146.

[26] Weinberg, A., Ullian, L., Richard, W.D., Cooper, P.. Informal Advice and Information-Seeking Between Physicians. J Med Ed. 1881; 56: 175-180.

[27] Oxman, A.D., Cook, D.J., Guyatt, G.H.. User's Guide to the Medical Literature. JAMA 1995;272,17:1367-1371.

[28] Stross, J.K., Harlin, W.R. The Dissemination of New Medical Information. JAMA 1979;241:2622-2624.

[29] Connely, D.P., Rich, E.C., Curley, S.P., Kelley, J.T.. Knowledge Resource Preferences of Family Physicians. Journal of Family Practice. 1990; 30: 355-359.

[30] Evidence-Based Working Group. Evidence Based Medicine: A New Approach to teaching the Practice of Medicine. JAMA. 1992;268:2420-2425.

[31] Adams, I.D., Chan, M., Clifford, P.C., et al. Computer Aided Diagnosis of Abdominal Pain: A Multi-centre Study. Brit Med J. 1986, 293:800-804.

[32] Myren, J., Bouchier, I.A.D., Watkson, G., deDombal, F.T.. Report of World Organization of Gasteroenterology. Scand J Gastero. 1988, Supplement 23:144

[33] Abbey, L.M. An Expert System for Oral Diagnosis. J. Dent. Educ. 1987;51:475-480.

[34] White, S.C. Computer-Aided Differential Diagnosis of Oral Radiographic Lesions. Dentomaxillofac. Radiol. 1989;18:53-59.

[35] Stheeman,S.E., vanStelt,P.F., Mileman,P.A.. Expert Systems in Dentistry. Past Performance- Future Prospects. J Dent. 1992;20:69.

[36] Sims-Williams, J.H., Brown, I.D., Matthewman, A., Stephens, C.D. A Computer-Controlled Expert System for Orthodontic Advice. Br. Dent. J. 1997;163:161-166.]

[37] Benson, P.E., Stephens, C.D., O'Brien, K.D. Orthodontic Products Update - Current Software for Teaching Orthodontics. Brit J Orthod 1991; 23,1:72-76

[38] Profitt, W.R. (1993). Baltimore, Contemporary Orthodontics, 2nd Edition, Mosby Year Book, Section III, Diagnosis and Treatment Planning, pp.175.

[39] Proffit, W.R., Ackerman, J.L., Rating Characteristics of Malocclusion: A Systematic Approach for Treatment Planning. Am J Orthod 1973;64,3:258-269.

[40] Profitt, W.R. (1993). Baltimore, Contemporary Orthodontics, 2nd Edition, Mosby Year Book, Section III, Diagnosis and Treatment Planning, pp.137-139

[41] Profitt, W.R. (1993). Baltimore, Contemporary Orthodontics, 2nd Edition, Mosby Year Book, Section III, Diagnosis and Treatment Planning, pp.175.

[42] Moorees, C.F.A., Grφn, A.M.(1969). Principles of Orthodontic Diagnosis. Angle Orthod. 1969;36,3:258-262.

[43] Moore, A.W. A Critique of Orthodontic Dogma The Angle Orthod, 1969;39,2: 69-83.

[44] Webster, Houghton Mifflin Company Ed., New York, Berkley Books, Webster's II: New Riverside Dictionary, 1984.P.208.

[45] Arnette. W.G., Bergman, R.T. Facial Keys to Orthodontic Diagnosis and Treatment Planning . Part I , Amer J Orthod 1993;103,4: 229.

[46] Angle, E.H.. Treatment of Malocclusion of the Teeth, ed 7, Philadelphia 1900, S.S. White Dental Manufacturing Co.

CHAPTER 2

CHAPTER 2

INTRODUCTION

2.01 Rationale for Project

New scientific findings and improved technology have placed significant demands on orthodontists. The need to apply proven principles, new scientific information, and new technology to clinical practice means the orthodontist must assimilate large amounts of scientific information and integrate it with a complex clinical database to determine the best treatment for each patient.

Historically, orthodontists did diagnosis and treatment planning manually. Since the 1970's, orthodontists have used computer software programs designed to perform specific tasks which support the process.[1] Recent advances in computer hardware and software technology, and the near universal use of high powered personal computers means affordable and accessible tools now exist, which can be used to develop a computer based decision support system. A decision support system is designed to support and enhance the diagnosis and treatment planning process. Systems have been developed to support decision making in medicine; however, to date few systems has been developed in the specialized area of orthodontics.

In addition to organizing the clinical database, a decision support system can include a knowledge base. This can comprise expertise in the form of scholarly literature and expert opinion. Integrating these components of knowledge is essential in clinical practice today, and this is difficult to do without the support of a computer system. Even the most experienced clinician finds the process of diagnosing and treatment planning an orthodontic case challenging. Specialized academic training and clinical experience have long been the clinician's tools. The challenge is even greater for the novice orthodontist armed with current knowledge and limited clinical experience.

The value of clinical experience cannot be underestimated however; the value of this experience is enhanced when combined with and supported by sound scientific evidence. Weed noted that the unaided human mind is often unable to recall all the relevant patient data and the related opinions from the literature, "and is often unable to take those two bodies of information and integrate them systematically to come up with the best course of action". [2] This clearly indicates the need for a decision support system.

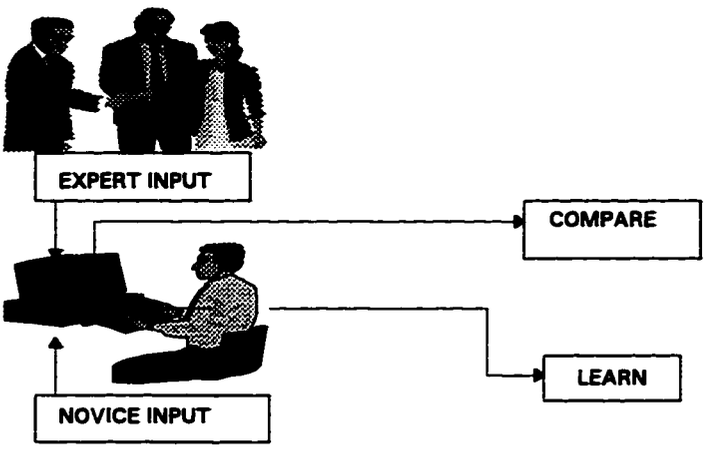
This research project was developed with the premise that: unaided clinical judgment can be flawed; a complex clinical database must be assembled and analyzed for use in orthodontic diagnosis and treatment planning; expert clinical opinion combined with and supported by sound scientific evidence is key to providing a knowledge base; novice orthodontists can benefit greatly from structured feedback in the diagnosis and treatment planning process and; a computer based decision support system can be developed to support and enhance the diagnosis and treatment planning process in orthodontics.

The purpose of this project was to develop a prototype computer based decision support system which focused on decision making in orthodontic diagnosis and treatment planning. More specifically, the decision support system was designed to help novice orthodontists work with and analyze a complicated clinical database. In addition, the system was designed to help novice orthodontists critically evaluate their diagnosis and treatment planning decisions by using a knowledge base which comprises expert feedback and structured literature reviews.

2.02 Illustrative Scenario

The computer based decision support system developed in this project was named ORTHO1. The basic concept behind the system is shown in Figure 2.01, Illustrative Scenario. The system was designed in modules set up for expert and novice input, case comparison, and learning. Expert input refers to data from a set of clinical cases analyzed by a group of expert orthodontists plus an expert oral surgeon. The components of each case analysis included patient history, clinical data, and information about the clinician's decisions pertaining to the case and proposed treatment. Novice input refers to the case analysis data entered by the novice orthodontist. For the purposes of this project, the novice orthodontists analyzed cases from the same group of cases which were analyzed by the experts. The novice case analysis was compared to the stored set of expert case analyses. By selecting the expert case which best matches the novice case, the novice orthodontist can then analyze his or her decision making relative to that of the experts. The system also provides the novice structured feedback which includes the experts' rationale for specific decisions and relevant literature reviews. The structured feedback provided the novice orthodontist with an opportunity to learn from both the experts and pertinent scientific literature. Such feedback also provided an opportunity for novices to critically evaluate their diagnosis and treatment planning decisions. Within the ORTHO1 system novice users were also given opportunities to change their input to reflect the learning which occurred during the use of the system.

Figure 2.01 Illustrative Scenario - Computer Based Decision Support System



SYSTEM DEVELOPMENT

2.03 Problem Domain

To focus the decision making process, a group of cases were selected; each was considered to have a "borderline" treatment requirement for mandibular advancement surgery. This means that the patients being evaluated and treatment planned had malocclusions which resulted from poor skeletal and dental relationships. Weaver, Major, and Glover noted that this type of problem can be resolved by treating the patient with orthodontics only, or with a combination of orthodontics and oral surgery and stated that "a patient with a borderline case, by definition, can be treated with either surgery or camouflage." [3]

A "borderline" clinical problem was chosen for this project because of the careful analysis required by both experts and novice orthodontists. It was hoped that by presenting cases which were challenging to diagnose and treatment plan the experts and novice orthodontists would be forced to rationalize and carefully evaluate their decisions.

2.04 Conceptual Model

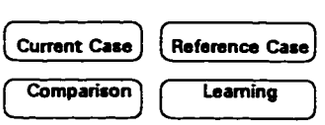
The initial stages of this project included the design of a conceptual model to serve as the framework upon which the computer-based decision support system was to be built. In designing the model the specialized areas of expert and knowledge based systems and orthodontic diagnosis and treatment planning were combined.

The model of the decision support system is shown in Figure 2.02. The model shows a general overview of the flow of information within the system; and more specifically, lists the six questions which are the framework for the comparative analyses and feedback generated by the resulting decision support system. Three key components of the ORTHO1 decision support system include novice input, expert input, and supporting literature. The information is stored as a clinical database and a knowledge base. The clinical database contains the novice opinion specific to the clinical cases while the knowledge base contains the expert opinion and rationale for diagnosis and treatment planning decisions plus the supporting references from scholarly literature.

The novice input for each case includes data related to specific choices made during the case analysis, the selected treatment plan, a weighting of the importance of choices made during the case analysis, and personal comments. The expert input is similar in format to the novice input; however, it represents a consensus opinion established from a group of experts. The comments section contains a rationale for the choices made in the diagnosis and treatment planning process.

The ORTHO1 decision support system has four modules: Reference Case, Current Case, Comparison, and Learning. See figure 2.03.

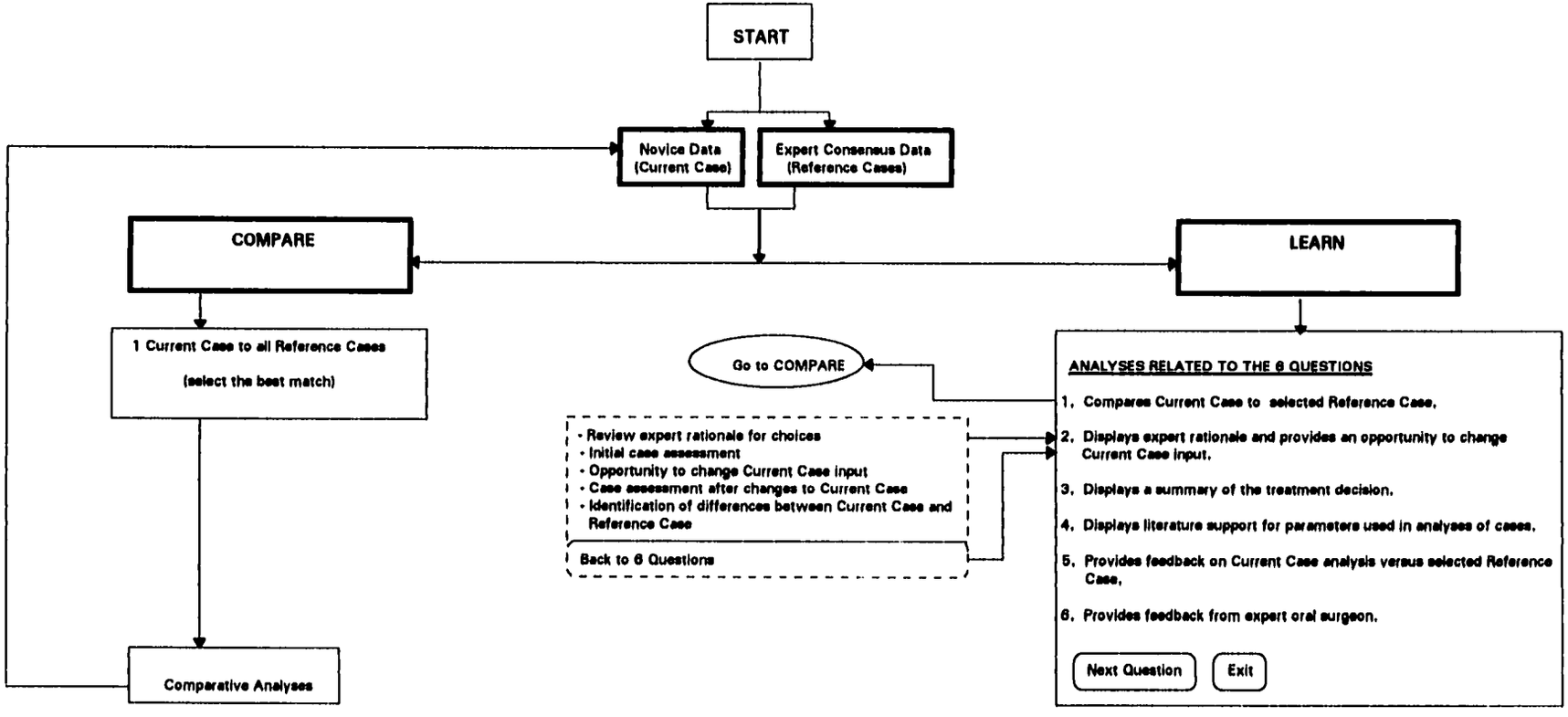
Figure 2.03 - ORTHO1 - Decision Support System Modules



The novice orthodontists enter each case into the Current Case module, and the expert consensus data is entered into the Reference Case module.

Subsections 2.05 through 2.08 contain information related to the selected clinical cases, subjects (expert and novice), consensus, selection and classification of clinical data (parameters), and supporting scholarly literature.

Figure 2.02 MODEL of DECISION SUPPORT SYSTEM



2.05 Clinical Cases

For the purposes of this study, ten cases were selected by three faculty members of the Graduate Orthodontics Division of the Faculty of Medicine and Oral Health Sciences at the University of Alberta. Cases were collected from private practice records of the three faculty members. To help focus the search for clinical cases, a set of criteria for selection of clinical cases was established. The three contributing faculty members were consulted in the selection of the following criteria:

- Class II dental and / or skeletal malocclusion
- Borderline" requirement for a combined orthodontic/orthognathic surgery treatment plan. [3]
- Skeletal component of the malocclusion limited to the mandible
- Non-growing patient
- Full orthodontic records and available patient history
- Patient consent for use of records in research study

2.06 Subjects - Expert Orthodontists, Expert Oral Surgeon, Novice Orthodontists

Three expert orthodontists were asked to participate in the case analysis and interview process. The experts were selected based on experience with surgical orthodontics, and years of clinical experience. Each expert has at least 15 years of clinical experience in orthodontics and routinely treats adult orthodontic cases. Each expert also has teaching experience in a University Orthodontics program. The experts were not familiar with any of the ten cases they reviewed.

Diagnosing and treatment planning cases of this nature are typically done following a careful analysis by an orthodontist and an oral surgeon. The orthodontist is unlikely to proceed with treatment without an oral surgeon's input and a mutually agreed upon treatment plan. Therefore, feedback from the oral surgeon was included in the program design. The head of the oral surgery department at the University of Alberta was selected as the expert oral surgeon on the basis of his experience in the diagnosis and treatment of combined orthodontic/orthognathic surgery cases.

Four novice orthodontists were selected, including two senior orthodontics residents (second year of training) and two "new" orthodontists (two or less years of post graduation clinical experience). The novice orthodontists were not familiar with any of the ten cases they reviewed.

2.07 Rules for Consensus

To establish an expert opinion, as entered in Reference Case Module of the ORTHO1 decision support system, consensus was needed between the experts. That is, one opinion which represented the consensus opinion of the experts as a group was required. To obtain this, a set of rules for consensus were established. Each expert agreed to the application of these rules in establishing the "expert" opinion. The rules for consensus between the three experts were as follows:

Rule #1

- *Two thirds majority for treatment choice*

  If two of the three experts agree on a treatment choice, consensus for treatment was reached.

Rule #2

- *Initial screening by treatment choice*

  If the consensus treatment decision was determined by two-thirds majority, the choices and weightings selected by the expert who did not agree with the consensus treatment decision were not considered.

  NOTE: Rules #3 - #5 assume that consensus on treatment choice has been established.

Rule #3

- *Two thirds majority for parameter choice or weight*

  If two of the three experts agree on a parameter choice or weight, consensus was reached.

Rule #4

- *Range of +/-1*

  The experts were considered to be in agreement if the weights were within the range of plus or minus 1.

Rule #5

- *Supported by Literature*

  If consensus was not reached through the initial analysis or through a follow-up interview process, a parameter choice and weighting was determined by the researcher. This was done only if the decision could be supported by credible research findings. (i.e. peer reviewed, published literature).

Rule #6

- *No Consensus Flagged by the System*

  If consensus still was not reached after applying rules 1 through 5, the parameter choice and weight were reported and "flagged" in the computer system. For example, a note would be flashed on the screen to alert the user to the problem.

2.08 Selection and Classification of Parameters

In this section, the 82 parameters used in each case analysis (reference cases and current cases) are listed. Figure 2.04 lists the parameters as they were presented to the experts and the system users (novice orthodontists). The list was compiled based on the diagnosis and treatment planning approach suggested by Proffit and Ackerman[4] and the protocol used at the Graduate Orthodontics programs at the University of Alberta and the University of Washington.

Each clinical case has 82 parameters which relate to the following:

- general information, including age, gender, race, medical history and status, patient objectives, and patient motivation;
- extra-oral findings, including facial form, facial proportions, facial type, lip and nose features, and temporomandibular joint findings;
- intra-oral findings, including oral hygiene, periodontal disease, relative tooth size analysis (maxillary versus mandibular dentition), occlusion, arch perimeter, and parafunctional habits;
- diagnostic imaging, including panorex radiographs, tomograms, posterior-anterior cephalometric radiographs, and any other radiographs;
- cephalometric analysis, including skeletal, dental, and soft tissue analyses; and
- proposed treatment including recommended extractions, recommended treatment combination (i.e. no treatment, orthodontics only, combination orthodontics/orthognathic surgery)

For each parameter, a series of choices were offered to the user. A total of 293 choices were offered for 82 parameters. The parameters and respective choices are contained in Appendix A, Figure A1.

In the Learning Module, the parameter choices and weights of the current case versus the selected reference case are compared. To help focus the feedback given by the system, the parameters are classified into four groups: Category, Concept, Cluster, and Subjective/Objective. These groupings were selected to help the system provide feedback on several levels. The 82 parameters used in each case analysis are further classified into subgroups. The groups and associated subgroups are listed in Figure 2.05.

The Category Group contains six subgroups which are commonly used to classify data in diagnosis and treatment planning.[5] These subgroups, as listed in Figure 2.06, include; general information, extra-oral findings, intraoral findings, diagnostic imaging,

cephalometrics, and proposed treatment. The six subgroups in the Category are used as headings in the data input section of the ORTHO1 system.

The parameters are subdivided into six different subgroups which make up the Concept Group, as listed in Figure 2.07. The Concept Group contains more clinical subgrouping of the data versus the Category Group. Concept subgroups include demographics/personal information, patient history, clinical assessment, model analysis, diagnostic imaging, and proposed treatment.

The parameters are divided into 14 subgroups which make up the Cluster Group, as listed in Figure 2.08. The subgroups include demographics/personal information, medical/health information, patient objectives, extraoral findings -clinical assessment, temporomandibular joint, intraoral findings -periodontal findings, intraoral findings -Bolton assessment, occlusion, esthetic assessment of dentition, perimeter assessment, diagnostic imaging, cephalometrics -skeletal, cephalometrics -soft tissue, and proposed treatment. These subgroups represent a more detailed breakdown of the clinical subgroupings used in the Category Group

The clinical case parameters are also classified as Objective or Subjective, and are listed in Figure 2.09. The Subjective/Objective Group classifies the parameters which can be manipulated by the orthodontist as subjective and those which are fixed as objective. [6]

FIGURE 2.04
SUMMARY of PARAMETERS

- ORTHO 1 PROGRAM -

1 Gender
2 Age (Category)
3 Race
4 Medical Status
5 Patient Objective(s) - Improved Function
6 Patient Objective(s) - Improved Dental Esthetics
7 Patient Objective(s) - Improved Facial Esthetics
8 Psychological Status
9 Psychological Effect of Malocclusion
10 Patient Motivation Regarding Treatment
11 Reported Habits
12 Facial Form (Frontal View) -transverse
13 Facial Proportions (Frontal View) -(vertical) Mid-Face
14 Facial Proportions (Frontal View) - Lower Face Height
15 Facial Form (Lateral View)
16 Facial Form (Lateral View) - Nasolabial Angle
17 Facial Form (Lateral View) - Labiomental Angle
18 Nose - Length
19 Nose - Other
20 Facial Type
21 Lip Posture (upper & lower)
22 Lip Posture (lower)
23 Lip Length (upper)
24 Temporomandibular Disorder
25 Muscle Pain (TMD)
26 Oral Hygiene
27 Gingival Attachment - mandibular anterior
28 Periodontal Disease
29 Teeth Present
30 Bolton Relationship
31 Bolton Discrepancy (Maxillary Overall Excess)
32 Bolton Discrepancy (Maxillary Anterior Excess)
33 Bolton Discrepancy (Mandibular Overall excess)
34 Bolton Discrepancy (Mandibular Anterior Excess)
35 molar relationship - Right
36 molar relationship - Left
37 cuspid relationship - Right
38 cuspid relationship - Left
39 curve of spee
40 overjet (millimeters)
41 incisor position in Class II cases
42 overbite - palatal impingement
43 overbite (millimeters)
44 Incisal Display at Rest (millimeters)
45 Gingival Display on Smiling (millimeters)
46 CR : CO Discrepancy
47 CR : CO Shift Transverse
48 CR : CO Shift AP
49 Perimeter - Maxillary Excess
50 Perimeter - Maxillary Deficiency
51 Perimeter - Mandibular Excess
52 Perimeter - Mandibular Deficiency
53 Parafunctional Habits
54 Panorex
55 Tomograms
56 Other Imaging
57 facial angle (FH - NPg)
58 SNB
59 SNPg
60 mandibular body length
61 ramus height
62 SNA
63 SN Length
64 ANB
65 Wits
66 Y-axis (FH to SGn)
67 lower incisor to NA (mm)
68 lower incisor to NPg (mm)
69 interincisal angle
70 mandibular plane angle
71 mandibular plane to SN
72 upper face height (Na - ANS)
73 lower face height (ANS - Me)
74 lower face ht. : total face ht.
75 nasolabial angle (soft tissue)
76 labiomental angle (soft tissue)
77 upper lip relative to E-plane
78 lower lip relative to E-plane
79 Extractions Required
80 Orthodontics Only
81 Orthodontics & Surgery
82 No Treatment

Figure 2.05
PARAMETER GROUPS and SUBGROUPS

- ORTHO1 PROGRAM -

CATEGORY

1. General Information
2. Extra-Oral Findings - Clinical Assessment
3. Intra-Oral Findings - Clinical Assessment
4. Diagnostic Imaging
5. Cephalometrics
6. Proposed Treatment

CONCEPT

1. Demographics / Personal Information
2. Patient History
3. Clinical Assessment
4. Model Analysis
5. Diagnostic Imaging
6. Proposed Treatment

CLUSTER

1. Demographics/Personal Information
2. Medical Health Information
4. Patient Objectives
3. Extra-Oral Findings - Clinical Assessment
5. Temporomandibular Joint
6. Intraoral findings - Periodontal Assessment
7. Intraoral findings - Bolton Analysis
8. Occlusion
9. Esthetic Assessment of Dentition
10. Perimeter Assessment
11. Diagnostic Imaging
12. Cephalometrics - Skeletal Relationships
13. Cephalomertics-Dental\ Soft Tissue Relationships
14. Proposed Treatment

SUBJECTIVE/OBJECTIVE

1. Subjective
2. Objective

Figure 2.06
SUMMARY of PARAMETERS by CATEGORY

- ORTHO 1 PROGRAM -

GENERAL INFORMATION

1 Gender
2 Age (Category)
3 Race
4 Medical Status
5 Patient Objective(s) - Improved Function
6 Patient Objective(s) - Improved Dental Esthetics
7 Patient Objective(s) - Improved Facial Esthetics
8 Psychological Status
9 Psychological Effect of Malocclusion
10 Patient Motivation Regarding Treatment
11 Reported Habits

EXTRAORAL FINDINGS

12 Facial Form (Frontal View) -transverse
13 Facial Proportions (Frontal View) -(vertical) Mid-Face
14 Facial Proportions (Frontal View) - Lower Face Height
15 Facial Form (Lateral View)
16 Facial Form (Lateral View) - Nasolabial Angle
17 Facial Form (Lateral View) - Labiomental Angle
18 Nose - Length
19 Nose - Other
20 Facial Type
21 Lip Posture (upper & lower)
22 Lip Posture (lower)
23 Lip Length (upper)
24 Temporomandibular Disorder
25 Muscle Pain (TMD)

INTRAORAL FINDINGS

26 Oral Hygiene
27 Gingival Attachment - mandibular anterior
28 Periodontal Disease
29 Teeth Present
30 Bolton Relationship
31 Bolton Discrepancy (Maxillary Overall Excess)
32 Bolton Discrepancy (Maxillary Anterior Excess)
33 Bolton Discrepancy (Mandibular Overall excess)
34 Bolton Discrepancy (Mandibular Anterior Excess)
35 molar relationship - Right
36 molar relationship - Left
37 cuspid relationship - Right
38 cuspid relationship - Left
39 curve of spee
40 overjet (millimeters)
41 incisor position in Class II cases
42 overbite - palatal impingement
43 overbite (millimeters)
44 Incisal Display at Rest (millimeters)
45 Gingival Display on Smiling (millimeters)
46 CR : CO Discrepancy
47 CR : CO Shift Transverse
48 CR : CO Shift AP
49 Perimeter - Maxillary Excess
50 Perimeter - Maxillary Deficiency
51 Perimeter - Mandibular Excess
52 Perimeter - Mandibular Deficiency
53 Parafunctional Habits

DIAGNOSTIC IMAGING

54 Panorex
55 Tomograms
56 Other Imaging

CEPHALOMETRICS

57 facial angle (FH - NPg)
58 SNB
59 SNPg
60 mandibular body length
61 ramus height
62 SNA
63 SN Length
64 ANB
65 Wits
66 Y-axis (FH to SGn)
67 lower incisor to NA (mm)
68 lower incisor to NPg (mm)
69 interincisal angle
70 mandibular plane angle
71 mandibular plane to SN
72 upper face height (Na - ANS)
73 lower face height (ANS - Me)
74 lower face ht. : total face ht.
75 nasolabial angle (soft tissue)
76 labiomental angle (soft tissue)
77 upper lip relative to E-plane
78 lower lip relative to E-plane

PROPOSED TREATMENT

79 Extractions Required
80 Orthodontics Only
81 Orthodontics & Surgery
82 No Treatment

Figure 2.07
SUMMARY of PARAMETERS by CONCEPT
- ORTHO 1 PROGRAM -

DEMOGRAPHICS / PERSONAL INFORMATION

1 Gender
2 Age (Category)
3 Race

PATIENT HISTORY

4 Medical Status
5 Patient Objective(s) - Improved Function
6 Patient Objective(s) - Improved Dental Esthetics
7 Patient Objective(s) - Improved Facial Esthetics
8 Psychological Status
9 Psychological Effect of Malocclusion
10 Patient Motivation Regarding Treatment
11 Reported Habits

CLINICAL ASSESSMENT

12 Facial Form (Frontal View) -transverse
13 Facial Proportions (Frontal View) -(vertical) Mid-Face
14 Facial Proportions (Frontal View) - Lower Face Height
15 Facial Form (Lateral View)
16 Facial Form (Lateral View) - Nasolabial Angle
17 Facial Form (Lateral View) - Labiomental Angle
18 Nose - Length
19 Nose - Other
20 Facial Type
21 Lip Posture (upper & lower)
22 Lip Posture (lower)
23 Lip Length (upper)
24 Temporomandibular Disorder
25 Muscle Pain (TMD)
26 Oral Hygiene
27 Gingival Attachment - mandibular anterior
28 Periodontal Disease
44 Incisal Display at Rest (millimeters)
45 Gingival Display on Smiling (millimeters)
46 CR : CO Discrepancy
47 CR : CO Shift Transverse
48 CR : CO Shift AP
53 Parafunctional Habits

MODEL ANALYSIS

29 Teeth Present
30 Bolton Relationship
31 Bolton Discrepancy (Maxillary Overall Excess)
32 Bolton Discrepancy (Maxillary Anterior Excess)
33 Bolton Discrepancy (Mandibular Overall excess)
34 Bolton Discrepancy (Mandibular Anterior Excess)
35 molar relationship - Right
36 molar relationship - Left
37 cuspid relationship - Right
38 cuspid relationship - Left
39 curve of spee
40 overjet (millimeters)
41 incisor position in Class II cases
42 overbite - palatal impingement
43 overbite (millimeters)
49 Perimeter - Maxillary Excess
50 Perimeter - Maxillary Deficiency
51 Perimeter - Mandibular Excess
52 Perimeter - Mandibular Deficiency

DIAGNOSTIC IMAGING

54 Panorex
55 Tomograms
56 Other Imaging
57 facial angle (FH - NPg)
58 SNB
59 SNPg
60 mandibular body length
61 ramus height
62 SNA
63 SN Length
64 ANB
65 Wits
66 Y-axis (FH to SGn)
67 lower incisor to NA (mm)
68 lower incisor to NPg (mm)
69 interincisal angle
70 mandibular plane angle
71 mandibular plane to SN
72 upper face height (Na - ANS)
73 lower face height (ANS - Me)
74 lower face ht. : total face ht.
75 nasolabial angle (soft tissue)
76 labiomental angle (soft tissue)
77 upper lip relative to E-plane
78 lower lip relative to E-plane

PROPOSED TREATMENT

79 Extractions Required
80 Orthodontics Only
81 Orthodontics & Surgery
82 No Treatment

Figure 2.08
LIST of PARAMETERS by CLUSTER
- ORTHO1 PROGRAM -

DEMOGRAPHICS/PERSONAL INFORMATION
1 Gender
2 Age (Category)
3 Race

MEDICAL/HEALTH INFORMATION
4 Medical Status
8 Psychological Status
9 Psychological Effect of Malocclusion
10 Patient Motivation Regarding Treatment
11 Reported Habits

PATIENT OBJECTIVES
5 Patient Objective(s) - Improved Function
6 Patient Objective(s) - Improved Dental Esthetics
7 Patient Objective(s) - Improved Facial Esthetics

EXTRAORAL FINDINGS - CLINICAL ASSESSMENT
12 Facial Form (Frontal View) -transverse
13 Facial Proportions (Frontal View) -vertical Mid-Face
14 Facial Proportions (Frontal View) -Lower Face Height
15 Facial Form (Lateral View)
16 Facial Form (Lateral View) - Nasolabial Angle
17 Facial Form (Lateral View) - Labiomental Angle
18 Nose - Length
19 Nose -Width
20 Facial Type
21 Lip Posture (upper & lower)
22 Lip Posture (lower)
23 Lip Length (upper)

TEMPOROMANDIBULAR JOINT
24 Temporomandibular Disorder
25 Muscle Pain (TMD)

INTRA ORAL FINDINGS - PERIODONTAL CONSIDERATIONS
26 Oral Hygiene
27 Gingival Attachment - mandibular anterior
28 Periodontal Disease
29 Teeth Present

INTRA ORAL FINDINGS - BOLTON ASSESSMENT
30 Bolton Relationship
31 Bolton Discrepancy (Mandibular Overall Excess)
32 Bolton Discrepancy (Mandibular Anterior Excess)
33 Bolton Discrepancy (Maxillary Overall Excess)
34 Bolton Discrepancy (Maxillary Anterior Excess)

OCCLUSION
35 Molar relationship - Right
36 Molar relationship - Left
37 Cuspid relationship - Right
38 Cuspid relationship - Right
39 Curve of spee
40 Overjet (millimeters)
41 Incisor position in Class II Cases
42 Overbite - palatal impingement
43 Overbite (millimeters)
46 CR : CO Discrepancy
47 CR : CO Shift Transverse
48 CR : CO Shift AP
53 Parafunctional Habits

ESTHETIC ASSESSMENT OF DENTITION
44 Incisal Display at Rest (millimeters)
45 Gingival Display on Smiling (millimeters)

PERIMETER ASSESSMENT
49 Perimeter - Maxillary Excess
50 Perimeter - Maxillary Deficiency
51 Perimeter - Mandibular Excess
52 Perimeter - Mandibular Deficiency

DIAGNOSTIC IMAGING
54 Panorex
55 Tomograms
56 Other Imaging

CEPHALOMETRICS - SKELETAL
57 facial angle (FH - NPg)
58 SNB
59 SNPg
60 mandibular body length
61 ramus height
62 SNA
63 SN Length
64 ANB
65 Wits
66 Y-axis (FH to SGn)
67 lower incisor to NA (mm)
68 lower incisor to NPg (mm)
69 interincisal angle
70 mandibular plane angle
71 mandibular plane to SN
72 upper face height (Na - ANS)
73 lower face height (ANS - Me)
74 lower face ht. : total face ht.

CEPHALOMETRICS - SOFT TISSUE
75 nasolabial angle (soft tissue)
76 labiomental angle (soft tissue)
77 upper lip relative to E-plane
78 lower lip relative to E-plane

PROPOSED TREATMENT
79 Extractions Required
80 Orthodontics Only
81 Orthodontics & Surgery
82 No Treatment

Figure 2.09
LIST of OBJECTIVE and SUBJECTIVE PARAMETERS
- ORTHO1 PROGRAM -

OBJECTIVE VARIABLES	
1	Gender
2	Age (Category)
3	Race
25	Muscle Pain (TMD)
29	Teeth Present
46	CR : CO Discrepancy
47	CR : CO Shift Transverse
48	CR : CO Shift AP
57	facial angle (FH - NPg)
58	SNB
59	SNPg
60	mandibular body length
61	ramus height
62	SNA
63	SN Length
64	ANB
65	Wits
66	Y-axis (FH to SGn)
67	lower incisor to NA (mm)
68	lower incisor to NPg (mm)
69	interincisal angle
70	mandibular plane angle
71	mandibular plane to SN
72	upper face height (Na - ANS)
73	lower face height (ANS - Me)
74	lower face ht. : total face ht.
75	nasolabial angle (soft tissue)
76	labiomental angle (soft tissue)
77	upper lip relative to E-plane
78	lower lip relative to E-plane

SUBJECTIVE VARIABLES	
4	Medical Status
5	Patient Objective(s) - Improved Function
6	Patient Objective(s) - Improved Dental Esthetics
7	Patient Objective(s) - Improved Facial Esthetics
8	Psychological Status
9	Psychological Effect of Malocclusion
10	Patient Motivation Regarding Treatment
11	Reported Habits
12	Facial Form (Frontal View) -transverse
13	Facial Proportions (Frontal View) -vertical Mid-Face
14	Facial Proportions (Frontal View) -Lower Face Height
15	Facial Form (Lateral View)
16	Facial Form (Lateral View) - Nasolabial Angle
17	Facial Form (Lateral View) - Labiomental Angle
18	Nose - Length
19	Nose -Width
20	Facial Type
21	Lip Posture (upper & lower)
22	Lip Posture (lower)
23	Lip Length (upper)
24	Temporomandibular Disorder
26	Oral Hygiene
27	Gingival Attachment - mandibular anterior
28	Periodontal Disease
30	Bolton Relationship
31	Bolton Discrepancy (Maxillary Overall Excess)
32	Bolton Discrepancy (Maxillary Anterior Excess)
33	Bolton Discrepancy (Mandibular Overall Excess)
34	Bolton Discrepancy (Mandibular Anterior Excess)
35	Molar relationship - Right
36	Molar relationship - Left
37	Cuspid relationship - Right
38	Cuspid relationship - Right
39	Curve of Spee
40	Overjet (millimeters)
41	Incisor position in Class II Cases
42	Overbite - palatal impingement
43	Overbite (millimeters)
44	Incisal Display at Rest (millimeters)
45	Gingival Display on Smiling (millimeters)
49	Perimeter - Maxillary Excess
50	Perimeter - Maxillary Deficiency
51	Perimeter - Mandibular Excess
52	Perimeter - Mandibular Deficiency
53	Parafunctional Habits
54	Panorex
55	Tomograms
56	Other Imaging
79	Extractions Required
80	Orthodontics Only
81	Orthodontics & Surgery
82	No Treatment

2.09 Use of Literature to Support Decision Making and Learning

One of the key features of the ORTHO1 decision support system is the knowledge base. This includes the expert clinicians' opinions, decision rationale, and structured literature reviews and references. The literature support for the ORTHO1 was provided in the form of structured reviews due to current trends in medicine.[7, 8] Physicians were reported to select information sources based on the greatest perceived benefit relative to cost, time, and effort required to use the source. In addition, the American College of Physicians is aggressively promoting evidence-based medicine, which requires clinical decision making be supported by scholarly literature. [9,10]

Structured reviews are succinct summaries of literature and are typically a one page "expanded abstract" which outlines study objectives, study design, results, discussion, and conclusions. The structured reviews are easily accessed by the user during the problem solving exercise. A list of references is also provided by the system. If the user does not have the time to read structured reviews or papers while using the system, he or she can refer to the reference list or papers at a convenient time. A sample structured review and an example of references relating to a specific parameter are shown in Appendix B, Figures B1 and B2.

2.10 Case Work-up

The clinical cases used in this project were prepared and presented to the expert and novice orthodontists in a standardized format. A copy of a case work-up is contained in Appendix C. Each case work-up included:

- General Information;
  personal history, medical history, treatment history, demographics.
- Clinical Photographs;
  extra-oral frontal and lateral views,
  intra-oral frontal, lateral and occlusal views.
- Study Models;
  hand held models.
- Model Photos;
  frontal, lateral and occlusal views.
- Model Analyses;
  Bolton analysis [11].
- Radiographs;
  Lateral cephalometric , PA cephalometric , and panoramic radiograph.
- Cephalometric Tracings;
  Lateral and PA cephalometric tracings.

- Cephalometric Analyses;
  Lateral Ceph -
  Alberta (including Wits)[12,13], Jarabak[14], McNamara[15] and Cogs[16,17] analyses.
  PA Ceph -
  Bergman[18, 19] and Grummons[20] analyses.

The same case data was provided to each expert and novice.

2.11 Interviews

Expert Orthodontists, Expert Oral Surgeon, and Novice Orthodontists

A series of interviews were done to collect data needed to later test the ORTHO1 decision support system. Three expert orthodontists, one expert oral surgeon, and four novice orthodontists were interviewed. The researcher conducted several sets of interviews which included: 1) interviews related to clinical case analyses by each expert orthodontist; 2) interviews related to clinical case analyses by each novice orthodontist; 3) an interview related to clinical case analyses by an oral surgeon; 4) before system use interviews with each novice orthodontist; and 5) after system use interviews with each novice orthodontist. Each individual was interviewed independently, using a standard interview format.

The data obtained from the expert interviews was used as part of the knowledge base of the decision support system. Once consensus was reached, the data was represented as the expert opinion.

During the interviews of expert orthodontists, each expert analyzed ten selected cases, as outlined in section 2.05, clinical cases. The expert was asked to analyze the case and decide on a treatment plan. Each parameter and the respective choices, as listed in Appendix A, Figure A1, were presented. The expert selected one of the choices, weighted the significance of that parameter, and made comments about his/her rationale for the choice and weight. The weight was to reflect the importance of the parameter relative to the expert's ultimate treatment decision; on a scale of zero to five, zero having no influence, one being least important, five being most important, how significant was the specified parameter in the ultimate treatment decision to do orthognathic surgery versus orthodontics only or no treatment?

The expert oral surgeon analyzed the same ten cases which were analyzed by the expert orthodontists. During the interview of the expert oral surgeon, the individual was asked to state the treatment plan for the case and to identify which of the 82 parameters used for each case analysis had an impact on the treatment decision, and why. This

information also was also used as part of the knowledge base. Due to programming constraints, this information was presented manually.

The novice orthodontists had 2 sets of interviews; the cases analysis interview, and the system use/user feedback interview. These interviews were conducted separately.

During the case analysis interviews, each novice analyzed five cases (either Group A: cases 1 through 5; or Group B: cases six through 10). Each novice analyzed 5 cases (versus 10) because of the significant time commitment required by the individual to do case analyses interviews, system use, and user feedback interviews. The case analyses interview format was similar to that used for the expert orthodontists. This novice data comprised the clinical database and was used to test the decision support system.

The user feedback /system user sessions had three components; "before use", system testing and "after use". The user feedback portion of the interviews were conducted using a series of questions. The objective of the "before-use" and "after-use" feedback interviews was to look, very generally, at evaluation of the ORTHO1 decision support program. The feedback interview questions were used to help determine if the program met the objectives of the project. Specific objectives for the ORTHO1 computer based decision support project included the following:

- to identify areas within the diagnosis and treatment planning process where novice orthodontist's decisions vary significantly from a group of experts,
- to categorize and analyze areas identified within the novice orthodontist's decision making process that differ from the experts, and
- to provide structured feedback related to the identified variations in decision making between the group of experts and the novice orthodontist.

The "Before-Use" interview questions were designed to find out:

- What the individual's computer background is.
- If the individual knows anything about computer based decision support.
- What the individual thinks about the concept of computer based decision
- support.
- What the individual's protocol for case analysis (diagnosis and treatment planning) currently is.

The "After-Use" interview questions were designed to find out:

- What the user's impressions of the computer based decision support system which has been developed.
- If the user's feels that the objectives of the computer system were met.

- If the user's has any suggestions for improvement of the computer system
- If the user's thinks the system prototype might be useful in his/her diagnosis and treatment planning process.

2.12 Consensus Process

Following the completion of the expert orthodontist interviews the rules for consensus, as outlined in section 2.07, were applied. The purpose of the consensus process was to establish an expert opinion which could be represented in the system's knowledge base. In situations where consensus was not reached following this process, the experts were contacted; and the parameters and choices in question, including proposed treatment, were discussed. Typically consensus was reached by this point. In the unlikely instance that consensus was not reached, it was agreed that the system would identify the problem by flagging the issue when the user accessed the parameter in question.

2.13 System Design

This section presents an overview of the ORTHO1 computer based decision support system design. Included are diagrams to demonstrate the flow of the system. The diagrams are designed to represent the system as it appears on the computer display screen. The data produced and the associated reports generated by the computer system are listed in Appendix D Figures D1 to D10. Listed in Appendix E are hardware and software requirements for the ORTHO1 system. The technical components of the system are discussed in Appendix F, which also includes an outline of the flow of data within the database.

The following are software components used to develop the ORTHO1 decision support system: Microsoft Access, a relational database management system; Visual Basic, a programming system which supports the creation of applications for the Microsoft Windows environment; and Crystal Reports for Visual Basic, a program designed for report generation.

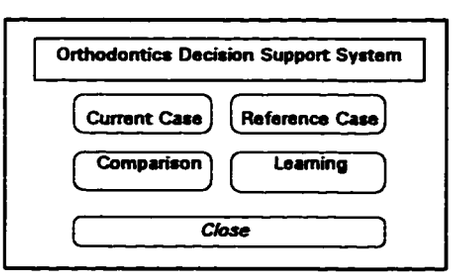
The relational database was used to store data in tables. Each table contains a specific classification of data. These tables contain the data input by the novice orthodontist and the experts respectively. The database program is then instructed to "relate" the information contained in the tables in specified ways. Visual Basic was used to develop the graphical user interface (GUI). The Crystal Reports for Visual Basic program was used to establish

specific connections with the database and produce custom designed reports and data display.

There are four components to the ORTHO1 decision support system: clinical database, knowledge base, reasoning and control rules, and user interface. The clinical database includes the clinical case data entered by the novice orthodontist, or system user. The knowledge base includes the case data entered as the expert consensus, and the background literature provided to support the decision making process. Reasoning and control rules are programmed into the system and used to drive the analysis. They are the algorithms. The user interface is the display which is used to prompt users for input. In addition, the "hard copy" data output is produced by the computer system. An example of the output produced for complete case is contained in Appendix D, Figures D1 to D10.

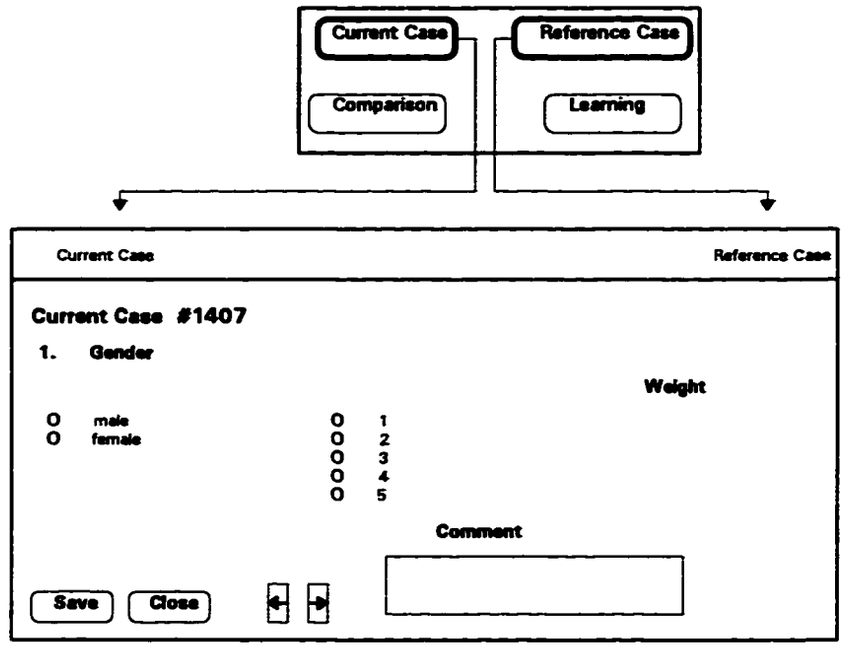
The ORTHO1 decision support system has four modules which can be accessed by the system user. They include; Current Case, Reference Case, Comparison and Learning (Figure 2.10).

Figure 2.10 Main Menu - ORTHO1 Computer System



The Current Case Module is a data input module and is illustrated in Figure 2.11. Here, the novice orthodontists enter data for each of 82 parameters which are analyzed for each case. The data input for each case includes; one of several choices pertaining to each parameter, a weight from zero to five , and a comment. Appendix A, Figure A1 contains a list of the 82 parameters and choices available to the user. The assignment of a weight to each parameter is discussed in Section 2.14, Algorithms. Note that the user can also enter comments.

Figure 2.11 Current Case and Reference Case Modules



The Reference Case Module is also a data input module, as illustrated in Figure 2.11. Here, the expert opinion pertaining to each of the 82 parameters is entered. The data is similar in structure to that in the Current Case Module however, the expert rationale for each parameter choice and weight is recorded.

In the Comparison Module, each current case is compared separately to all reference cases. The current case is compared by matching parameters, weights and treatment choice. The user can select one or all of the parameter, weight, or outcome sort options. The program will accordingly sort and rank, in ascending order, each reference case and the number of matched parameters, weights, or treatment choice. The user can then select any one of the reference cases for further comparative analysis with the current case. Typically this will be the reference case highlighted by the system as having the most matches. Figure 2.12 shows graphically the flow of the Comparison Module.

In the Learning Module, the analysis is done through a series of six questions as shown in Figure 2.13. Question #1, *(How did I do?)* activates the comparison between the current case and all of the reference cases, as outlined above. Once the user has selected the reference case to be used in subsequent analyses, the user can proceed to questions two through six.

Question #2, *(Why did the experts say what they said?)* compares the current case to the reference case, as in the Comparison Module. Once the reference case is selected for comparative analysis, the user can proceed to the Rationale section of the program. In this section, the choice and weight for each of the 82 parameters the novice entered to represent the current case are compared to the expert consensus which has been entered into the reference case. A message is displayed to indicate whether the parameter choices and weights selected for the current case matched those for the selected reference case. (Figure 2.14). Four options are offered in the Rationale section: "What-if", "What Best", "Question", and "Outcome". The Rationale section has two distinct cycles. During the first cycle, the Initial Case Analysis, the data originally entered for the current case and reference case, is used. The system informs the novice user about his or her initial diagnosis and treatment planning decisions versus those of the expert consensus.

The "What-if" selection for the Initial Case Analysis leads directly into a section titled Variance Analysis. In this Variance Analysis, the parameters are classified into four groups: Concept, Category, Cluster, and Subjective/Objective. See Figure 2.15. A discussion of the classification of parameters into groups is contained in Section 2.08. Information displayed includes the number of parameters in a given subheading, the number of parameters which matched between the current case and reference case being compared, and the weight score are displayed. A written comment about the scores (excellent, good, fair, poor) is also provided. The method for determining these comments and for calculating the weight score is outlined in Section 2.14, Algorithms.

Following a review of the analysis results for the Initial Case Analysis, the user is encouraged to enter the next cycle, the What-if Case Analysis. See Figures 2.14 and 2.15. Here the user is given an opportunity to change parameter choice and weight, if desired. The expert opinion in the form of parameter choice, weight, and rationale are displayed for the user's reference. Upon completion of the What-if cycle, changes made to the current case are displayed; and the analysis by group is done, using the new data. This "What-if" cycle can be repeated at the user's discretion. Note that the user has access to the supporting literature throughout this process.

The "What Best" selection highlights the non-matching parameters which were identified by the system when the current case and the selected reference case were compared. The term what best was used because, by reviewing the choices made related to the non-matching parameters and by changing the original answer if desired, the user can improve the matching of the current case with the reference case. The system therefore

helps the user by identifying non-matching parameters. If the user chooses to change his or her input relative to these parameters, the "best" possible match between the cases will be reached. The user can use this section as a screening tool to help identify non-matching parameters and to identify parameter choices which might require reassessment.

Question #3, *(What is the outcome (i.e. treatment decision?),* is shown in figure 2.17. This section provides a written summary of the current case treatment choice and the general reasons for the treatment decision.

Question #4, *(Can I find out more information on the parameters used in the case assessment?),* activates the display of literature as it pertains to each parameter. See Figure 2.18.

Question #5, *(What are the key Variances in my case assessment?)* activates the "marking" of the current case versus the reference case analysis. The method of calculating the ratios and the interpretation of these ratios is explained in Section 2.14, Algorithms. The classification of the parameters into groups is described in Section 2.08 and summarized in Figures 2.04 to 2.09.

Question #6, *(What did the oral surgeons say?)* will activate (in Version 2.0) a display similar to the one shown in Figure 2.20. The display shows the treatment choices and decision rationale made by the expert oral surgeon.

Figure 2.12 Comparison Module

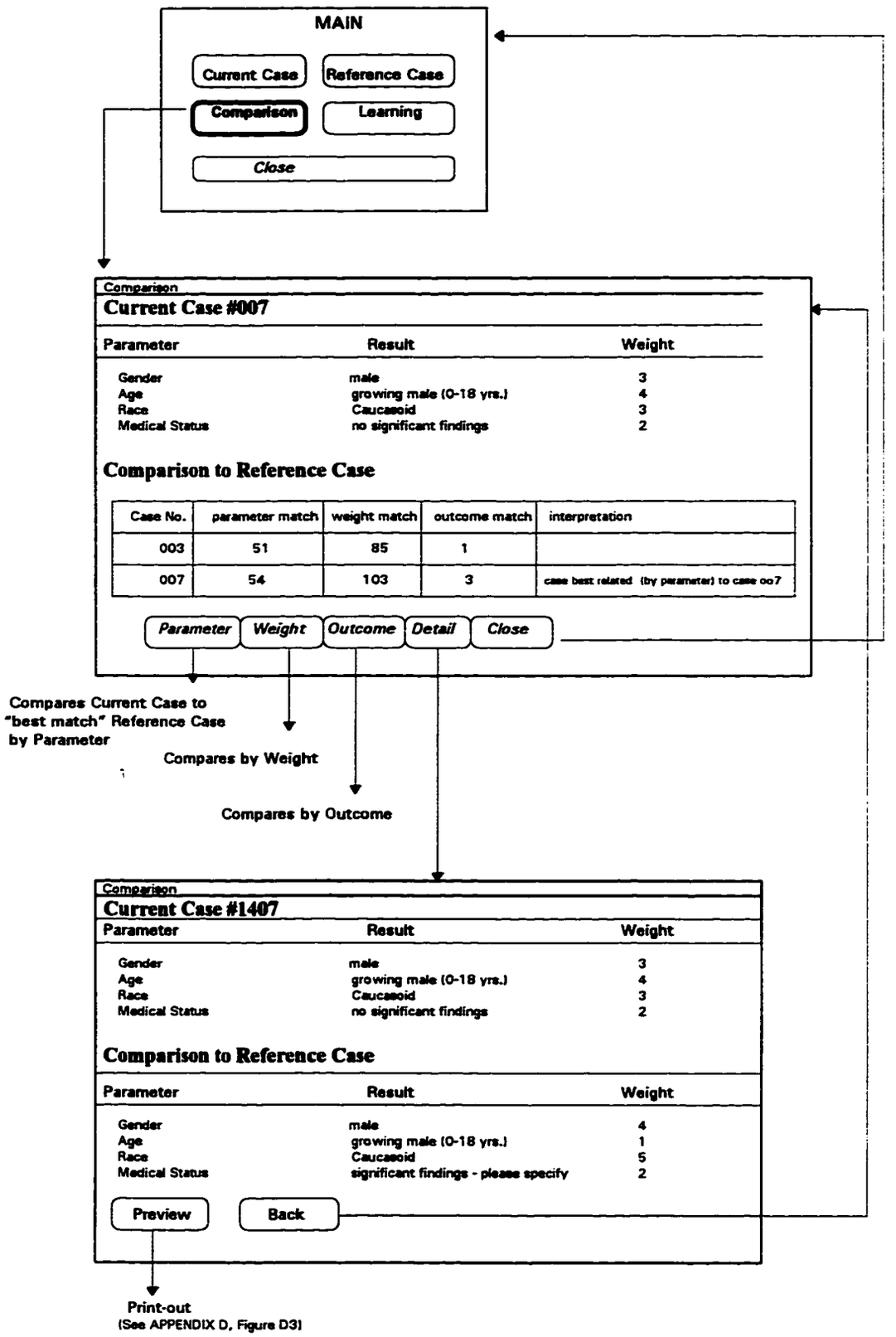


Figure 2.13 Learning Module - Question #1

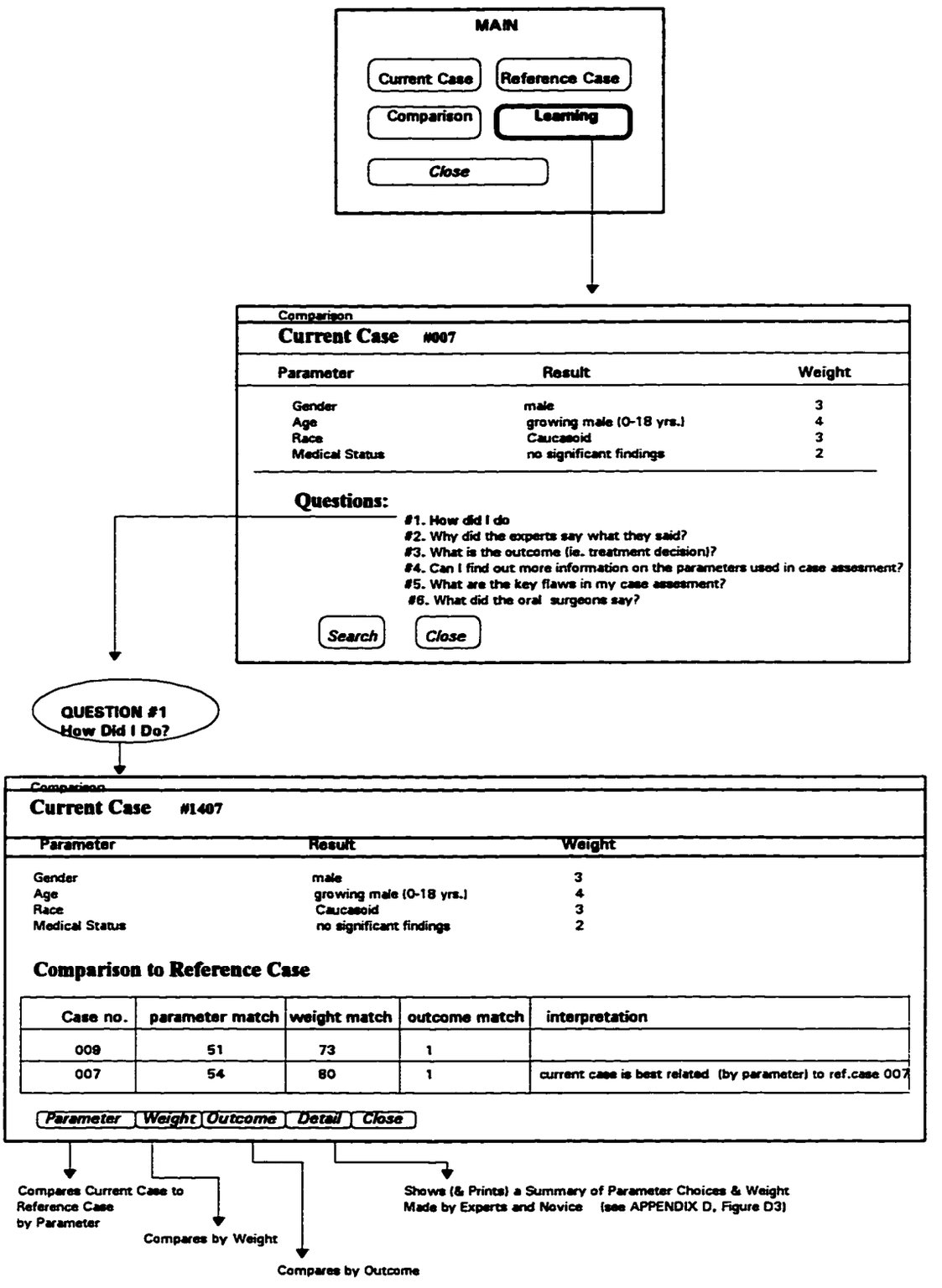


Figure 2.14 Learning Module - Question #2

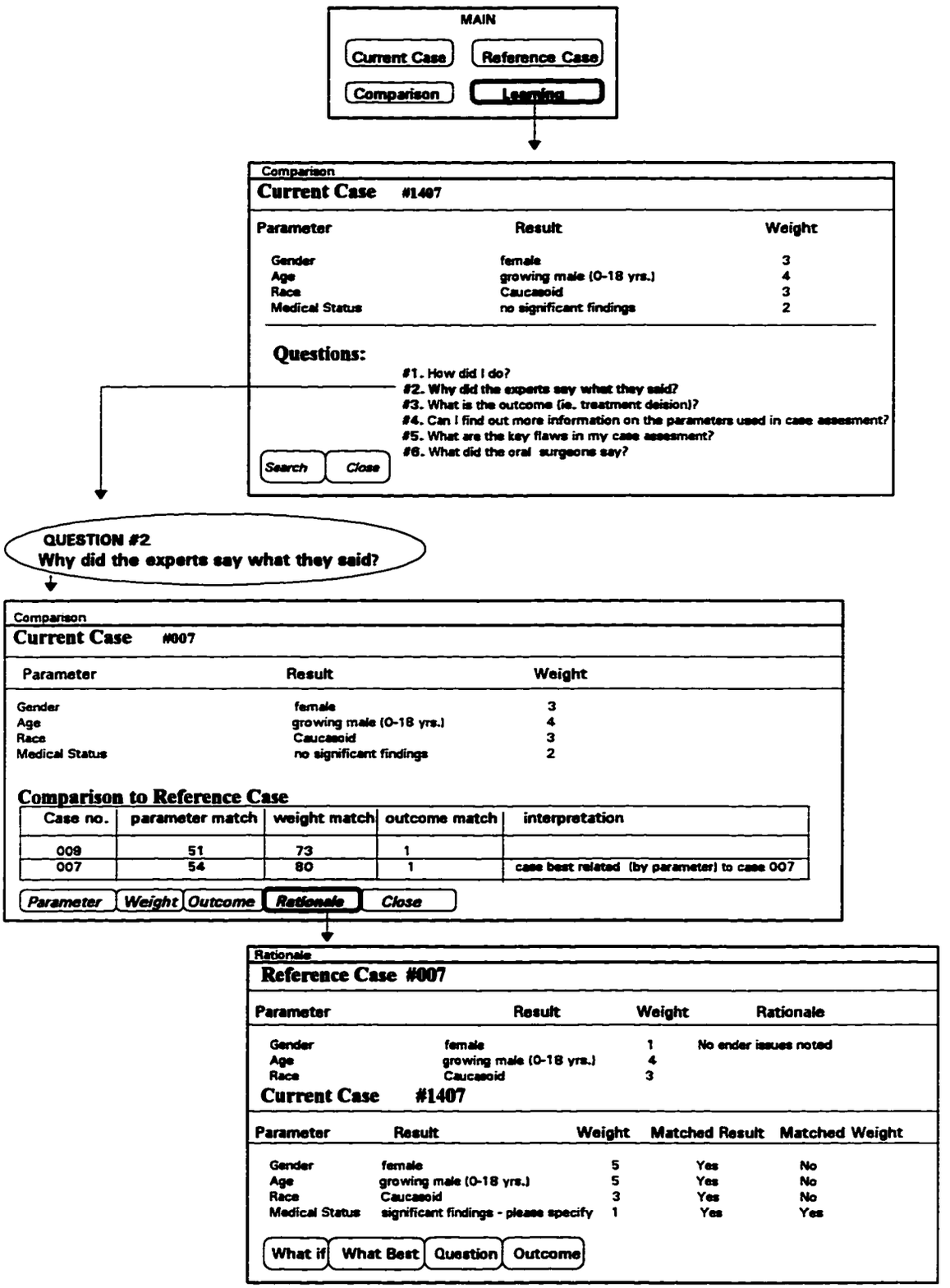


Figure 2.15 Learning Module - Question #2

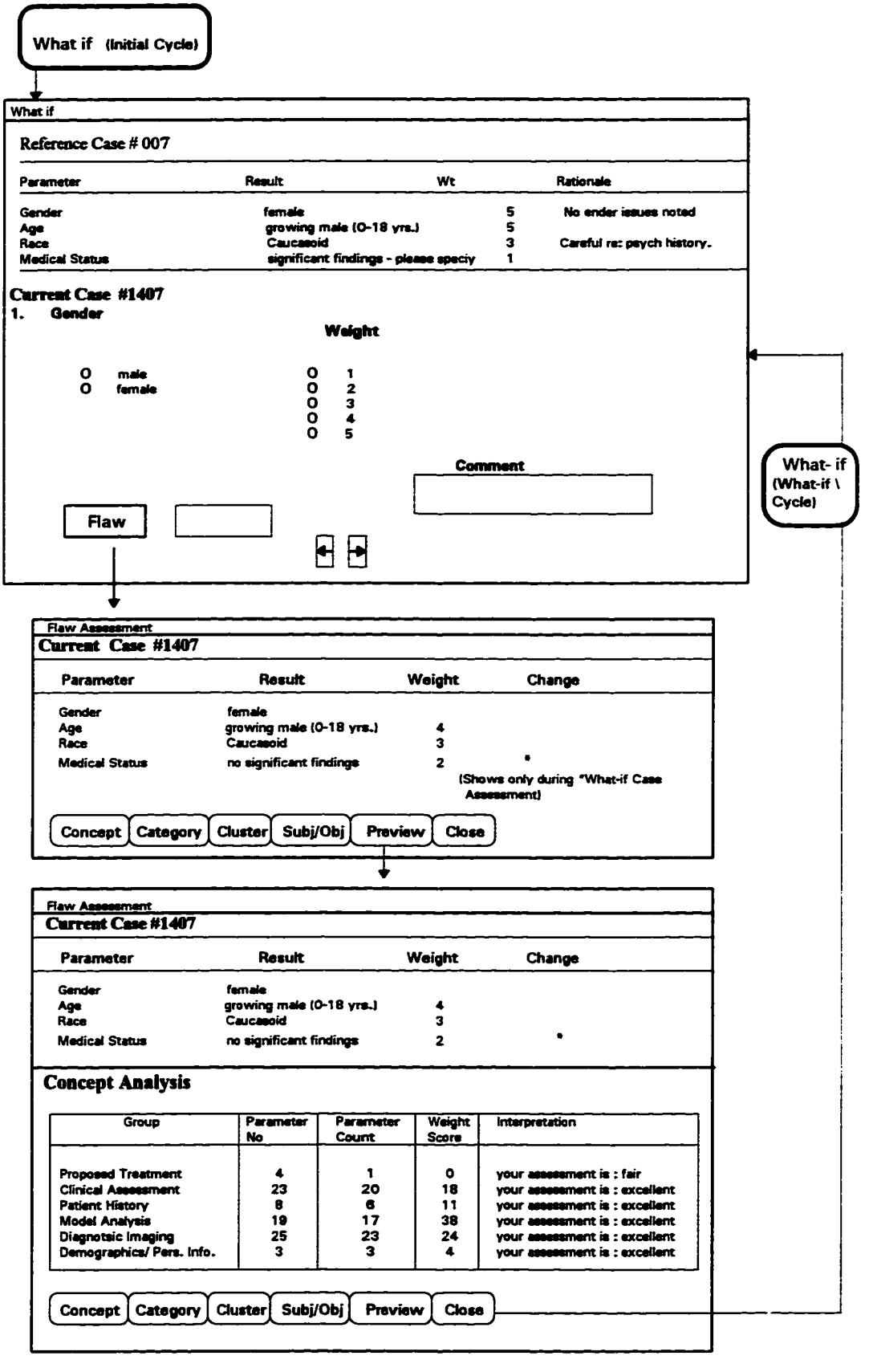


Figure 2.16 Learning Module - Question #2

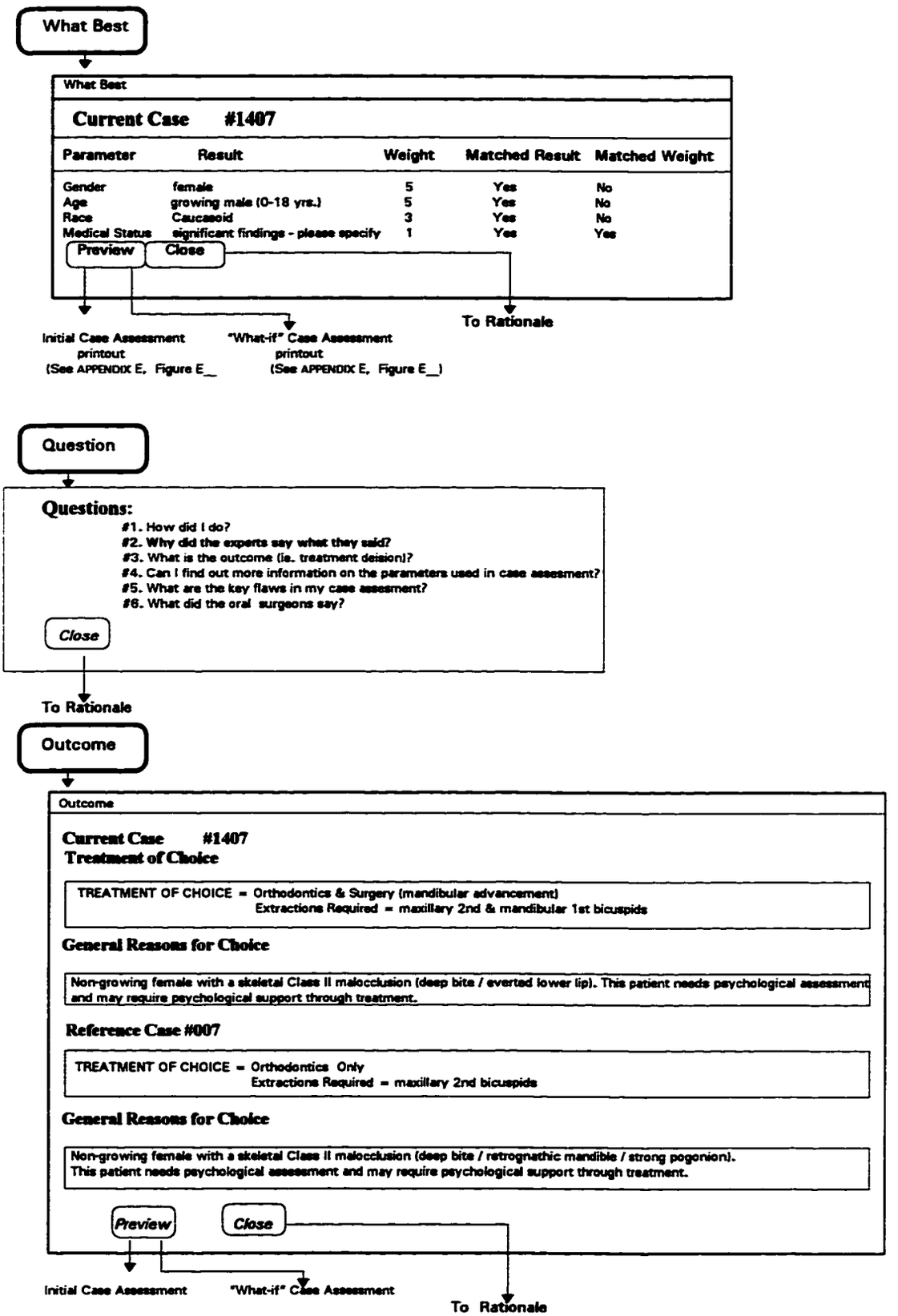


Figure 2.17 Learning Module - Question #3

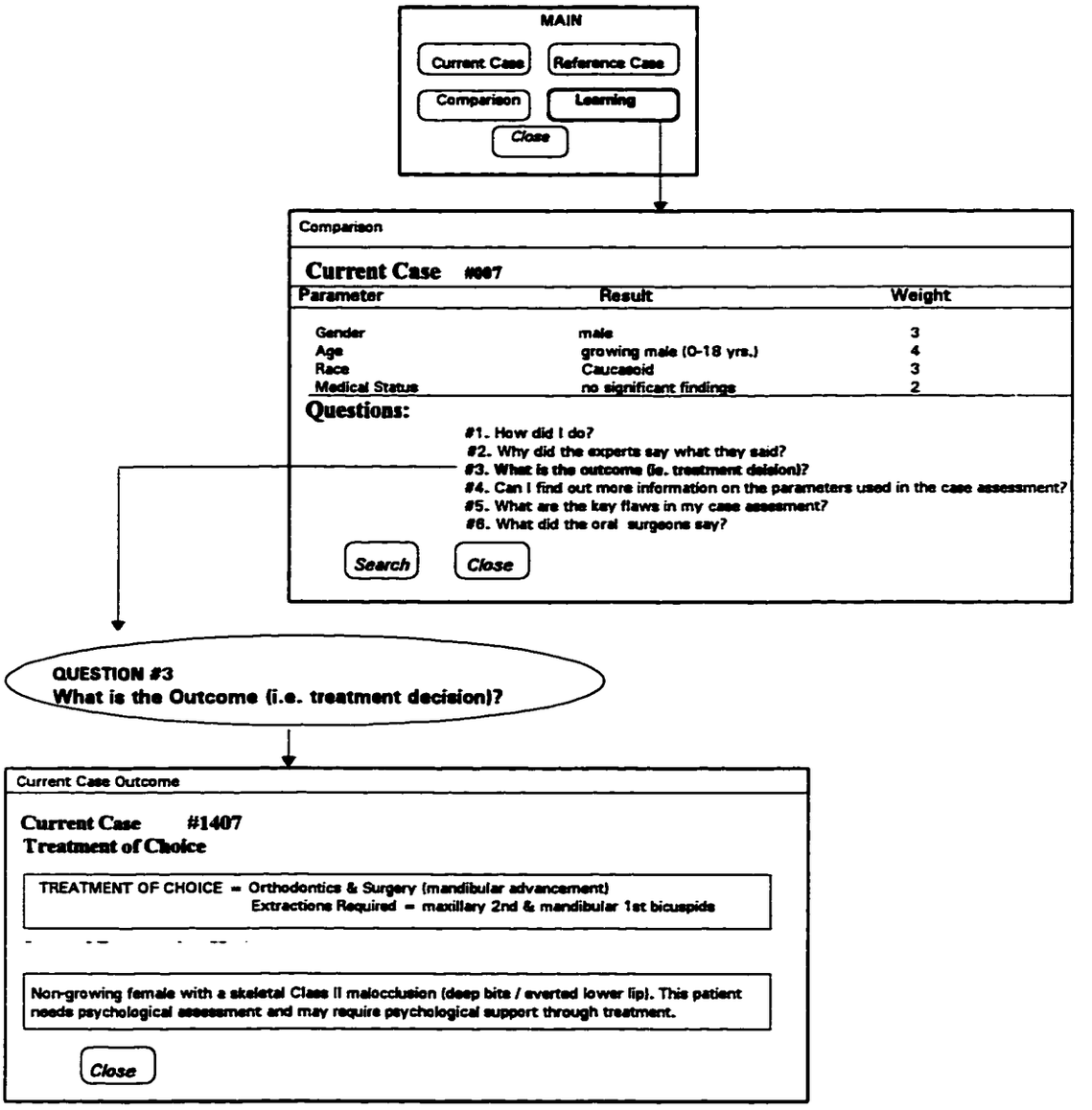


Figure 2.18 Learning Module - Question #4

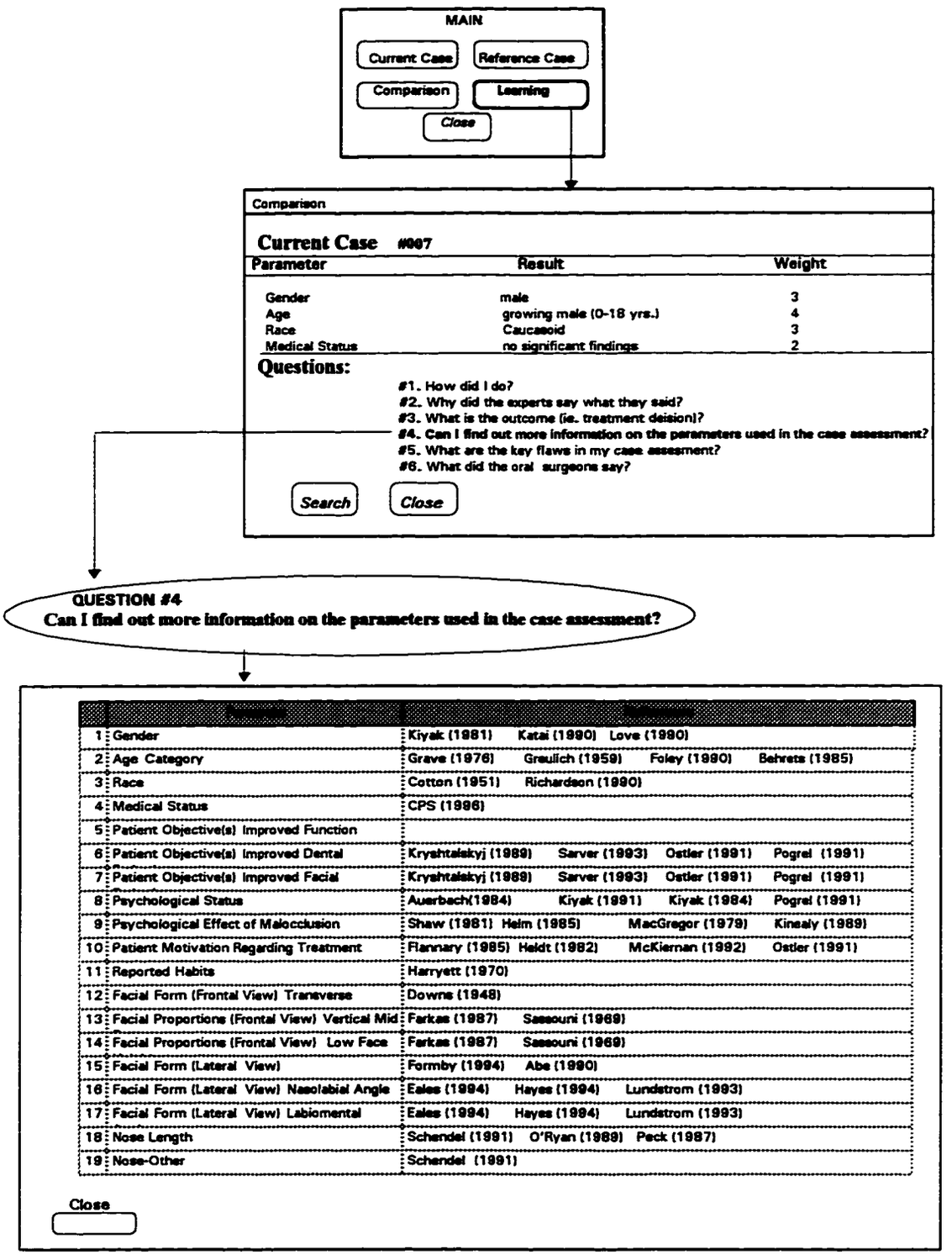
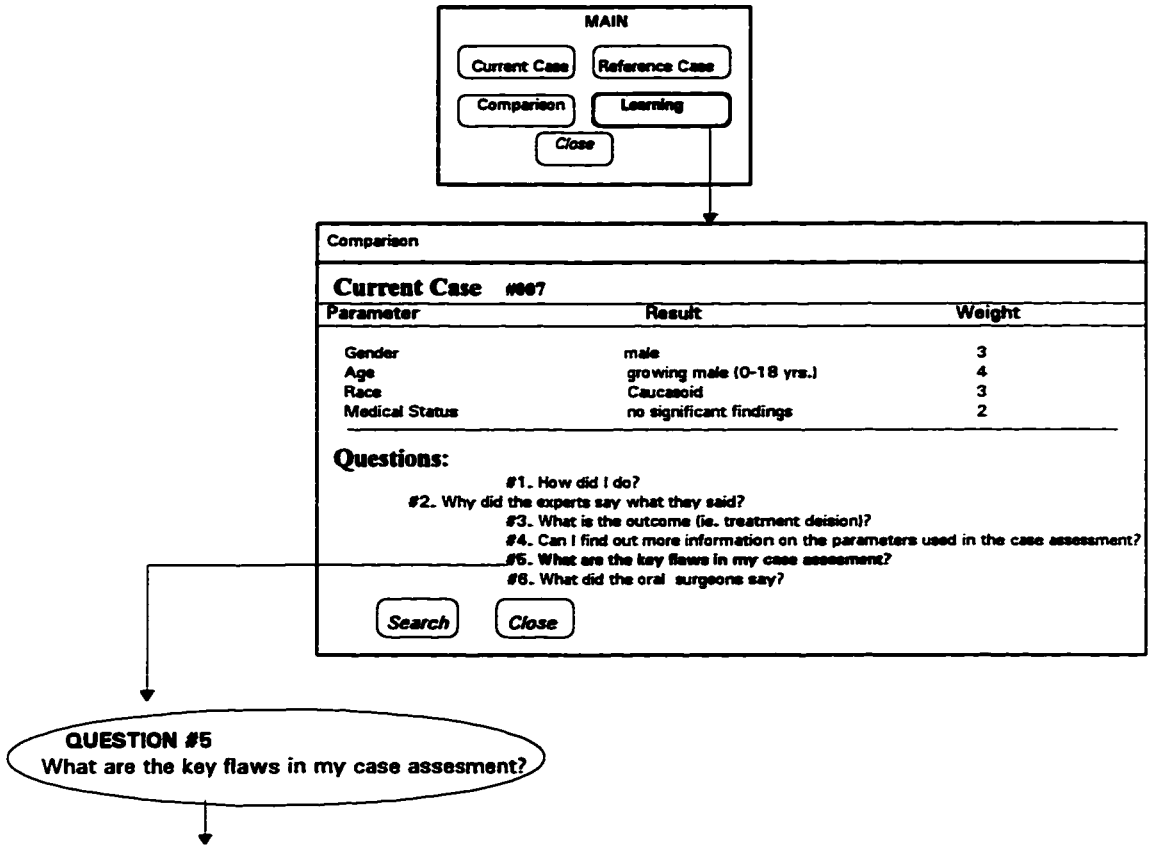
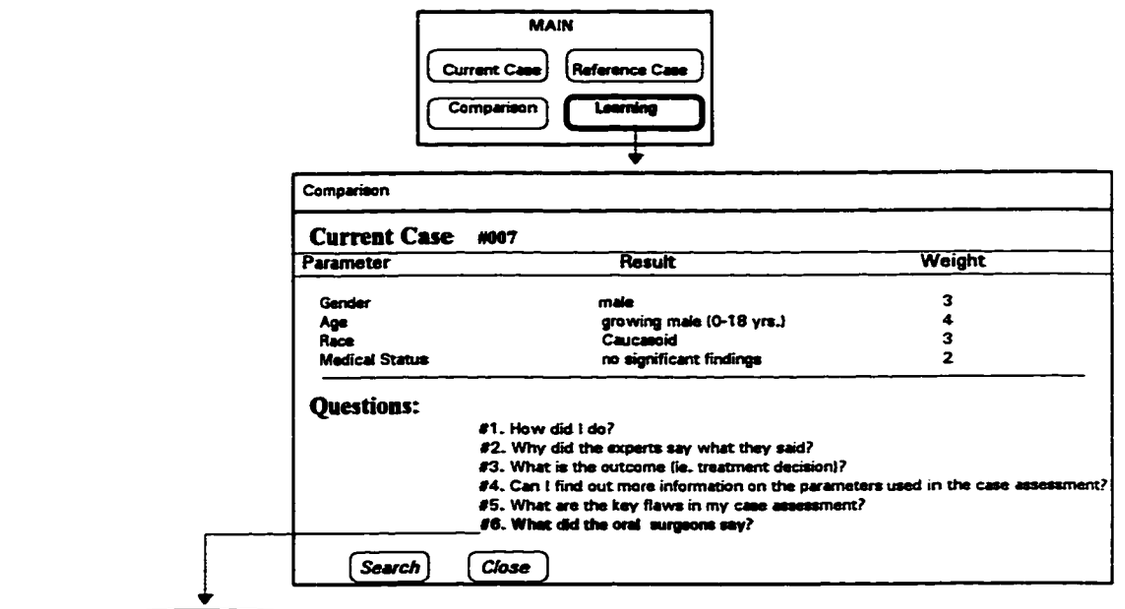


Figure 2.19 Learning Module - Question #5



Concept Flaws			
Scenario	Ratio	Interpretation	
1	0.70	Clinical assessment	your assessment is good
1	1.00	Demographics / Pers. Info.	your assessment is excellent
1	0.88	Diagnostic Imaging	your assessment is excellent
1	0.84	Model Analysis	your assessment is excellent
Category Flaws			
Scenario	Ratio	Interpretation	
1	0.91	Cephalometrics	your assessment is excellent
1	0.67	Diagnostic Imaging	your assessment is good
	0.64	Extra-Oral Findings	your assessment is good
Cluster Flaws			
Scenario	Ratio	Interpretation	
1	1.00	Cephalometrics - Skeletal	your assessment is excellent
1	0.50	Cephalometrics - Soft Tissue	your assessment is good
Subjectve / Objective Flaws			
Scenario	Ratio	Interpretation	
1	.04	Objective	your assessment is poor
1	.00	Subjective	your assessment is poor

Figure 2.20 Learning Module - Question #6



CASE #	TREATMENT DECISION	RATIONALE
1	• mandibular advancement • 4 bicuspid extraction	1. to establish Class I molar & cuspid relationships 2. moderate arch length deficiency 3. proclined max. & mand. incisors 4. convex profile 5. slight lower lip eversion 6. reduced lower face height
2	• periodontal consult • extract 8's • careful monitoring of TMJoints • mandibular advancement	1. retrusive mandible 2. soft tissue functional problems (upper lip) 3. reduced lower face height 4. prominent Pg & nasal tip 5. noted concerns about extent of trauma
3	• no surgery • orthodontics only • possibly adv. genioplasty • extract 4 x 1st bicuspids	1. chief complaint is dental not skeletal 2. good class I molar at present 3. concern about changing patients looks given that this is not in C.C. 4. patient age
4	• psychological assessment • restorative assessment • periodontal assessment • extract #28 & #48 • gnathological splint • mandibular advancement	1. concerned about psychological status (pt. is stressed / having problems coping). 2. facial asymmetry 3. reduced lower face height 3. poor chin projection 4. retroclination of max. incisors
5	• extract 8's • extract 4 x 1st bicuspids • mandibular advancement • advancement genioplasty	1. severely hypoplastic mandible 2. extremely convex profile 3. Class II molar & cuspid relationship 4.proclination of incisors 5. lower lip eversion
6	• remove and temporize crowns on #11&# 21 • extract 8's • extract 4 x 1st bicuspids • mandibular advancement • advancement genioplasty	1. Class II occlusion (want to establish Class I) 2. lip incompetence 3. retrognathic profile
7	• non-surgical • extract 4x 2nd bicuspids	1. good frontal view 2. good incisal display and dental esthetics 3. good profile and chin projection 4. Class I molar Left / end:end molar Right 5. reasonable skeletal relationships

2.14 Algorithms

An algorithm is defined as a systematic mathematical procedure used to derive a solution to a problem .[21] In this project, an algorithm has been designed to help compare data entered in the Current Case and Reference Case Modules. A Likert scale was used, as shown in Figure 2.21, for weighting of parameters. When assessing the cases, the experts and the novice orthodontists were asked to assign a value or weight from zero to five to the choice they selected for each parameter. The value was based on how important that parameter was in determining the treatment decision they chose for the case. A weight of zero was assigned if the parameter did not apply. For example, parameter number 49 is "Perimeter - Maxillary Excess". If the case actually had a maxillary perimeter deficiency, a weight of zero is assigned because the parameter did not apply to the case in question. A weight of one implied that the choice for the specific parameter had very little impact on the treatment decision. A weight of five implied that the choice for the parameter had an extremely significant impact on the treatment decision.

Figure 2.21 Likert Scale Related to Weighting of Parameters

WEIGHT	COMMENT
0	No influence
1	Very slightly significant
2	Slightly significant
3	Significant
4	Very significant
5	Extremely significant

The objective of constructing the weight score was to apply an algorithm which counted the evidence by the number of concurrent parameter matches (between the current and selected reference case) and accounted for the weight factors.

In order for the weight score to reflect the significance of the variable in determining the ultimate treatment decision, the weight (zero through five) was added to the cumulative score. This was done as an alternative to simply counting the number of matched and unmatched parameters. This means that three matched parameters, each of which were assigned a weight of one, will have less impact on the cumulative score than one matched parameter which was weighted four or five.

The score is also affected by the weighting of the non-matching parameters. In this instance, the weight of the current case parameter was included; however, the absolute difference between the weight from the current case and the weight from the reference case is subtracted. For example, for a given parameter choice, the novice (current case) and the

expert consensus (reference case) match; but expert (reference) weight is 2 and the novice weight is 4. For the Cumulative Score, 1 is added to the count to reflect the parameter match. To account for the weight, 4 will be added and then the absolute difference between the weights (4-2=2) will be subtracted from the total score. This means the weight score is penalized because the weights did not match exactly, therefore, 2 was added to the count. The programming used to execute the algorithm is contained in Figure 2.22, Programming for Cumulative Score Algorithm.

Figure 2.22 Programming for Cumulative Score Algorithm

Current Case

- parameter #34 = PC(34)
- weight for parameter # 34 = WC(34)

Reference Case

- parameter # 34 = PR(34)
- weight for parameter # 34 = WR(34)

General

- total number of parameters that match between the reference case and the current case = TP
- total weight score(cumulative) = TW

Application of Logic

If PC(34) = PR(34) then TP + 1(increment of one)

If and only if PC(34) = PR(34) then the following will happen:

If WC(34) = WR(34) then TW + WC(34)(increment of WC(34))

If WC(34) <> WR(34) then:

If ABS = absolute value of the difference WC(34) - WR(34) then

(TW + WR34) - ABS(increment of WR(34) - ABS)

When the matching has been done and the algorithm applied, a best matched case is highlighted by the computer system. A written comment is then constructed by the computer system, based on the search/sort criteria (i.e. parameter, weight, outcome). For example, using "parameter" as the search/sort criterion when comparing current case #1407 with all of the reference cases (1 through 10), the system provides an interpretation as follows: "the current case is best related (by parameter) to reference case #007". See Figures 2.12 and 2.13.

As noted in the System Design section (Section 2.13), the system provides a written comment about the scores calculated in the case comparison. The performance of the

novice, is determined by the parameter, weight, or outcome match between the current and selected reference case and is classified as excellent, good, fair, or poor. A ratio of total parameters to matching parameters is used. As listed in Figures 2.04 to 2.09, the 82 parameters used in each case analysis are classified into groups and subgroups. Feedback is given for each subgroup within the Category, Concept, Cluster and Subjective/Objective groups. The ratio is calculated by dividing the number of matching parameters per subgroup by the total number of parameters per subgroup. Comments are provided as feedback to the user as follows:

- excellent - requires a ratio of .76 to 1.00
- good - requires a ratio of .50 to .75
- fair - requires a ratio of .26 to .49
- poor - requires a ratio of .00 to .25

2.15 Pilot Testing

Prior to testing the system, several testing procedures were done. To review the case analysis format, the 82 parameters and the respective choices were reviewed with two expert orthodontists and one novice orthodontist. None of these individuals participated in the final interview process. Changes in parameters, choices and format were made based on their input.

A practice case analysis and interview was done with an expert orthodontist and separately with a novice orthodontist. Neither of the individuals who participated in the pilot case analysis interviews participated in the final interview process reported in this study nor did they contribute to the review of case analysis format.

The system prototype was also tested with an expert orthodontist.

2.16 System Testing

The system prototype was tested by each of the 4 novice orthodontists during the system use/user feedback sessions. Each novice analyzed five clinical cases (either Group A: cases 1 through 5; or Group B: cases six through 10). The interviews related to clinical case analyses were conducted at a separate session from the system testing. Data collected from the novice orthodontists during the initial interview session was entered into the system prior to the system testing session. To ensure the novice had an opportunity to input data into the system, he or she entered one case into the system using the Current Case input module. Due to time constraints, the data for the remaining four case was entered into the system by the researcher, prior to the system testing session.

Prior to using the system, the before-use interview was conducted. Each novice orthodontist was then asked to use the ORTHO1 decision support system. Initially, the system was explained, a sample case was used as data for a demonstration run of the system, the novice was given the code numbers for the current cases which they had analyzed, and then was instructed to test the system by using the Comparison Module and the Learning Module. The related case work-ups were available for review as needed. Following completion of the system use component of the session, the after use interview was conducted.

RESULTS

2.17 System Development

The ORTHO1 decision support prototype was developed in the context of a Masters of Science research project, done in conjunction with a clinical based orthodontics program. The project was exploratory in nature and represents the initial step in a more comprehensive process of system development.

Some background literature was available to support the concept of knowledge based system development and served as a general guide for the system development process for this project. However, given the unique nature of the orthodontic diagnosis and treatment planning process, a special system development process resulted. Therefore, the development process for this project has been presented as a research finding.

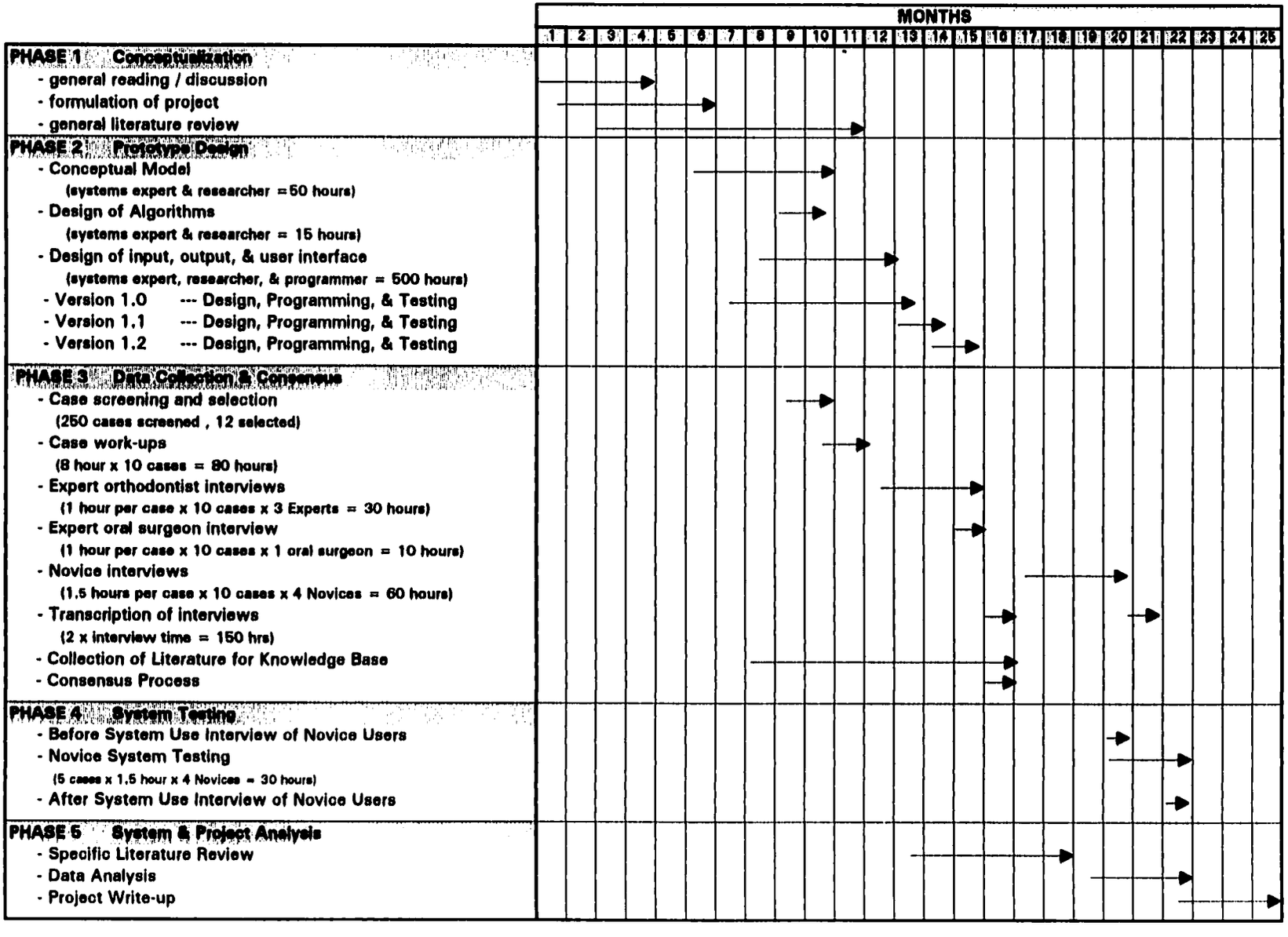
Five Phases of the System Development Process

The process followed in the development of the ORTHO1 system can be divided into five phases; Conceptualization, Prototype Design, Data Collection and Consensus, System Testing, System and Project Analysis. The five phases, related steps and timeline which documents the system development process are shown in Figure 2.23.

The Conceptualization Phase involved the formalization of the project idea and the performance of a literature review. The Prototype Design Phase included the design of a conceptual model followed by the production of a system prototype. The conceptual model, as shown in Section 2.04, Figure 2.02, provided the framework upon which the decision support system was built. The conceptual model design required about 50 hours of combined input from a systems expert and the researcher. The more detailed prototype system required the additional input of a computer programmer and required about 500 hours of input. Three versions of the prototype were produced, each one was refined from the previous version.

The Data Collection and Consensus Phase included the screening and selection of clinical cases, case work-ups, interviews of expert orthodontists, interview of an expert oral surgeon, interviews of novice orthodontists, transcription of interviews, collection of supporting literature, and the application of the consensus process. Two hundred and fifty cases were screened and 12 cases were selected for analysis by the expert orthodontists, an expert oral surgeon, and the novice orthodontists. Ten of the cases were used in the actual case analyses and system testing. Case records were reproduced and case work-ups were done, as described in Section 2.10. In total, about 100 hours of interviews were

Figure 2.23 Five Phases of the ORTHO1 System Development Process



conducted to collect data from the three expert orthodontists, the expert oral surgeon, and the four novice orthodontists. The format of the interviews was as follows: the expert or novice was asked to analyze a case in the manner preferred by him or her; a treatment plan was established; the researcher systematically reviewed each parameter and the respective choices (as listed in Appendix A, Figure A1). For each parameter the expert or novice was asked to select one of the choices, apply a weight to that choice, and make comments about the rationale for the choice and weight. The weight was to reflect the importance of the parameter relative to the treatment decision. This process was repeated for each case which was analyzed. The interviews were subsequently transcribed. About 20 hours were required to establish a consensus opinion between the expert orthodontists. Ongoing throughout Phase 3 was the accumulation of literature to be used in the knowledge base.

The System Testing Phase required the Novice orthodontists to use the decision support system. In addition, "before system use" and "after system use" interviews were conducted. About 20 hours of system testing was performed. Four novice orthodontists reviewed five cases each. Table 2.01 shows the format of the system testing session.

Table 2.01 Format and Timing of System Testing by Novice Orthodontists

	Hours / Session	Total Time (4 Novice Testers)
1. Before Use Interview	0.5	2
2. System Overview	0.5	2
3. Case Input by Novice (1 case only)	0.5	2
4. System Use by Novice (5 cases)	5	20
5. After Use Interview	0.5	2
TOTAL TIME	7	28

The System and Project Analysis Phase, performed by the researcher, included an additional literature review which focused on the project in its final format, data analysis, and project write-up.

The ORTHO1 Decision Support Prototype

The result of the first phases of the system development process was the ORTHO1 decision support prototype. Data for system testing was collected in phase 3.

The ORTHO1 decision support system has four key design components; a clinical database, a knowledge base, reasoning and control rules, and a user interface. It also has four modules which can be accessed by the system user. They include; Reference Case, Current Case, Comparison, and Learning Modules. The Current Case and Reference Case

Modules are data input modules. The system user enters clinical data into the clinical database by using the Current Case Module. The researcher entered the expert opinion into the knowledge base by using the Reference Case Module. Additional data, in the form of literature support, was added into the knowledge base by the researcher.

In the Comparison Module the system compares each current case with all reference cases in the knowledge base. The system then highlights the best matched reference case for use in further comparative analysis. In the Learning Module the matching process done in the Comparison Module is also performed. When the best matched reference case is identified, the learning module performs subsequent comparative analyses by answering a series of six questions. The six questions and the related analyses are summarized in Table 2.02.

Table 2.02 The Questions and Related Analyses of the Learning Module

Question #1	**How did I do?** A parameter by parameter comparison of the matched current case and reference case.
Question #2	**Why did the experts say what they said?** A display of the expert rationale for each decision, a display of the non-matching parameters, and an opportunity for the user to change his/her decisions based on expert opinion and literature support.
Question #3	**What is the outcome? (i.e. treatment decision)** A written summary of the user's treatment decision and major reasons for that decision.
Question #4	**Can I find out more on information on the parameters used in case assessment?** Displays a list of literature which pertains to each parameter in the case analysis.
Question #5	**What are the key variances in my case assessment?** Displays the "marking" of the current case versus the reference case analysis and provides a report to the user comparing his or her case assessment relative to the matched reference case.
Question #6	**What did the oral surgeon say?** Displays the case analysis and treatment recommendations made by an expert oral surgeon.

Literature Support

The literature support for the ORTHO1 decision support system was provided in the form of structured reviews, lists of related references, and actual published papers. Although the structured reviews and published papers were presented manually in this project, the ease of access to these resources was appreciated by the users. During the system use, two of the four users reviewed literature related to parameter choices they were uncertain about. Both of these users reported that the use of literature affected their related decision.

The classification of scientific literature was reviewed by Oxman.[10] Four levels of literature were identified: Level 1 - randomized controlled trials; Level 2 - cohort studies; Level 3 - case control studies; and Level 4 - case studies and case reports. Of the articles included in the systems knowledge base none were Level 1 or Level 2 literature.

Consensus Process

The rules for consensus were applied to the information obtained from the expert orthodontists. To establish a consensus opinion for representation in the system's knowledge base, three expert orthodontists were interviewed regarding 10 case analyses each. A total of 13,710 variables were processed in the establishing consensus.

Table 2.03 Variables Managed in the Consensus Process

		Variables per Clinical Case	Total # of Variables
Expert Orthodontists	3		
Number of Clinical Cases	10		
Number of Parameters		82	2,460
Number of Parameter Choices		293	8,790
Number of Weighting Factors		82	2,460
TOTAL	30	457	13,710

Consensus was reached by applying the rules for consensus for each parameter and each weight in each clinical case. These rules are summarized in Table 2.03.

Table 2.04 Summary of Rules For Establishing Consensus

Rule #1	**Two Thirds Majority for Treatment Choice** • If two of the three experts agree on a treatment choice, consensus for treatment was reached.
Rule #2	**Initial Screening by Treatment Choice** • If the consensus treatment decision is determined by two-thirds majority, the choices and weightings selected by the expert who did not agree with the consensus treatment decision were not considered.
	NOTE: Rules #3 - #5 assume that consensus on treatment choice has been established
Rule #3	**Two Thirds Majority** • Two thirds majority for parameter choice or weight • If two of the three experts agree on a parameter choice or weight, consensus was reached.
Rule #4	**Range of +/- 1** • The experts were considered to be in agreement if the weights were within the range of plus or minus 1.
Rule #5	**Supported by Literature** • If consensus was not reached through the initial analysis or through a follow-up interview process, a parameter choice and weighting was determined by the researcher. This was done only if the decision could be supported by credible research findings. (i.e. peer reviewed, published literature).
Rule #6	**No Consensus Flagged by System** • If consensus still was not reached after applying rules 1 through 5, the parameter choice and weight were reported and "flagged" in the computer system. For example, a note would be flashed on the screen to alert the user to the problem.

Four levels of difficulty when negotiating a consensus opinion:

Level 1 = following the initial screening for outcome, consensus was established by applying Rules #1 through #4.

Level 2 = following the initial screening for outcome, consensus was established by applying Rule #5. This means a follow-up interview and discussion / negotiation with one, two or three of the experts was required before consensus was reached.

Level 3 = following a follow-up interview and discussion / negotiation process, consensus was not established. The researcher was then forced to apply Rule #5: a parameter choice and weighting was determined by the researcher. This was done only if the decision could be supported by credible research findings. (i.e. peer reviewed, published literature).

Level 4 = Consensus was not established.

The rules for consensus were explained to the experts prior to the case analysis and interview process. All three expert orthodontists agreed to the consensus process. Additional clarification was not required from any of the experts and, although requested, no additional suggestions were made to improve or change the consensus process.

Of the ten cases analyzed by the three expert orthodontists, Level 1 consensus was established for treatment choice in eight cases. The three experts agreed unanimously on the treatment choice in five of those eight cases. A follow-up discussions with the experts regarding the two remaining cases resulted in Level 2 consensus. Consensus was established in about 65 percent of the case variables by Level 1 consensus. Level 2 consensus was established for an additional 30 percent of the variables. Of the remaining 5 percent of the variables, an additional round of negotiations resulted in Level 3 consensus. Due to the cooperative nature of the experts, Level 4 non-consensus was not applied.

Case Matching and Algorithms

In the Learning and Comparison Modules, the matching between the current case and the reference case was done using three separate matching commands; parameter, weight, outcome. Using the parameter match command, the system consistently matched the current case with the corresponding reference case. It became clear however, that by matching by weight or outcome alone, the chances of identifying the correct case match was limited. It was observed that, when using the weight and outcome match commands, the algorithm used to match the current case with the reference was not specific enough to produce a clinically meaningful result. That is, matching by weight provided a mathematical match based on the numbers used for weighting each parameter. Using the outcome match command resulted, in some instances, in three of the ten reference cases being matched. The focus of the results of system testing is therefore related to case matching by parameter.

2.18 User Performance

The system testing was done with four novice orthodontists. Each novice analyzed five cases; Group A: cases 1 through 5 or; Group B: cases 6 through 10. The novices analyzed the cases and were then interviewed. In a subsequent session, the novice input one case into the Current Case module of the system. The other four cases were entered by the researcher because of time constraints.

In the user performance analyses, the novice user's performance was gauged relative to that of the experts. The results represent comparative analyses performed between the

current case and the selected (best matched) reference case. The user performance results are presented under the following subheadings: initial case analysis, what best analysis, what-if case analysis, and use of system modules.

Initial Case Analysis

These following performance results for the initial case analysis reflect the novice orthodontist's performance prior to accessing structured feedback, as provided by the ORTHO1 system.

Appendix H, Figure H1 contains a detailed summary of the novice user's performance record and Table 2.05 shows a synopsis of this data. The results presented in Table 2.05 reflect a performance criterion of >75%. This translates into an "excellent" rating, as discussed in Section 2.14, Algorithm. Table 2.06 contains additional data from the Initial Case Analysis including the number of non-matching parameters by each novice and a summary of the results related to the proposed treatment subgroup. The results have been listed by groupings of parameters and are further divided into subgroups, as discussed in Section 2.08. The groups are Category, Concept, Cluster, Subjective/Objective. The parameters contained in each subgroup are listed in Figures 2.06 to 2.09. In addition, a sensitivity analysis was done to show the changes in performance ratings with 3 different levels of acceptability; >75%, >80%, >85%.

Table 2.05 Summary of Parameter Matches Between Novice Users and Experts - Performance >75% - Initial Case Analysis -

Group - CONCEPT SUBGROUPS	# of Parameters in Subgroup	# of Cases Where Performance >75% N1	N3	N2	N4
Demographics / Personal Information	3	5	5	5	5
Patient History	8	2	3	1	3
Clinical Assessment	23	5	3	5	2
Model Analysis	19	5	5	4	5
Diagnostic Imaging	25	5	5	5	5
Proposed Treatment	4	1	4	2	3
	82				

Group - CATEGORY SUBGROUPS	# of Parameters in Subgroup				
General Information	11	3	5	3	4
Extra-Oral Findings	14	3	3	3	1
Intra-Oral Findings	28	5	5	5	5
Diagnostic Imaging	3	3	4	2	3
Cephalometrics	22	5	5	5	5
Proposed Treatment	4	1	4	2	3
	82				

Group - CLUSTER SUBGROUPS	# of Parameters in Subgroup				
Demographics / Personal Information	3	5	5	5	5
Medical Health Information	5	3	3	3	3
Patient Objectives	3	4	5	1	3
ExtraOral Findings_Clinical Assessment	12	3	3	1	0
Temporomandibular Joint	2	5	5	5	5
IntraOral Findings_Periodontal	4	5	5	4	3
IntraOral Findings_Bolton Assessment	5	5	5	5	5
Esthetic Assessment of Dentition	2	5	4	4	4
Occlusion	12	4	4	3	5
Perimeter Assessment	5	3	4	2	3
Diagnostic Imaging	3	3	4	2	4
Cephalometrics_Soft Tissue	4	5	5	4	3
Cephalometrics_Skeletal	18	5	5	5	5
Proposed Treatment	4	1	4	2	3
	82				

SUBJECTIVE / OBJECTIVE SUBGROUPS	# of Parameters in Subgroup				
Objective	52	5	4	5	5
Subjective	30	4	5	2	4
	82				

Table 2.06 SYNOPSIS OF INITIAL CASE ANALYSES AND WHAT-IF CASE ANALYSES RESULTS
Cases 1 - 10 N1 / N2 / N3 / N4

GROUP A	CASE #1		CASE #2		CASE #3		CASE #4		CASE #5	
	N1	N3	N1	N3	N1	N3	N1	N3	N1	N3
INITIAL CASE ANALYSIS										
# of Non-Matching Parameters	12	9	9	8	14	12	7	5	5	3
Parameters in Proposed Treatment Subgroup	4	4	4	4	4	4	4	4	4	4
# of Non-Matching Parameters Related to Proposed Treatment Group:										
Extractions Required	1	1	1	0	1	0	0	0	1	0
Orthodontics Only	1	1	0	0	1	0	0	0	0	0
Orthodontics & Surgery	1	1	0	0	0	0	0	0	0	0
No Treatment	0	0	0	0	1	0	0	0	0	0
	25%	25%	75%	100%	25%	100%	100%	100%	75%	100%
FOLLOWING WHAT-IF ANALYSIS:										
# of Changed Parameters	3	1	4	0	4	2	2	1	3	0
# of Changed Weights	5	1	7	4	6	8	4	1	5	3
Changes Related to Proposed Treatment										
Extractions Required	1	1	1	0	1	0	0	0	0	0
Orthodontics Only	1	1	0	0	1	0	0	0	0	0
Orthodontics & Surgery	1	1	0	0	0	0	0	0	0	0
No Treatment	0	0	0	0	1	0	0	0	0	0
	25%	25%	75%	100%	25%	100%	100%	100%	100%	100%

GROUP B	CASE #6		CASE #7		CASE #8		CASE #9		CASE #10	
	N2	N4	N2	N4	N2	N4	N2	N4	N2	N4
INITIAL CASE ANALYSIS										
# of Non-Matching Parameters	14	13	16	18	9	6	16	12	11	9
Parameters in Proposed Treatment Subgroup	4	4	4	4	4	4	4	4	4	4
# of Non-Matching Parameters Related to Proposed Treatment Group										
Extractions Required	1	1	1	1	0	0	1	0	0	0
Orthodontics Only	0	0	1	1	0	0	1	0	0	0
Orthodontics & Surgery	0	0	1	1	0	0	1	0	0	0
No Treatment	0	0	0	0	0	0	0	0	0	0
	75%	75%	25%	25%	100%	100%	25%	100%	100%	100%
FOLLOWING WHAT-IF ANALYSIS:										
# of Changed Parameters	8	4	12	7	7	9	13	14	7	15
# of Changed Weights	6	2	4	3	7	4	4	6	2	8
Changes Related to Proposed Treatment										
Extractions Required	1	0	0	0	0	0	0	0	0	0
Orthodontics Only	0	0	0	0	0	0	0	0	0	0
Orthodontics & Surgery	0	0	0	0	0	0	0	0	0	0
No Treatment	0	0	0	0	0	0	0	0	0	0
	75%	100%	100%	100%	100%	100%	100%	100%	100%	100%

SUMMARY OF INITIAL CASE ANALYSIS			% of Total
Total Case Analyses	20	=	100%
Cases with Non-Matching Treatment Plans	10	=	50%
			% of Non-Matching Treatment Plans
Cases with Non-Matching Extraction Protocols	10	=	100%
Cases With Non-Matching Surgical Plans	6	=	60%

As system testers, the novice orthodontists did 20 separate case analyses. N1 and N3 each analyzed the 5 cases in Group A; N2 and N4 each analyzed the 5 cases in Group B. Of these 20 case Initial Case Analyses, 10 (50%) were assigned treatment plans that did not match those assigned by the experts. Of those 10 cases, 6 differed in whether combined orthodontics/orthognathic surgery was required while all ten differed in the recommended extraction protocol. N1 matched with expert opinion in 1 of 5 cases, N2 in 2 of 5 cases, N3 in 4 of 5 cases, and N4 matched in 3 cases. (See Table 2.06).

A summary of the Initial Case Analysis results by group are as follows (See Appendix H, Table H1 and Table 2.05):

Concept Group

Each of the four novice users scored 100% in the demographics and personal information subgroup, and the diagnostic imaging subgroup. Stated another way, all 4 novices matched 3/3 (i.e. 100%) of the parameters in the demographics/personal information subgroup in all 5 cases, and 25/25 parameters in the diagnostic imaging subgroup in all 5 cases. Performance ranged between 74% (14/19) and 100%(19/19) in the model analysis subgroup. Scores in the patient history and clinical assessment subgroups ranged from 37% (3/8) to 100% (8/8) and 65% (15/23) to 96% (22/23) respectively. In the patient history subgroup, N3 and N4 scored >75% (6/8) in 3 of the 5 cases compared to N1 and N2 who scored >75% in 2 and 1 cases respectively.

Category Group

All 4 Novice users scored >75% for all cases analyzed in the intra-oral findings and cephalometrics subgroups. Performance by N1, N2 and N3 exceeded 75% (11/14) in the extra-oral findings subgroup in 3 cases. N4's performance exceeded 75% in only 1 case, and scored between 50% (7/14) and 64% (9/14) in the other four cases analyzed.

N3 performed well in the diagnostic imaging subgroup scoring >75% (3/3) in 4 of the 5 cases analyzed, while N1 and N4 scored >75% in 3 cases. A wide variation was noted in the general information subgroup with scores >75% (9/11) being obtained in 3 cases (N1 and N2) to 4 or 5 cases (N4 and N3).

Cluster Group

All novices performed well in 4 of the 14 subgroups which comprise the Cluster groups. The 4 Cluster subgroups identified included; demographics/personal information, temporomandibular joint, Bolton assessment, and cephalometrics - skeletal. All 4 Novices scored >75% in 5/5 cases. N1 and N3 performed well overall, scoring >75% in all

subgroups within the Cluster Group for at least 3 of the 5 cases analyzed. N2 scored >75% in 3 or 4 cases compared in the following subgroups; medical health information, intra-oral findings -periodontal considerations, esthetic assessment of dentition, occlusion, and cephalometrics -soft tissue. In the subgroups of patient objectives, extraoral findings - clinical assessment, perimeter, and diagnostic imaging N2 scored below 75% in at least 3 of the 5 cases analyzed. N4 scored below 75% (9/12) in each of 5 cases analyzed in the extraoral findings-clinical assessment subgroup and had 4 scores below 59% (7/12).

Subjective/Objective Group

Three novice orthodontists matched >75% of the objective parameters in 5 cases (N1, N2 and N4) while N3 scored >75% in 4 cases. Using this >75% criterion in the subjective parameter subgroup, performance dropped to 4/5 cases scoring >75% for N1 and N4 and 2/5 for N2. N3 scored >75% for subjective parameters in all 5 cases.

Specific Parameters

It is interesting to note that N4 did not match in parameter choice facial type in 3 of the 5 cases analyzed. In the Concept Group this parameter falls into the clinical assessment subgroup; for Category, the extraoral findings subgroup; and for Cluster, the extraoral findings-clinical assessment subgroup. This performance pattern was also noted for several other parameters.

Sensitivity Analysis of Novice Performance Ratings

The acceptable performance level (i.e. number of current case parameters which matched with reference case parameters) by the novice system users was analyzed given 3 different levels of acceptability; >75%, >80% and >85%. The changes in novice performance given each of the 3 acceptability criteria are shown in Appendix I, Table I1.

The results in the proposed treatment subgroup remained the same given the 3 levels of acceptability for performance by novice system users. Note that there are 4 parameters in the proposed treatment subgroup. A score of 3/4 is equal to 75%.

The novice performance given the >75% acceptability criteria has been reported in the preceding subsections. By changing the level of acceptability from >75% to >85%, some significant changes were noted. In the Concept group the following changes occurred: N1, N2, and N4 showed a notable drop in performance in the clinical assessment and model analysis subgroups. In clinical assessment, N1 fell below the 85% mark in 3 additional cases - falling from what appeared to be an excellent performance with 5/5 cases topping the >75% mark to a questionable performance of 2/5 cases meeting the >85% criteria; N2

dropped from 5/5 cases to 1/5 cases in clinical assessment and 4/5 to 1/5 cases in model analysis; N4 fell from 2/5 to 0/5 cases recorded with acceptable performance in the clinical assessment subgroup.

Novice performance in the Category group - general information subgroup, showed all 4 novices scored below acceptable in an additional 1 or 2 cases when the level of acceptability was raised from >75% to >85%. N2 also failed to reach the >85% mark in an additional 2 cases in the extraoral findings and intraoral findings subgroups; falling form 3/5 to 1/5 and 5/5 to 3/5 acceptable cases respectively.

When the acceptability criteria were raised from >75% to >85%, novice performance in terms of number of cases where performance was considered to be acceptable resulted in the following changes in the Cluster Group: In the medical health information subgroup, N1 dropped from 3/5 to 0/5 cases recording acceptable performance; N3 and N2 both dropped from 3/5 to 1/5; In the extraoral-clinical assessment subgroup N1 and N3 both recorded 1/5 acceptable cases, which reflected a drop from acceptable performance in 3/5 to 1/5 case. Performance in the intraoral findings- Bolton assessment subgroup reflected a reduction of 2 cases, from 5/5 to 3/5 cases for N2; In the occlusion subgroup, N2 and N4 dropped 2 cases in the acceptable record, from 3/5 to 1/5 and 5/5 to 3/5 respectively; N1 and N3 show problems with the perimeter assessment subgroup, falling from 3/5 to 0/5 and 4/5 to 2/5 acceptable cases respectively.

The sensitivity analysis performed on the Objective/Subjective subgroups showed a drop in acceptable performance levels on the subjective subgroup. By increasing the level of acceptable performance from >75% to >85%, performance by N3 and N4 dropped 3 cases from 5/5 acceptable cases to 2/5 and 4/5 to 1/5 respectively. The performance by N1 fell from 4/5 to 2/5 while N2 dropped from 2/5 to 1/5.

Time Required for Case Analysis

During the Initial Case Analysis, the novice orthodontists spent considerably longer analyzing the case records and case work-up. In general, the experts spent from 5 to 15 minutes while the novice orthodontists spent on average 30 to 45 minutes. The interview times per case, which include the case analysis time, took about 1 hour for the experts and 1.5 hours for the novices. The novice orthodontists typically spent longer that the experts reviewing the case records (especially cephalometric analyses). Two novice users reported that they were compensating for lack of experience by focusing on the details of the case data.

What Best Analysis

The "What Best" selection highlights the non-matching parameters which were identified during the comparison between the current case and the selected reference case. This analysis helps the system user identify parameters which need to be focused upon during the What-if Case Analysis.

What-if Case Analysis

Following a review of the analysis results for the Initial Case Analysis, the user is encouraged to enter the next cycle, the What-if Case Analysis. As illustrated in Figure 2.15, the What-if Case Analysis provides an opportunity for the user to change parameter choice and weight, if desired. The expert opinion parameter choice, weight, and decision rationale are displayed for the user's reference. Upon completion of the What-if cycle, changes made to the current case are displayed; the analysis by group is redone using the new data. This What-if cycle can be repeated at the user's discretion. Note that the user has access to the supporting literature throughout this process. During the system testing each novice user went through the What-if cycle once. All 4 novices noted that, if they were more familiar with the system and had more time, they would probably have cycled through the What if section at least once more.

Table 2.06 contains a summary of the number of non-matching parameters listed during the Initial Case Analysis and subsequently during the What-if Case Analysis.

During the What-if Cycle, each novice made changes in parameter choices and weights. These changes improved their matching within subgroups with the experts. N1 changed from 2 to 4 parameter choices in each case and 4 to 7 parameter weights. N3 analyzed the same 5 cases as N1 and changed from 0 to 2 parameter choices and up to 4 parameter weights in 4 cases and 8 in 1 case. N2 changed from 8 to 13 parameter choices in the 5 cases analyzed and from 4 to 7 parameter weights. N4 made the most changes in parameter choices, recording from 4 to 9 changes in 3 cases and 14 or 15 choices in 2 cases. Weight changes for parameters related to each of the 5 cases ranged from 2 to 8.

Three of the novice users made notes to question the experts decision and noted an argument in support of their decision or indicated why they chose not to change their parameter choice.

The ultimate goal in diagnosis and treatment planning is to establish the best treatment plan for each patient. Following the use of the system knowledge base in the What-if Cycle, several treatment parameters were changed by the novice users, as noted above. Each proposed treatment subgroup comprises 4 treatment parameters; extractions

required, orthodontics only, orthodontics and surgery, and no treatment. It is these 4 treatment parameters which are combined to represent the treatment plan. N2 altered 1 treatment plan, N2 and N4 each altered 2 treatment plans, and N3 chose not to alter any treatment plans. The changes in parameters ranged from altering the extraction protocol (in 3 of the 5 cases) to changing from a combined orthodontics\surgery plan to a non-surgical orthodontics treatment plan in 3
cases. A summary of treatment plan changes made by novice users following changes made during the What-if Case Analyses is shown in Table 2.07.

Table 2.07 Summary of Treatment Plan Changes by Novice Users Following What-if Case Analysis

	N1	N2	N3	N4	Total
# of Treatment Plans	5	5	5	5	20
# of Non-Matching Treatment Plans	4	3	1	2	10
% of Non-Matching : Total Treatment Plans	80.0%	60.0%	20.0%	40.0%	50.0%
# of Treatment Plans Changed	1	2	0	2	5
- Changed Extraction Protocols	1	2	0	2	5
- Changed Surgery Protocols	0	2	0	1	3

Use of System Modules

The Comparison Module and the Learning Module were used by all four novice users. The Comparison Module was reported by all users to be a useful tool for identifying the best matched Reference Case and for reviewing a quick comparison between the Current Case and the selected Reference Case. The Learning Module was reported unanimously to be the most useful part of the ORTHO1 decision support system. The structured feedback from the knowledge base; expert rationale and literature support were utilized by all novice users. The users reported that the analyses and feedback provided by the system did influence their ultimate diagnosis and treatment planning decisions; as reflected in the What-if case analyses.

2.19 User Feedback

During the system testing sessions the Novice users were asked two sets of questions; before system use and after system use. The following is a summary of feedback provided by the novice ORTHO1 decision support system users:

Feedback - Before System Use

- None of the novice orthodontists had formal computer training
- All of the novice orthodontists owned personal computers which they used three to four times per week.
- Software applications which all the novice orthodontists used included word processing, spreadsheet, and orthodontic cephalometric analysis.
- Other software applications used by at least two of the users included Quicken (accounting package), Power Point and Corel Draw (graphics), Entertainment Pack (games), and interactive CD ROM Orthodontic Case Presentation package.
- The two novice users who had access to the Internet reported frequent use of e-mail, World Wide Web, and Gate (library database searching).
- The two novice users who did not use the Internet reported that they intended to sign up for a server in the near future.
- Each novice user reported a slightly different "process used for case analysis". The novices agreed on the following case analysis protocol:

  a) patient's chief complaint; b) database assembly and analysis; patient history/ medical history/chief complaint, radiographic/photo and model assessment; facial, perimeter, AP, transverse, vertical, interactions (growth, habits, other); c) problem list; d) treatment alternatives; e) first treatment choice; f) consult with patient and family; g) final treatment plan.

Feedback - After System Use

- Given the fact that they used the computer system for only five cases, the users reported it probably hadn't changed their diagnosis and treatment planning process.
- Two of the four users reported that, over time, they might integrate a system like ORTHO1 into their treatment planning regimen.
- All users thought the objectives of the project, as stated in Section 1.06, had been met.
- All users thought the ORTHO1 decision support system had helped them focus their diagnosis and treatment planning process and re-evaluate it critically.
- One user suggested that the system provided a practical way of becoming more "experienced" without actually treating patients.
- One user indicated that the system had shown that a more "scientific" method of diagnosis and treatment planning in orthodontics was possible. The combination of

structured literature reviews, reference citations, and expert feedback was "dynamite".

DISCUSSION

2.20 Project Limitations

This research project was undertaken as a requirement for the completion of a Masters of Science in Orthodontics. Budget constraints seriously the project size. There were limitations on the number of clinical cases tested, the number of novice users, and the number of experts who contributed to the knowledge base. Budget constraints significantly limited the technical support required for developing the user interface. Therefore, the creation of a "user friendly" product was also limited.

It is important to note that this project is exploratory in nature. It is an initial step in a more comprehensive process of systems development, and it is considered to be an applied informatics project at the level of bench testing.[22] Background information has been taken primarily from medical informatics literature. This project had no roadmap, no existing protocol, and no comparable systems which might have served as a template. Hence, a considerable amount of time and energy was required to create the conceptual framework and subsequent model upon which the decision support system was designed. The ideas used to develop the conceptual framework, and subsequently to build the decision support system for orthodontics diagnosis and treatment planning, were taken from existing expert systems in medicine.

2.21 General Discussion

The purpose of this research project was to develop a prototype computer-based decision support system which focused on decision making in orthodontic diagnosis and treatment planning for orthodontic specialists. More specifically, the decision support system was designed to help novice orthodontists work with and analyze a complicated database, to provide decision support through a knowledge base, and to help novice orthodontists critically evaluate their diagnosis and treatment planning decisions.

The motivations for attempting this exploratory research project are reflected in the four following points for discussion: data management and knowledge based systems, ongoing critical appraisal, research based clinical practice, and evidence based clinical practice. By identifying some of the issues related to these points, and by developing a computer-based system to help address some of the issues, a small step towards improving the present "state of the art" in the oldest clinical specialty in dentistry will have been taken.

Data Management and Knowledge Based Systems

It has been well documented that the unaided human mind is limited in its capacity to store, organize and integrate large amounts of information. Huth stated that a professional's "capacity for knowing is sharply limited by the brain's capacity for the storage of information and the processing of it." [23] Weed noted that difficulties in making sound clinical judgments follow from "the limitations of unaided human minds in applying a very large body of knowledge."[24]

Rowsell, and Adams et al demonstrated that the quality of decision making improves by simply organizing the clinical data in a logical manner. [25, 26] Weed stated that "effective coupling of medical knowledge to action can be greatly facilitated by simple associative mechanisms" and suggested that medical content be stored in an efficient database structure.[27] Although orthodontists have done this manually for over a century, using computers can speed up the process and allow the orthodontist to manage significantly larger, more complex, and hopefully more comprehensive databases. Computer software programs have typically been designed to support the diagnosis and treatment planning process, rather than to improve or enhance it. Modern technology can now facilitate the development of computer systems which can also support and enhance the diagnosis and treatment planning process. These systems, known as knowledge based or expert systems, include a knowledge base which can include pertinent literature and expert opinion. Integrating these components of knowledge is essential in clinical practice today, but is difficult for the clinician to do without the support of a computer system. Although the value of clinical experience cannot be underestimated, the value of this experience is enhanced when combined with and supported by scholarly scientific literature. Weed noted that the unaided human mind is often unable to recall all the relevant patient data and the related opinions from the literature, "and is often unable to take those two bodies of information and integrate them systematically to come up with the best course of action".[28] This clearly indicates the need for a decision support system.

Critical Appraisal of Clinical Decision Making

To maintain a standard of excellence in diagnosis and treatment planning, both novice and experienced orthodontists need critical appraisal of their clinical decision making.

The literature states that as clinicians become more specialized, they also tend to become more parochial in their view. Hence, the potential for a more limited view versus a broader view of diagnosis and treatment planning by orthodontic specialists. As stated by Proffit, " the natural bias of any specialist is to characterize problems in terms of his or her own special interests."[29]

The decision support system developed in this project can be a useful tool in the ongoing critical appraisal of one's diagnosis and treatment planning. The system can provide feedback to the orthodontist about his or her performance relative to a "gold standard", which is reflected in the system's knowledge base. The knowledge base can also help keep the orthodontist informed of current scholarly literature related to diagnosis and treatment planning parameters. It is hoped that this system will stimulate orthodontists to adopt an ongoing practice of critical appraisal of their clinical decision making. The end result: learning through critical evaluation and acquisition of knowledge provided by the decision support system.

Research Based Clinical Practice

The ORTHO1 decision support system has the potential to support a research focus in a clinical practice setting. The data management capacity of the system can result in the production of useful clinical practice profile information. Numerous practice management software programs are available today. Examples include Ortho II, Ortho Trac, and OMS. These programs contain a wealth of information. However, typically the databases are not designed for clinical database compilation. This limits their use in clinical based research to a simple classification of information, general practice profiling, and financial applications. For example, the Ortho II was used to search a practice database in order to find acceptable cases for use in this study. Based on the limited search criteria which could be used, 250 cases were identified, 17 of which were truly acceptable, from which 12 cases were selected. These programs are excellent when used for the functions for which they were designed, but clinical research is not one of those functions.

The ORTHO1 decision support system is flexible in design. The clinical database and knowledge base can be organized for specified data structure and can be changed to suit specific research requirements.

Evidence Based Clinical Practice

Huth suggested that critical or structured reviews of scholarly literature be collected in a database.[30] Given that the American College of Physicians is aggressively promoting evidence-based medicine, which requires clinical decision making be supported by scholarly literature, the development of a knowledge base as suggested by Huth will be essential to clinical decision making in the future.[31] The nature of orthodontics practice does not lend itself well to clinical trials. This is clearly evidenced by the lack of literature related to controlled clinical trials and cohort studies. However, clinical outcomes can be evaluated and used as benchmarks against which orthodontists can critically evaluate their treatment

decisions, treatment mechanics, and treatment outcome. The decision support system can potentially provide this type of information.

2.22 System Development

As previously stated, this research project was exploratory in nature. Some background literature was available to support the concept of knowledge based system development and served as a general guide for the system development process for this project. However, given the unique nature of the orthodontic diagnosis and treatment planning process, a special system development process resulted. Therefore, the development process for this project was presented as a research finding.

Development Process

Stead listed five stages of systems development as follows: 1) work specification: What are the needs the researcher wants to meet? What are the functional specifications? What are the technical specifications? 2) developing and testing components or modules "should be a small, isolatable subset of a system with a defined input and output." 3) combining components or modules into the system and testing the system; 4) integrating the system into the appropriate environment; 5) routine use in an operational setting.[32]

The development process for the ORTHO1 system, which related directly to Stead's first three stages, was divided into five phases: Conceptualization, Prototype Design, Data Collection and Consensus, System Testing, and System and Project Analysis. The Phases, related steps, and timeline for the system development process are shown in Figure 2.23.

The first part of the Conceptualization Phase was the formalization of the idea: Does a computer-based decision support system exist which focuses on the decision making process in orthodontic diagnosis and treatment planning? If such a system does not exist, is it possible to develop a prototype system? This research idea is clearly expressed in the research questions and hypotheses formulated later in the project. They are listed in Sections 1.06 and 1.08 respectively. An extensive literature review revealed that a decision support system tailored to orthodontic diagnosis and treatment planning for orthodontic specialists did not exist. Some expert systems have been developed in dentistry, but are typically designed to support diagnosis. Examples include Expert System in Oral Diagnosis, ORAD (Oral Radiographic Diagnosis), and Jeremiah (an expert system designed to support decision making in orthodontics by inexperienced general practitioners). Numerous decision support systems exist in medicine, such as the CADAP (computer-aided decision support to the diagnosis of abdominal pain), and QMR (quick medical reference). Due to the limited

research in knowledge based systems in orthodontics, the medical literature was relied upon for much of the supporting background information. The Conceptualization Phase was the initial brainstorming phase. The researcher and systems expert spent many hours asking some of the following questions: Can we develop a system within the limitations of the project? What do we really want the system to do? What might the proposed system do? What might the proposed system look like? What are the key features of existing systems that we might want to incorporate into the system? How do we develop this proposed decision support system?

The Prototype Design Phase included the design of a conceptual model followed by the production of a system prototype. The conceptual model, as shown in Section 2.04, Figure 2.02, provided the framework upon which the decision support system was built. To design the conceptual model, about 50 hours of combined input from a systems expert and the researcher were required. The more detailed prototype system required the additional input of a computer programmer and required about 500 hours of input. Three versions of the prototype were produced; each one was refined from the previous version.

The Data Collection and Consensus Phase included the screening and selection of clinical cases, case work-ups, interviews of expert orthodontists, interview of an expert oral surgeon, interviews of novice orthodontists, transcription of interviews, collection of supporting literature, and the application of the consensus process. About 20 hours were required to establish a consensus opinion between the expert orthodontists. Ongoing throughout Phase 3 was the accumulation of literature to be used in the knowledge base.

The System Testing Phase required the Novice orthodontists to use the decision support system. In addition, "Before system use" and "after system use" interviews were conducted.

To summarize, the system development process was intense, time consuming and challenging. The result was a functioning decision support system prototype.

Consensus Process

The consensus process is an extremely important part of constructing a quality knowledge base. It is designed to help produce one opinion which represents an amalgamation of the experts analyses and opinions. Hopefully the process will help eliminate radical opinions and help identify issues which require further investigation, discussion, or clarification. It is important that at least three experts are used. This helps avoid deadlocks in the process if two individuals have strong and opposing views.

Algorithms

As noted in the results section, the matching between the current case and the reference case performed in the learning and comparison modules, was done using three separate matching commands: parameter, weight, outcome. Using the parameter match command, the system consistently matched the current case with the corresponding reference case. However, it was clear that by matching by weight or outcome alone, the chance of identifying the correct case match was limited. The researchers found that, when using the weight and outcome match commands, the algorithm used to match the current case with the reference was not specific enough to produce a clinically meaningful result.

Given the present system design, matching the current and reference cases by weight provided a mathematical match based on the numbers used for weighting each parameter. Clearly, this is unlikely to produce a result which has clinical meaning. To help focus the matching by weight, and give it clinical significance, some screening tools can be used. For example, if each clinical case in the knowledge base is identified by some key parameters (i.e. Class II, division 2 malocclusion, deep bite, non-growing, moderate crowding in maxilla, moderate crowding in mandible), then the cases can be matched based on some clinical parameters. This will help eliminate the mathematical matching by weight until a clinically appropriate case has been identified for comparison. Then the matching by weight helps identify the parameters by perceived importance, relative to the treatment decision.

In some instances, using the outcome match command resulted in three of the ten reference cases being matched. Given that there are fewer treatment possibilities than cases, one expects more than one reference case to be matched to each current case. Because there can be more than one acceptable treatment choice for a given case, the experts might be asked to select two treatment choices. Each choice could be given a weight to reflect the perceived value of the plan relative to what he or she considers to be ideal.

When using a larger knowledge base which contains more clinical cases related to numerous problem domains, it will be important to screen the group of reference cases to eliminate attempts by the system to match to irrelevant cases. For example, a reference case patient with a Class III skeletal malocclusion should not be considered for matching with a current case patient with a Class II skeletal malocclusion. An initial screening of reference cases will prevent the system from trying to find a matching case from an inappropriate problem domain.

2.23 User Performance

The novice user's performance was gauged relative to that of the experts. Data was first collected following the Initial Case Analysis and again following the What-If Case Analysis. The results represent comparative analyses performed between the current case and the selected (best matched) reference case. The four novice users are referred to as N1, N2, N3, and N4.

Initial Case Analysis

User performance results in this subsection relate to the performance by the novice user prior to accessing user feedback (i.e. expert decision rationale and literature support) provided by the system.

As system testers, the novice orthodontists did 20 separate case analyses. N1 and N3 each analyzed the 5 cases in Group A; N2 and N4 each analyzed the 5 cases in Group B. Of these 20 case analyses, 10 were assigned treatment plans that did not match those assigned by the experts. Of those 10 cases, 3 differed in whether combined orthodontics/orthognathic surgery was required, while all ten differed in the recommended extraction protocol. In 50% of the case analyses, the novice users selected different treatment plans from those of the experts; and in 30% of those cases, the novice users differed in a very significant way (i.e. proposed orthognathic surgery for the patient while the experts did not). Disagreement in extraction protocols are not uncommon in orthodontic treatment planning, even between experts. It is rarely a simple decision, and compensations made by the clinician in treatment mechanics can sometimes compensate for anticipated negative consequences. However, the consequence of subjecting a patient to orthognathic surgery are significant and must be carefully considered. The ORTHO1 system, in the What-if Analysis, provides an opportunity for the user to review his or her treatment planning decision.

Novice orthodontists took significantly longer to analyze clinical cases than did the experts. In fact, in some cases the novice took over 3 times as long to analyze the case and report a chosen treatment plan. This is thought to be a reflection of the level of experience, confidence and/or or lack thereof. In fact, two novice users reported that they tried to compensate for their lack of experience by paying attention to the details of the case work-ups.

The case analyses by group showed some interesting results. A criteria of 75% was set as a cut off point for good acceptable matching. Note that this means in a subgroup with 3 parameters, all 3 parameters must match; while in a subgroup with 14 parameters,

11 must match to meet or exceed the 75% mark. This places a burden on the user to perform well in subgroups with a limited number of parameters; in fact, in small subgroups no mistakes are acceptable. In the future, an algorithm might be designed to help address this issue.

In the Concept Group, performance by all novice users was strong in demographics/personal information, model analysis, and diagnostic imaging. Some problems in reaching the 75% mark were noted in the patient history and clinical assessment subgroups. N3 and N4 did not perform well in clinical assessment, while N1 and N3 showed problems in the patient history subgroup.

In the Category Group, all novice users performed well in introral findings and cephalometrics. N1 and N2 had some problems in general information; N1 and N2, and in particular N4, had problems in diagnostic imaging. Note that the problems which showed in the Concept subgroup, general information, are reflected in the Category Group under general information. The problems with diagnostic imaging now are more clearly reflected as problems related to film interpretation rather than cephalometric analysis.

The novice users generally had problems in medical health information, patient objectives, extraoral findings, perimeter, diagnostic imaging, and cephalometrics-soft tissue. These subgroups contain a significant number of subjective parameters, ones which require judgments be made in selecting parameter choices. It is not surprising that the novice users have some performance difficulties in these subgroups.

The objective of grouping and subgrouping of parameters was to provide a method for analyzing user performance. By looking at the same data organized in different ways, the user is given several ways to look at his or her performance, compared to that of the experts.

To help identify specific problems in a user's performance it is also important to look at performance relative to individual parameters. For example, N4 did not match in parameter choice for facial type in 3 of 5 cases analyzed. In the Concept Group, this parameter falls into the clinical assessment subgroup. For Category; extraoral findings, and for Cluster; extraoral findings-clinical assessment. N4's poor performance is reflected in all of the Groups and can be specifically identified. This means the system can help the user to focus in on problem areas within their decision making and specifically identify problem parameters. In the What-if analysis the decision support system then gives the user access to the knowledge base as a means of supporting the decision making, stimulating the user to look critically at his or her performance, and providing an opportunity to learn from the system.

Sensitivity Analysis of Novice Performance Ratings

The first analysis of user performance was done by applying a criterion for acceptable performance of >75%. Upon reviewing the sensitivity analysis results it became apparent that, by increasing the performance criteria to >80% or >85%, the users performance reports were notably different. Details of the sensitivity analysis are contained in I, Figure I1. The performance by all novices in the proposed treatment subgroup did not change. However, by applying the >85% criterion for acceptability, the following subgroups showed a notable reduction in the number of cases in which novice system users matched >85% of the parameters with the experts: Concept Group -clinical assessment; Category Group - general information; Cluster Group -medical health information, extraoral findings -clinical assessment, perimeter assessment. These subgroups were identified when the >75% performance criterion was applied however, the impact of the results is emphasized by increasing the criterion to >85%. Also, given that orthodontists are consulted because of their specialized expertise, a performance level of at least 80% is considered to be necessary.

Based on the findings of this sensitivity analysis, some changes in the system feedback on user performance have been recommended. The existing performance criteria set in the ORTHO1 system are as follows; excellent equals 76-100%, good equals 50-75%, fair equals 26-49%, and poor equals 0-25% The performance evaluation criteria should be changed to reflect the following changes: excellent equals 86-100%, good equals 76-85%, poor equals 61-65%, and unacceptable equals 0-60%.

What Best Analysis

The "What Best" selection highlights the non-matching parameters which were identified during the comparison between the current case and the selected reference case. The What Best analysis is a good screening tool which can be employed by the system user to check the number of parameters which do not match with the experts. This analysis helps to identify parameters which need to be focused upon during the What-if Case Analysis and can help the user decided if an additional cycle through the What-if Analysis is necessary.

What-if Case Analysis

The novices responded in some instances, with an interesting combination of uncertainty and certainty about their parameter choices. For example, in Case #7, N4 noted that the experts clinical assessment of lower face height was inconsistent with the cephalometric values presented. N4 therefore chose to keep the parameter choice even

though it did not match the experts. This occurred with 3 of the novice orthodontists who, after reviewing the experts' decision rationale, noted why they had chosen not to change their parameter choice. This is a clear reflection of critical self evaluation and self confidence. The novice was informed of an inconsistent parameter choice by the system, given the opportunity to review the experts' decision rationale and the related supporting literature, and also given the opportunity to change his or her choice if desired. Changing their parameter choice is optional. This is an example of how the ORTHO1 decision support system can facilitate critical self assessment of decisions made in orthodontic diagnosis and treatment planning.

The changes made during the What-if Analysis are summarized in Table 2.06. Note that of the 10 cases where novice users did not match the treatment plan of the experts, 5 or 50% of those treatment plans were changed following a review by the novice of expert rationale and selected supporting literature. Parameter choices and weights relating to specific parameters were also changed in each case analyzed. These changes reflect the impact of the ORTHO1 system on learning. The Change in treatment plans, other parameter choices and weights, in combination with user feedback (which will be discussed in a later section) support the notion that learning has in fact occurred. A longitudinal observation of the novice user's performance will help substantiate this observation.

Reflecting on the finding that only 50% of the non-matching proposed treatment subgroups were changed following use of the ORTHO1 system's knowledge base, some issues were identified. As shown in the changes made in parameters (including treatment parameters), weights, and as reflected in the users feedback interviews, novice orthodontists did critically evaluate their performance and learn from the system's knowledge base. However, in the ultimate goal of establishing the best treatment plan for each patient, only 50% of the proposed treatment subgroups were changed following the What-if Analysis. Suggested reasons for this low level of change include: lack of user confidence in the ORTHO1 system, inadequate expertise, failure to identify all appropriate parameters, and failure of the system to capture the subtleties of the parameters.

The ORTHO1 decision support system is a prototype which was tested for the first time in this project. The novice users were not familiar with the system or the medium for learning. Although not reflected in the user feedback interviews, it is possible that, over time the user will develop confidence in the system's knowledge base and be more strongly influenced by the system.

The quality of the expertise must be considered. There were instances where in fact the novice user's made suggestions about some non-matching parameters which suggested that the experts were incorrect. The quality of the knowledge base is only as good as the expert

opinion and supporting literature from which it is comprised. If the user's perceive the expertise of the system to be flawed, they will not develop confidence in its ability to support and enhance their own decision making.

The identification of all parameters which might influence in the case analyses is essential to the quality of the analyses done by the system. One is left wondering if the reason proposed treatment parameters were not changed by the users is because an important one was in fact not considered. Brainstorming with experts will be an important step towards answering this question.

The subtleties within the parameters must also be considered. A good example is the proposed treatment parameter; proposed extractions. Clinically, this parameter choice is very important. The impact of this parameter choice is significant for the patient and the orthodontist. Factors which must be considered when selecting an extraction protocol include the following: impact on facial profile, soft tissue support, impact on periodontal support, impact on periodontal condition, Bolton discrepancy, required treatment mechanics, and required patient compliance. Although many of these variables were considered in the case analyses, a more detailed section relating to the extraction protocol might have helped focus the decision making process in this parameter of the proposed treatment subgroup. Perhaps if the novice orthodontist's extraction protocol were not exactly matching, but the rationale for selection were sound, the system might in fact record that answer as "matching", to be reflected in the subsequent analysis and system feedback.

User Feedback

The novice orthodontists all reported using a computer 3 to 4 times per week for such software as Quicken, Corel Draw, Power Point, word processing, spreadsheet, and a cephalometric analysis package. All 4 novices were users or interested in using the internet. Case analysis protocols were similar for all of the novices. This reflects the standard approach to diagnosis and treatment planning promoted by Proffit.

Following ORTHO1 system testing the novices reported that, due to limited exposure to the system, they had not changed their personal diagnosis and treatment planning routine. Two of the four users did indicate a willingness to integrate a decision support system like ORTHO1 into their regimen and all 4 novices were positively impressed by the system and the potential benefits to them as clinicians.

CONCLUSIONS

The purpose of this research project was to develop a prototype computer-based decision support system which focused on decision making in orthodontic diagnosis and treatment planning for orthodontic specialists. More specifically, the decision support system was designed to help novice orthodontists work with and analyze a complicated database, provide decision support using a knowledge base, and to help novice orthodontists to critically evaluate their diagnosis and treatment planning decisions. This is more specifically stated in the following research questions:

- Can expertise within the domain of orthodontic diagnosis and treatment planning be structured so that it can be represented within a computer system?
- Can expertise within the domain of orthodontic diagnosis and treatment planning be used to assist novice orthodontists in decision making?
- Can a computer system, when dealing with problem solving in orthodontic diagnosis and treatment planning, help identify weaknesses for the purposes of learning?

The ORTHO1 decision support system was developed to help answer these questions. The four components of the system include a clinical database, a knowledge base, reasoning and control rules, and user interface. The expertise, in the form of expert opinion and scholarly literature, is contained in a knowledge base. The clinical database comprises the users case analyses. This expertise is shared with the system user as comparative analyses are performed between the user's clinical case and the best matched reference case from the knowledge base. By using built in reasoning and control rules and a series of feedback mechanisms to the user, the expert decision rationale and pertinent literature are shared with the user. The user interface is simply the vehicle used to display the information to the system user. The result; a computer-based decision support system which provides expertise specific to orthodontic diagnosis and treatment planning process and can be used to assist novice orthodontists in decision making. Through the system's analytical and feedback mechanisms, the ORTHO1 decision support system also helps identify weaknesses in the user's diagnosis and treatment planning strategy. The weaknesses are pointed out by the system and the knowledge base (expertise) is used to assist the user with areas of weakness.

In conclusion, the computer-based decision support prototype developed for this research project is the product of the initial stages of overall system development. Extensive system testing and evaluation are the next important steps in the development process. Following this, system implementation is possible.

By developing a system prototype designed to help critically review the diagnosis and treatment planning process in orthodontics, a small step towards improving the present "state of the art" in the oldest clinical specialty in dentistry has been taken.

REFERENCES

[1] Faber, R. D., Burstone, C.J., Solonche, D.J. Computerized Interactive Orthodontic Treatment Planning. Am J Orthod ,1978; 73, 1: 36-46.

[2] Weed, L.L. Knowledge Coupling, New Premises and New Tools for Medical Care and Education. Ann Arbour, Springer-Verlag, 1991. p.1.

[3] Weaver, N. E.; Major, P.W.; Glover, K.E.; Varnhagen, C.K., Grace. M.. Orthodontists' Perceptions of Need for a Jaw Surgery. International Journal of Adult Orthodontics and Orthognathic Surgery. 1996;11, 1: 49.

[4] Profitt, W.R. (1993), Baltimore. Contemporary Orthodontics, 2nd Edition, Mosby Year Book, Section III, Diagnosis and Treatment Planning, pp. 137.

[5] Profitt, W.R. (1993), Baltimore. Contemporary Orthodontics, 2nd Edition, Mosby Year Book, Section III, Diagnosis and Treatment Planning, pp. 137- 224.

[6] Moore, A.W. A Critique of Orthodontic Dogma. Angle Orthod 1969;39, 2:69-82.

[7] Huth, E.J., The Use of Medical Literature. Ann Int Med 1989;110,2: 99-100.

[8] Connely, D.P., Rich, E.C., Curley, S.P., Kelley, J.T. Knowledge Resource Preferences of Family Physicians. J Fam Pract. 1990; 30: 355-359.

[9] Evidence-Based Working Group. Evidence Based Medicine: A New Approach to teaching the Practice of Medicine. JAMA. 1992;268:2420-2425.

[10] Oxman, A.D., Cook, D.J., Guyatt, G.H.. User's Guide to the Medical Literature. JAMA 1995;272,17:1367-1371.

[11] Bolton, W.A.. The Clinical Application of a Tooth Size Analysis. Am J Orthod. 1962;48:504 - 529.

[12] University of Washington Graduate Orhtodontics. Washington "Alberta" Analysis.

[13] Jacobson, A. The "Wits" Appraisal of Jaw Disharmony. Am J Orthod. 1975;67:125-138.

[14] Mah, J. Jarabak Skeletal Analysis. Student Paper. University of Alberta. 1990.

[15] McNamara, J.A. A Method of Cephalometric Evaluation. AJO 1984,86;6:449-469. Cephalometrics for Orthognathic Surgery. J Oral Surg 1978;36: 269-277.

[16] Burstone, Charles J., James, R.B., Murphy, G.A., Norton L.A. Cephalometrics for Orthognathic Surgery. J Oral Surg 1978;36: 269-277.

[17] Wylie, G.A., Fish, L.C., Epker, B.N. Cephalometrics: A Comparison of Five Analyses Currently Used in the Diagnosis of Dentofacial Deformities. Int J Adult Orthod Orthog Surg 1987;2:15-35.

[18] Bergman, R. Practical Applications of the PA Cephalometric Head Film. Orthodontic Review. 1988:20-26

[19] Major, P.W., Johnson, D.E., Hesse, K.L., Glover, K.E. Landmark Identification Error in Posterior anterior Cephalometrics. Angle Orthod 1994;64:447-454.

[20] Grummons, D.C., Kappeyne, M.A., Van de Coppello, A. Frontal Asymmetry Analysis. JCO 1987;21:448-465.

[21] Cook, Thomas; Russell, Robert A., Introduction to Management Science, 4th Edition. Prentice-Hall. New Jersey, 1989.

[22] Stead, W.W., Haynes, R.B., Fuller, S., Travis, L.E., Beck, J.R.,Fenichel, C.H. et al Designing Medical Informatics Library and Research Projects to Increase What is Learned. Unpublished. Vanderbilt University, 1993.

[23] Huth, E.J., The Use of Medical Literature. Ann. Int Med 1989;110,2:99-100.

[24] Weed , L.L. Knowledge Coupling, New Premises and New Tools for Medical Care and Education. Ann Arbour, Springer-Verlage. p.xvi.

[25] Rowsell , K.V.. The Application of Knowledge Based Decision Support: Computer-Aided Diagnosis of Abdominal Pain at Ormskirk & District General Hospital, 1988-1993.1993 South Lancashire Health Authority.

[26] Adams ID, Chan M, Clifford PC et al. Computer Aided Diagnosis of Abdominal Pain: A Multi-Centre Study. British Med J. 1986, 293:800-804.

[27] Weed, Lawrence L., (1991), Knowledge Coupling. New Premises and New Tools for Medical Care and Education. New York, Springer-Verlag.p1.

[28] Weed, Lawrence L., (1991), Knowledge Coupling. New Premises and New Tools for Medical Care and Education. New York, Springer-Verlag.p1.

[29] Profitt, W.R. (1993). Contemporary Orthodontics, 2nd Edition, Mosby Year Book, Section III, Diagnosis and Treatment Planning, pp. 137 -264.

[30] Huth, E.J., The Use of Medical Literature. Ann. Int Med 1989;110,2:99-100.

[31] Evidence Based Working Group. Evidence-Based Medicine: A New Approach to Teaching the Practice of Medicine. JAMA, 1992;268:2420-2425.

[32] Stead, W.W., Haynes, R.B., Fuller, S., Travis, L.E., Beck, J.R.,Fenichel, C.H. et al Designing Medical Informatics Library and Research Projects to Increase What is Learned. Vanderbilt University, 1993.

CHAPTER 3

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DISCUSSION

3.01 Project Limitations

This research project was undertaken as a requirement for the completion of a Masters of Science in Orthodontics. Budget constraints seriously limited the project size. There were limitations on the number of clinical cases tested, the number of novice users, and the number of experts who contributed to the knowledge base. Budget constraints significantly limited the technical support required for developing the user interface. Therefore, the creation of a "user friendly" product was also limited.

It is important to note that this project is exploratory in nature. It is an initial step in a more comprehensive process of systems development, and it is considered to be an applied informatics project at the level of bench testing.[1] Background information has been taken primarily from medical informatics literature. This project had no roadmap, no existing protocol, and no comparable systems which might have served as a template. Hence, a considerable amount of time and energy was required to create the conceptual framework and subsequent model upon which the decision support system was designed. The ideas used to develop the conceptual framework, and subsequently to build the decision support system for orthodontics diagnosis and treatment planning, were taken from existing expert systems in medicine.

3.02 General Discussion

The purpose of this research project was to develop a prototype computer-based decision support system which focused on decision making in orthodontic diagnosis and treatment planning for orthodontic specialists. More specifically, the decision support system was designed to help novice orthodontists work with and analyze a complicated database, to provide decision support through a knowledge base, and to help novice orthodontists critically evaluate their diagnosis and treatment planning decisions.

The motivations for attempting this exploratory research project are reflected in the four following points for discussion: data management and knowledge based systems, ongoing critical appraisal, research based clinical practice, and evidence based clinical practice. It is the hoped that, by identifying some of the issues related to these points, and by developing a computer-based system to help address some of the issues, a small step

towards improving the present "state of the art" in the oldest clinical specialty in dentistry will have been taken.

Data Management and Knowledge Based Systems

It has been well documented that the unaided human mind is limited in its capacity to store, organize and integrate large amounts of information. Huth stated that a professional's "capacity for knowing is sharply limited by the brain's capacity for the storage of information and the processing of it." [2] Weed noted that difficulties in making sound clinical judgments follow from "the limitations of unaided human minds in applying a very large body of knowledge."[3]

Rowsell, and Adams et al demonstrated that the quality of decision making improves by simply organizing the clinical data in a logical manner. [4, 5] Weed stated that "effective coupling of medical knowledge to action can be greatly facilitated by simple associative mechanisms" and suggested that medical content be stored in an efficient database structure.[6] Although orthodontists have done this manually for over a century, using computers can speed up the process and allow the orthodontist to manage significantly larger, more complex, and hopefully more comprehensive databases. Computer software programs have typically been designed to support the diagnosis and treatment planning process, rather than to improve or enhance it. Modern technology can now facilitate the development of computer systems which can also support and enhance the diagnosis and treatment planning process. These systems, known as knowledge based or expert systems, include a knowledge base which can include pertinent literature and expert opinion. Integrating these components of knowledge is essential in clinical practice today, but is difficult for the clinician to do without the support of a computer system. Although the value of clinical experience cannot be underestimated, the value of this experience is enhanced when combined with and supported by scholarly scientific literature. Weed noted that the unaided human mind is often unable to recall all the relevant patient data and the related opinions from the literature," and is often unable to take those two bodies of information and integrate them systematically to come up with the best course of action".[6] This clearly indicates the need for a decision support system.

Critical Appraisal of Clinical Decision Making

To maintain a standard of excellence in diagnosis and treatment planning, both novice and experienced orthodontists need critical appraisal of their clinical decision making.

The literature states that as clinicians become more specialized, they also tend to become more parochial in their view. Hence, the potential for a more limited view versus a

broader view of diagnosis and treatment planning by orthodontic specialists. As stated by Proffit, " the natural bias of any specialist is to characterize problems in terms of his or her own special interests."[7]

The decision support system developed in this project can be a useful tool in the ongoing critical appraisal of one's diagnosis and treatment planning. The system can provide feedback to the orthodontist about his or her performance relative to a "gold standard", which is reflected in the system's knowledge base. The knowledge base can also help keep the orthodontist stay informed of current scholarly literature related to diagnosis and treatment planning parameters. It is hoped that this system will stimulate orthodontists to adopt an ongoing practice of critical appraisal of their clinical decision making. The end result: learning through critical evaluation and acquisition of knowledge provided by the decision support system.

Research Based Clinical Practice

The ORTHO1 decision support system has the potential to support a research focus in a clinical practice setting. The data management capacity of the system can result in the production of useful clinical practice profile information. Numerous practice management software programs are available today. Examples include Ortho II, Ortho Trac, and OMS. These programs contain a wealth of information. However, typically the databases are not designed for clinical database compilation. This limits their use in clinical based research to a simple classification of information, general practice profiling, and financial applications. For example, the Ortho II was used to search a practice database in order to find acceptable cases for use in this study. Based on the limited search criteria which could be used, 250 cases were identified, 17 of which were truly acceptable, from which 12 cases were selected. These programs are excellent when used for the functions for which they were designed, but clinical research is not one of those functions.

The ORTHO1 decision support system is flexible in design. The clinical database and knowledge base can be organized for specified data structure and can be changed to suit specific research requirements.

Evidence Based Clinical Practice

Huth suggested that critical or structured reviews of scholarly literature be collected in a database.[2] Given that the American College of Physicians is aggressively promoting evidence-based medicine, which requires clinical decision making be supported by scholarly literature, the development of a knowledge base as suggested by Huth will be essential to clinical decision making in the future.[8] The nature of orthodontics practice does not lend

itself well to clinical trials. This is clearly evidenced by the lack of literature related to controlled clinical trials and cohort studies. However, clinical outcomes can be evaluated and used as benchmarks against which orthodontists can critically evaluate their treatment decisions, treatment mechanics, and treatment outcome. The decision support system can potentially provide this type of information.

3.03 System Development

As previously stated, this research project was exploratory in nature. Some background literature was available to support the concept of knowledge based system development and served as a general guide for the system development process for this project. However, given the unique nature of the orthodontic diagnosis and treatment planning process, a special system development process resulted. Therefore, the development process for this project was presented as a research finding.

Development Process

Stead listed five stages of systems development as follows: 1) work specification: What are the needs the researcher wants to meet? What are the functional specifications? What are the technical specifications? 2) developing and testing components or modules "should be a small, isolatable subset of a system with a defined input and output." 3) combining components or modules into the system and testing the system; 4) integrating the system into the appropriate environment; 5) routine use in an operational setting.[1]

The development process for the ORTHO1 system, which related directly to Stead's first three stages, was divided into five phases: Conceptualization, Prototype Design, Data Collection and Consensus, System Testing, and System and Project Analysis. The Phases, related steps, and timeline for the system development process are shown in Figure 2.23.

The first part of the Conceptualization Phase was the formalization of the idea: Does a computer-based decision support system exist which focuses on the decision making process in orthodontic diagnosis and treatment planning? If such a system does not exist, is it possible to develop a prototype system? This research idea is clearly expressed in the research questions and hypotheses formulated later in the project. They are listed in Sections 1.06 and 1.08 respectively. An extensive literature review revealed that a decision support system tailored to orthodontic diagnosis and treatment planning for orthodontic specialists did not exist. Some expert systems have been developed in dentistry, but are typically designed to support diagnosis. Examples include Expert System in Oral Diagnosis, ORAD (Oral Radiographic Diagnosis), and Jeremiah (an expert system designed to support

decision making in orthodontics by inexperienced general practitioners). Numerous decision support systems exist in medicine, such as the CADAP (computer-aided decision support to the diagnosis of abdominal pain), and QMR (quick medical reference). Due to the limited research in knowledge based systems in orthodontics, the medical literature was relied upon for much of the supporting background information. The Conceptualization Phase was the initial brainstorming phase. The researcher and systems expert spent many hours asking some of the following questions: Can we develop a system within the limitations of the project? What do we really want the system to do? What might the proposed system do? What might the proposed system look like? What are the key features of existing systems that we might want to incorporate into the system? How do we develop this proposed decision support system?

The Prototype Design Phase included the design of a conceptual model followed by the production of a system prototype. The conceptual model, as shown in Section 2.04, Figure 2.02, provided the framework upon which the decision support system was built. To design the conceptual model, about 50 hours of combined input from a systems expert and the researcher were required. The more detailed prototype system required the additional input of a computer programmer and required about 500 hours of input. Three versions of the prototype were produced; each one was refined from the previous version.

The Data Collection and Consensus Phase included the screening and selection of clinical cases, case work-ups, interviews of expert orthodontists, interview of an expert oral surgeon, interviews of novice orthodontists, transcription of interviews, collection of supporting literature, and the application of the consensus process. About 20 hours were required to establish a consensus opinion between the expert orthodontists. Ongoing throughout Phase 3 was the accumulation of literature to be used in the knowledge base.

The System Testing Phase required the Novice orthodontists to use the decision support system. In addition, "before system use" and "after system use" interviews were conducted.

To summarize, the system development process was intense, time consuming and challenging. The result was a functioning decision support system prototype.

Consensus Process

The consensus process is an extremely important part of constructing a quality knowledge base. It is designed to help produce one opinion which represents an amalgamation of the experts analyses and opinions. Hopefully the process will help eliminate radical opinions and help identify issues which require further investigation, discussion, or

clarification. It is important that at least three experts are used. This helps avoid deadlocks in the process if two individuals have strong and opposing views.

Algorithms

As noted in the results section, the matching between the current case and the reference case performed in the learning and comparison modules, was done using three separate matching commands: parameter, weight, outcome. Using the parameter match command, the system consistently matched the current case with the corresponding reference case. However, it was clear that by matching by weight or outcome alone, the chance of identifying the correct case match was limited. The researchers found that when using the weight and outcome match commands, the algorithm used to match the current case with the reference was not specific enough to produce a clinically meaningful result.

Given the present system design, matching the current and reference cases by weight provided a mathematical match based on the numbers used for weighting each parameter. Clearly, this is unlikely to produce a result which has clinical meaning. To help focus the matching by weight, and give it clinical significance, some screening tools can be used. For example, if each clinical case in the knowledge base is identified by some key parameters (i.e. Class II, division 2 malocclusion, deep bite, non-growing, moderate crowding in maxilla, moderate crowding in mandible), then the cases can be matched based on some clinical parameters. This will help eliminate the mathematical matching by weight until a clinically appropriate case has been identified for comparison. Then the matching by weight helps identify the parameters by perceived importance, relative to the treatment decision.

In some instances, using the outcome match command resulted in three of the ten reference cases being matched. Given that there are fewer treatment possibilities than cases, one expects more than one reference case to be matched to each current case. Because there can be more than one acceptable treatment choice for a given case, the experts might be asked to select two treatment choices. Each choice could be given a weight to reflect the perceived value of the plan relative to what he or she considers to be ideal.

When using a larger knowledge base which contains more clinical cases related to numerous problem domains, it will be important to screen the group of reference cases to eliminate attempts by the system to match to irrelevant cases. For example, a reference case patient with a Class III skeletal malocclusion should not be considered for matching with a current case patient with a Class II skeletal malocclusion. An initial screening of reference cases will prevent the system from trying to find a matching case from an inappropriate problem domain.

3.04 User Performance

The novice user's performance was gauged relative to that of the experts. Data was first collected following the Initial Case Analysis and again following the What-If Case Analysis. The results represent comparative analyses performed between the current case and the selected (best matched) reference case. The four novice users are referred to as N1, N2, N3, and N4.

Initial Case Analysis

User performance results in this subsection relate to the performance by the novice user prior to accessing user feedback (i.e. expert decision rationale and literature support) provided by the system.

As system testers, the novice orthodontists did 20 separate case analyses. N1 and N3 each analyzed the 5 cases in Group A; N2 and N4 each analyzed the 5 cases in Group B. Of these 20 case analyses, 10 were assigned treatment plans that did not match those assigned by the experts. Of those 10 cases, 3 differed in whether combined orthodontics/orthognathic surgery was required, while all ten differed in the recommended extraction protocol. In 50% of the case analyses, the novice users selected different treatment plans from those of the experts; and in 30% of those cases, the novice users differed in a very significant way (i.e. proposed orthognathic surgery for the patient while the experts did not). Disagreement in extraction protocols are not uncommon in orthodontic treatment planning, even between experts. It is rarely a simple decision, and compensations made by the clinician in treatment mechanics can sometimes compensate for anticipated negative consequences. However, the consequence of subjecting a patient to orthognathic surgery are significant and must be carefully considered. The ORTHO1 system, in the What-is Analysis, provides an opportunity for the user to review his or her treatment planning decision.

Novice orthodontists took significantly longer to analyze clinical cases than did the experts. In fact, in some cases the novice took over 3 times as long to analyze the case and report a chosen treatment plan. This is thought to be a reflection of the level of experience, confidence and/or lack thereof. In fact, two novice users reported that they tried to compensate for their lack of experience by paying attention to the details of the case work-ups.

The case analyses by group showed some interesting results. A criteria of 75% was set as a cut off point for good acceptable matching. Note that this means in a subgroup with 3 parameters, all 3 parameters must match; while in a subgroup with 14 parameters, 11 must

match to meet or exceed the 75% mark. This places a burden on the user to perform well in subgroups with a limited number of parameters; in fact, in small subgroups no mistakes are acceptable. In the future, an algorithm might be designed to help address this issue.

In the Concept Group, performance by all novice users was strong in demographics/personal information, model analysis, and diagnostic imaging. Some problems in reaching the 75% mark were noted in the patient history and clinical assessment subgroups. N3 and N4 did not perform well in clinical assessment, while N1 and N3 showed problems in the patient history subgroup.

In the Category Group, all novice users performed well in intraoral findings and cephalometrics. N1 and N2 had some problems in general information; N1 and N2, and in particular N4, had problems in diagnostic imaging. Note that the problems which showed in the Concept subgroup, general information, are reflected in the Category Group under general information. The problems with diagnostic imaging now are more clearly reflected as problems related to film interpretation rather than cephalometric analysis.

The novice users generally had problems in medical health information, patient objectives, extraoral findings, perimeter, diagnostic imaging, and cephalometrics-soft tissue. These subgroups contain a significant number of subjective parameters, ones which require judgments be made in selecting parameter choices. It is not surprising that the novice users have some performance difficulties in these subgroups.

The objective of grouping and subgrouping parameters was to provide a method for analyzing user performance. By looking at the same data organized in different ways, the user is given several ways to look at his or her performance compared to that of the experts.

To help identify specific problems in a user's performance, it is also important to look at performance relative to individual parameters. For example, N4 did not match in parameter choice for facial type in 3 of 5 cases analyzed. In the Concept Group, this parameter falls into the clinical assessment subgroup while in the Category and Cluster Groups the facial type parameter is listed in the extraoral findings and extraoral findings-clinical assessment subgroups respectively. N4's poor performance is reflected in all of the Groups and can be specifically identified. This means the system can help the user to focus in on problem areas within their decision making and specifically identify problem parameters. In the What-if analysis, the decision support system then gives the user access to the knowledge base as a means of supporting the decision making, stimulating the user to look critically at his or her performance, and providing an opportunity to learn from the system.

Sensitivity Analysis of Novice Performance Ratings

The first analysis of user performance was done by applying a criterion for acceptable performance of >75%. Upon reviewing the sensitivity analysis results, it became apparent that by increasing the performance criteria to >80% or >85%, the users' performance reports were notably different. Details of the sensitivity analysis are contained in Appendix I Figure I1. The performance by all novices in the proposed treatment subgroup did not change. However, by applying the >85% criterion for acceptability, the following subgroups showed a notable reduction in the number of cases in which novice system users matched >85% of the parameters with the experts: Concept Group - clinical assessment; Category Group - general information; Cluster Group - medical health information, extraoral findings - clinical assessment, perimeter assessment. These subgroups were identified when the >75% performance criterion was applied. However, the impact of the results is emphasized by increasing the criterion to >85%. Also, given that orthodontists are consulted because of their specialized expertise, a performance level of at least 80% is considered to be necessary.

Based on the findings of this sensitivity analysis, some changes in the system feedback on user performance are recommended. The existing performance criteria set in the ORTHO1 system are as follows: excellent equals 76-100%, good equals 50-75%, fair equals 26-49%, and poor equals 0-25% The performance evaluation criteria should be changed to reflect the following changes: excellent equals 86-100%, good equals 76-85%, poor equals 61-65%, and unacceptable equals 0-60%.

What Best Analysis

The "What Best" selection highlights the non-matching parameters which were identified during the comparison between the current case and the selected reference case. The What Best analysis is a good screening tool which can be employed by the system user to check the number of parameters which do not match with the experts. This analysis helps to identify parameters which need to be focused upon during the What-if Case Analysis, and can help the user decided if an additional cycle through the What-if Analysis is necessary.

What-if Case Analysis

The novices responded, in some instances, with an interesting combination of uncertainty and certainty about their parameter choices. For example, in Case #7, N4 noted that the experts clinical assessment of lower face height was inconsistent with the cephalometric values presented. N4 therefore chose to keep the parameter choice even though it did not match that of the experts. This occurred with 3 of the novice orthodontists who, after reviewing the experts' decision rationale, noted why they had chosen not to change their parameter choice. This is a clear reflection of critical self evaluation and self confidence. The novice was informed of an inconsistent parameter choice by the system, given the opportunity to review the experts' decision rationale and the related supporting literature, and also given the opportunity to change his or her choice if desired. Changing the parameter choice is optional. This is an example of how the ORTHO1 decision support system can facilitate critical self assessment of decisions made in orthodontic diagnosis and treatment planning.

The changes made during the What-if Analysis are summarized in Table 2.06. Note that of the 10 cases where novice users did not match the treatment plan of the experts, 5 or 50% of those treatment plans were changed following a review by the novice of expert rationale and selected supporting literature. Parameter choices and weights relating to specific parameters were also changed in each case analyzed. These changes reflect the impact of the ORTHO1 system on learning. The change in treatment plans, and other parameter choices and weights, in combination with user feedback (which will be discussed in a later section), support the notion that learning has in fact occurred. A longitudinal observation of the novice user's performance will help substantiate this observation.

Reflecting on the finding that only 50% of the non-matching proposed treatment subgroups were changed following use of the ORTHO1 system's knowledge base, some issues were identified. As shown in the changes made in parameters (including treatment parameters), and weights, and as reflected in the users' feedback interviews, novice orthodontists did critically evaluate their performance and learn from the system's knowledge base. However, in the ultimate goal of establishing the best treatment plan for each patient, only 50% of the proposed treatment subgroups were changed following the What-if Analysis. Suggested reasons for this low level of change include lack of user confidence in the ORTHO1 system, inadequate expertise, failure to identify all appropriate parameters, and failure of the system to capture the subtleties of the parameters.

The ORTHO1 decision support system is a prototype which was tested for the first time in this project. The novice users were not familiar with the system or the medium for learning. Although not reflected in the user feedback interviews, it is possible that, over time

the user will develop confidence in the system's knowledge base and be more strongly influenced by the system.

The quality of the expertise must be considered. There were instances where in fact the novice users made suggestions about some non-matching parameters which suggested that the experts were incorrect. The quality of the knowledge base is only as good as the expert opinion and supporting literature from which it is comprised. If the users perceive the expertise of the system to be flawed, they will not develop confidence in its ability to support and enhance their own decision making.

The identification of all parameters which might influence the case analyses is essential to the quality of the analyses done by the system. One is left wondering whether the users did not change the proposed treatment parameters because an important one was not considered. Brainstorming with experts will be an important step towards answering this question.

The subtleties within the parameters must also be considered. A good example is the proposed treatment parameter, proposed extractions. Clinically, this parameter choice is very important. The impact of this parameter choice is significant for the patient and the orthodontist. Factors which must be considered when selecting an extraction protocol include the following: impact on facial profile, soft tissue support, impact on periodontal support, impact on periodontal condition, Bolton discrepancy, required treatment mechanics, and required patient compliance. Although many of these variables were considered in the case analyses, a more detailed section relating to the extraction protocol might have helped focus the decision making process in this parameter of the proposed treatment subgroup. Perhaps if the novice orthodontist's extraction protocol were not exactly matching, but the rationale for selection were sound, the system might in fact record that answer as "matching", to be reflected in the subsequent analysis and system feedback.

User Feedback

The novice orthodontists all reported using a computer 3 to 4 times per week for such software as Quicken, Corel Draw, Power Point, word processing, spreadsheet, and a cephalometric analysis package. All 4 novices were users or interested in using the internet. Case analysis protocols were similar for all of the novices. This reflects the standard approach to diagnosis and treatment planning promoted by Proffit.

Following ORTHO1 system testing, the novices reported that, because of limited exposure to the system, they had not changed their personal diagnosis and treatment planning routine. Two of the four users did indicate a willingness to integrate a decision

support system like ORTHO1 into their regimen, and all 4 novices were positively impressed by the system and the potential benefits to them as clinicians.

3.05 Suggestions for System Enhancements

The actual ORTHO1 decision support system was developed as a "proof of concept". The conceptual model, shown in figure 2.02, was designed to serve as a framework upon which a decision support computer system could be built. The system was subsequently built and tested to prove that the concept was realistic. This research project dealt with the initial phase of the system development, which included the design of a conceptual model, and the production and testing of the system prototype. Future system enhancements can now be considered. These include enhancement of the following: user interface, knowledge base - literature support, knowledge base - expert opinion, and algorithm.

Knowledge Base - Literature Support and Expert Opinion

The literature support for the ORTHO1 was provided in the form of structured reviews, lists of references, and actual published papers. It is technically possible to connect electronically with MEDLINE, Bibliolink, GATE, or even the National Library of Medicine. In some cases, publication abstracts can be used. The problem with this approach is accessing the appropriate literature at the right time. Often the literature searches are not specific enough to support problem solving in specific domains, resulting in wholesale literature support. The purpose of literature support is to help in problem solving. The body of literature needs to be filtered so that it is concise and appropriate to the problem domain, and hence the use of selected structured reviews. In addition, the American College of Physicians is aggressively promoting evidence-based medicine, which requires that clinical decision making be supported by scholarly literature. It seems appropriate that this approach to literature support be implemented in clinical decision making in dentistry and orthodontics.

The application of META analysis to peer reviewed articles is also being promoted by the American College of physicians. This can also be considered for application to the knowledge base in the future.

It is also important to emphasize the need to maintain a high quality of literature support in the knowledge base. Strict selection of scholarly publications and structured reviews for inclusion in the knowledge base is necessary in order to maintain the integrity of the decision support provided by the system.

The decision support provided by a computer-based system is only as good as its knowledge base. Therefore, to maintain a standard of excellence, it is essential that expert

opinion be carefully obtained and that experts be selected very carefully. Recommended criteria for selection of experts include the following: a) at least five years of full time clinical experience in the related area of specialization; b) participation in ongoing scholarly pursuits; c) knowledge of the current literature related to the related area of specialization; d) selection by a professional advisory committee.

To maintain and/or enhance the quality of the knowledge base, a minimum of 3 experts, an increased number and broader range of carefully screened clinical cases, and careful management of the database is required.

A minimum of 3 experts must be used in establishing consensus for the expert opinion contained in the knowledge base. The quality, not the number, of contributing experts is the issue. To ensure the representation of a standard of excellence in expert opinion, establishing a professional advisory committee under the auspices of a professional association such as The Canadian Association of Orthodontists or The American Association of Orthodontists is recommended.

Note that the advisory committee can perform several important roles in the maintenance and enhancement of the knowledge base. It can help design the database to reflect the following: specific objectives and problem domains; and regional, national and international trends in expertise. The committee can also screen clinical cases to be included in the knowledge base.

The professional advisory committee will be instrumental in maintaining the integrity of the knowledge base and in assessing the impact of the decision support system on the system users and the profession. System evaluation is discussed later in this chapter.

Knowledge Base - Other

The knowledge base used for this project related to the specific problem domain of diagnosis and treatment planning for Class II patients with a borderline requirement for orthognathic surgery. This problem domain was used to focus the decision making process for the purposes of developing and testing the system. An expanded knowledge base and improved algorithms will now help expand the focus of the system and make it useful in other problem domains. Two additions might include expert consult opinions and a clinical outcome module.

One problem with the knowledge base as it is now designed, is that the expert opinion is provided only by orthodontists and an oral surgeon. A valuable future addition to the knowledge base will be expert consult opinions. The opinions will relate to specific issues in orthodontic diagnosis, treatment planning, and patient management. Some example include the following:

- periodontal consults re: mucogingival problems, timing of grafting, caries, juvenile periodontitis
- oral medicine consults re: oral cancer screening, common oral pathology, pregnancy gingivitis
- restorative consults re: management options for patients with Bolton mandibular excess (peg laterals)
- radiographic consults re: radiographic anatomy or pathology
- dental hygiene consults re: home care , oral hygiene instruction, patient compliance
- dental materials review
- consult re: temporomandibular dysfunction relative to orthodontics

A useful addition to the systems' knowledge base will be an Outcome Module, a historical look at the outcome of the case after it has been treated. This will likely address such questions as these: What was the treatment plan which was implemented? How long did it take to treat the case? What were the treatment mechanics used? What went right in the treatment of this case? What went wrong in the treatment of this case? What would the clinician do differently if he or she had the opportunity to treat the case again? Feedback can then be provided on the outcome of the case with specific practical or clinical notes added by the experts or the clinician who treated the case.

Other System Enhancements

User Interface and Functionality

The creation of a good user interface is technically challenging and requires a significant amount of programming effort. Given the objectives of this project and the related financial limitations, a functional user interface was developed. Interface enhancements were minimal, and done only to facilitate the production of an acceptable interface needed for system testing. User interface is an important issue which must be addressed during the next stage of program development and evaluation.

The system, in its present state, is not particularly user friendly. This is a problem which can be remedied with good programming support. In addition, the system has been criticized for not being robust; that is, the user should not be able to "crash" the system while adventuring through the modules. Unfortunately, navigating the system unsupervised can result in disaster. This again is a problem which requires programming resources to remedy, and will be addressed in additional versions of the program. These programming

enhancements will be done prior to implementation of the system into a clinical or learning environment.

On-line Access for Expert Input

On-line access to experts can be considered in the future. To obtain quality input from the experts, a significant time commitment is required. If the data collection protocol has been formalized and reviewed, and the expert agrees to follow the protocol carefully, it is possible for the expert to access the system electronically and contribute to the knowledge base from a remote site, such as his or her private office. If the data collection process is efficient and convenient, a better commitment from the experts is expected. A screening process reviewed by the researcher or system manager is recommended prior to actual additions to the knowledge base. This means the remote data will be sent to a temporary file and will be reviewed. A follow-up interview will be done if necessary. Rules for consensus will be applied, and finally added to the knowledge base.

3.06 Other Issues for Consideration

Two "other" issues have been selected for further discussion: evaluation and learning. The researcher believes that these two issues must be addressed in the next stage of this research project.

The five stages of systems development reported by Stead included the following: 1) work specification; 2) developing and testing components or modules; 3) combining components or modules into the system and testing the system; 4) integrating the system into the appropriate environment; 5) routine use in an operational setting.[10] Stage 1 has been addressed in this project and is reflected in the research questions, research hypotheses, and project objectives, as stated in Chapter 1. Stages 2 has been addressed in the development of the modules of the ORTHO1 system, and Stage 3 has been partially a addressed through the production of the ORTHO1 system prototype and system testing with novice orthodontists. Implementation of the system, initially in a controlled environment and then in an operational setting are the next stages is the overall system development. Before this occurs, it is essential that the potential impact of this system be evaluated. It is also important that the relationship between system development and evaluation be understood. Appendix K, Figure K1 shows the relationship of system development stage to level of evaluation.

System Evaluation

Wyatt noted that technology is now so advanced that the tools required to create medical expert systems are readily available. He noted three reasons to evaluate expert systems: ethical, medical, and intellectual.[9] The potential impact of an expert system must be evaluated in terms of its effectiveness, and safety, and its impact on the use of resources.

Lundsgaarde reported that approximately ninety percent of medical expert systems have not been adequately evaluated prior to implementation in a clinical setting.[10] Having now produced a system prototype, scientific evaluation of the system must be a priority on the next stage of the systems development process. Although evaluation has not been the focus of this project, the importance of the process must not be under-emphasized. Several articles on systems evaluation have been included in the bibliography.

According to Stead, evaluation of the ORTHO1 system can be done at five levels: Level 1, problem definition; Level 2, laboratory bench testing; Level 3, investigator controlled field trials; Level 4, validation; and Level 5, routine operational testing.[1] Level 1 requires that the need which is to be met by the system be formally identified. Research on existing systems and literature review are important components of Level 1 evaluation. Level 2 evaluation involves bench testing, such as prototyping of the system. To test the prototype, paper cases or scenarios are acceptable; however, testing with real cases provides a more realistic testing environment. Levels 1 and 2 of Stead's evaluation criteria have been addressed in this project. A more sophisticated Levels 3 evaluation, plus Levels 4 and 5, should be part of a future project. This will include field testing in an environment which is initially researcher controlled, then in an environment which is not researcher controlled and will be an important next step in the evaluation process. This next stage of testing is also supported by Wyatt.[9]

Learning Process

The objectives of this project included the following: to identify the areas in the diagnosis and treatment planning where novice orthodontists vary from expert consensus; to provide them with feedback about those differences; and to provide the novice orthodontist with structured feedback related to the identified variations. Implied in those objectives is the concept of learning. It was not an objective of this project to address the intricacies of learning theory. The system, however, has good potential as a learning tool. A suggestion for future research relates to the development of the ORTHO1 decision support system as a learning tool. Features of the system which can be refined to maximize its

impact as a learning tool include; the design of screens, format of feedback, wording of feedback, and the format for assessing the novice orthodontist's performance.

The Association of American Medical Colleges recommended, in a report about physicians for the twenty first century, that students "sharpen and enhance independent learning and problem-solving skills" through the study of informatics. Implementation of an enhanced version of the ORTHO1 decision support system in an institutional setting might be considered in the future.

3.07 Suggestions For Applications of ORTHO1 Decision Support System

The following are suggestions for applications of the ORTHO1 decision support system:

- Board exam testing;

  A set of cases can be built into the knowledge base using the examiner's analysis of each case to represent the expert opinion. The individual being examined can then analyze the cases and input his or her analysis into the Current Case Module. The on-screen feedback can be suppressed, and used only by the examiners. Marking criteria can be built into the system and a summary report of results can be produced.

- Self-testing

  Given a set of reference cases which are identical to the cases being analyzed by the system user, the user can test his or her decision making in diagnosis and treatment planning relative to a group of experts;

- Electronic Study Club

  Continuing education for an orthodontic practitioner is essential. The decision support system can be used as a vehicle for communication between a group of peers. Case treatment plans, treatment mechanics and treatment outcomes can be analyzed and compared. The knowledge base can be used for reference when clinicians are treatment planning, and as a tool to help maintain a critical and scientific approach to diagnosis and treatment planning;

- Teaching tool in graduate orthodontics programs

  Similar to the board exam testing application, a set of cases can be built into the knowledge base along with the professor's analysis of each case. The cases can be selected to represent a particular orthodontic problem, and the professor's opinion represented in a way which can highlight the salient features of the case. The resident can then analyze the case and input his or her analysis into the Current

Case Module. The on-screen feedback can be tailored to be instructive and constructive.

- Review and comparison of case outcome in private practice

  This application is similar to that of the electronic study. The clinician can also store cases in the database for longitudinal comparison of treatment planning, treatment mechanics, and treatment outcomes related to similar cases;

- Professional upgrading related to diagnosis and treatment planning

  The ORTHO1 system can be used as a continuing education tool for professional upgrading. An orthodontist can benefit from the following: a critical review of his or her diagnosis and treatment planning techniques, an update on current and relevant scholarly literature, and structured feedback regarding the opinion of a group of experts.

CONCLUSIONS

The purpose of this research project was to develop a prototype computer-based decision support system which focused on decision making in orthodontic diagnosis and treatment planning for orthodontic specialists. More specifically, the decision support system was designed to help novice orthodontists work with and analyze a complicated database, provide decision support using a knowledge base, and to help novice orthodontists to critically evaluate their diagnosis and treatment planning decisions. This is more specifically stated in the following research questions:

- Can expertise within the domain of orthodontic diagnosis and treatment planning be structured so that it can be represented within a computer system?
- Can expertise within the domain of orthodontic diagnosis and treatment planning be used to assist novice orthodontists in decision making?
- Can a computer system, when dealing with problem solving in orthodontic diagnosis and treatment planning, help identify weaknesses for the purposes of learning?

The ORTHO1 decision support system was developed to help answer the research questions listed above. The four components of the system include a clinical database, a knowledge base, reasoning and control rules, and user interface. The expertise, in the form of expert opinion and scholarly literature, is contained in a knowledge base. The clinical database comprises the user's case analyses. This expertise is shared with the system user as comparative analyses are performed between the user's clinical case and the best matched reference case from the knowledge base. By using built in reasoning and control rules, and a series of feedback mechanisms to the user, the expert decision rationale and pertinent literature are shared with the user. The user interface is simply the vehicle used to display the information to the system user. The result: a computer-based decision support system which provides expertise specific to orthodontic diagnosis and treatment planning process, and which can be used to assist novice orthodontists in decision making. Through the system's analytical and feedback mechanisms, the ORTHO1 decision support system also helps identify weaknesses in the user's diagnosis and treatment planning strategy. The weaknesses are pointed out by the system, and the knowledge base (expertise) is used to assist the user with areas of weakness.

In conclusion, the computer-based decision support prototype developed for this research project is the product of the initial stages of overall system development. Extensive system testing and evaluation are the next important steps in the development process. Following this, system implementation is possible.

By developing a system prototype designed to help critically review the diagnosis and treatment planning process in orthodontics, a small step towards improving the present "state of the art" in the oldest clinical specialty in dentistry has been taken.

BIBLIOGRAPHY

1. Adams, I.D., Chan, M., Clifford, P.C., et al. Computer Aided Diagnosis of Abdominal Pain: A Multi-centre Study. Brit Med J. 1986, 293:800-804.

2. Brown, I.D., Adams, S.R., Stephens, C.D., Errit, S.J., Sims-Williams, J.H. The Initial Use of a Computer-Controlled Expert system in the Treatment Planning of Class II Division I Malocclusion. BJO 1991;18:1-7.

3. Council on Dental Practice. Computer Technology in Dental Practice. JAMA 1980;101:938-943

4. deDombal, F.T.. Computer-Aided Decision Support in Clinical Medicine. International Journal of Biomedical Computing 1989; 24,9:9-16.

5. deDombal, F.T., Dallos, V., McAdam, W.A.F.. Can Computer Aided Teaching Packages Improve Clinical Care in Patients with Acute Abdominal pain? Yearbook of Medical Informatics 1992:286-288.

6. deDombal, F.T.. The Development of Knowledge-Based Decision Support from 1955 to 2005. Theoretical Surgery. 1993, 299:1-8.

7. Evidence-Based Working Group. Evidence Based Medicine: A New Approach to teaching the Practice of Medicine. JAMA. 1992;268:2420-2425.

8. Evaluation of A Prototype, Ann Int Med, 110 (1989) 824-832.

9. Lau, F., Hebert, M., Simpson, J.. A Scientific Approach to Evaluating Health Information Systems. Workshop Presented for EDM Management Systems, Edmonton, Alberta. July 22, 1995.

10. McAdam, W.A.F., Brock, B.M., Armitage, T., Davenport, P., Chan, M., deDombal, F.. Twelve Years' Experience of Computer-Aided Diagnosis in a District General Hospital. Annals of the Royal College of Surgeons of England 1990;72:140-146

11. Myren, J., Bouchier, I.A.D., Watkson, G., deDombal, F.T. Report of World Organization of Gasteroenterology. Scandinavian Journal of Gasteroenterology. 1988, Supplement 23:144

12. Profitt, W.R. (1993). Contemporary Orthodontics, 2nd Edition, Mosby Year Book, Section III, Diagnosis and Treatment Planning, pp. 137 -264.

13. Richardson, W.S., Detsky, A.S., User's Guide to the Medical Literature. How to Use a Clinical Decision Analysis. JAMA 1995;273,20:1610-1613.

14. Richards, D., Lawrence, A. Evidence Based Dentistry. Brit Dent J 1995;:270-273.

15. Richardson, W.S., Detsky, A.- For the Evidence -Based Working Group. User's Guide to Medical Literature. VII. How to Use a Clinical Decision Analysis. A. Are the Results of the Study Valid? JAMA 1995;273,16:1292-1295.

16. Richardson, W.S., Detsky, A.- For the Evidence -Based Working Group. User's Guide to Medical Literature. VII. How to Use a Clinical Decision Analysis. B.What Are the Results and Will They Help Me in Caring for My Patients? JAMA 1995;273,20:1610-1613.

17. Salley, JJ.; Zimmerman, J.L.; Ball, M.J. (Eds.).Dental Informatics: Strategic Issues For The Dental Profession. New York. Springer -Verlage 1990.

18. Shortliffe, Edward H.; Perreault, Leslie E.. Ed.. Medical Informatics, Computer Applications in Health Care.1990. New York, Addison-Wesley Publishing Company.

19. Shortliffe, E.H.. Computer Programs to Support Clinical Decision Making. JAMA 1987; 258:61-66.

20. Siever, Adam; Holtzman, Samuel. Decision Analysis: A Framework for Critical Care Decision Assistance. Int J ClinMonitor Comp 1989;:137-156.

21. Sims-Williams, J.H., Brown, I.D., Matthewman, A., Stephens, C.D. A Computer Controlled Expert System for Orthodontic Advice. Brit Dent J 1987, 163;5:161-166.

22. Stephens, C.D., Mackin, N., Sims-Williams, J.H. The Development and Validation of an Orthodontic Expert System. Brit J Orthod 1996;23 :1-9.

23. Stheeman,S.E., vanStelt,P.F., Mileman,P.A.. Expert Systems in Dentistry. Past Performance- Future Prospects. J. Dent. 1992;20:68-73.

24. Wilson, M.C., Hayward, R.S., Tunis, S.R., Bass, E., Guyatt, G.. User's Guide to the Medical Literature. JAMA 1995;274,20:1630-1632.

25. Wyatt, J.; Spiegelhalter, D.. Evaluating Medical Expert Systems: What to Test and How? . Medical Informatics, 1990;15,3:205-217.

26. Yoon, Y., Guimaraes, T., O'Neal, Q. Exploring the Factors Associated With Expert Systems Success. MIS Quarterly. March 1995.

27. Zimmerman, J.L.; Ball, M.J.; Petroski, S.P. Computers in Dentistry. The Dental 1982;30:739-744

REFERENCES

[1] Stead, W.W., Haynes, R.B., Fuller, S., Travis, L.E., Beck, J.R.,Fenichel, C.H. et al Designing Medical Informatics Library and Research Projects to Increase What is Learned. Unpublished. Vanderbilt University, 1993 (unpublished).

[2] Huth, E.J., The Use of Medical Literature. Ann. Int Med 1989;110,2:99-100.

[3] Weed , L.L. Knowledge Coupling, New Premises and New Tools for Medical Care and Education. Ann Arbour, Springer-Verlage. p.xvi.

[4] Rowsell , K.V.. The Application of Knowledge Based Decision Support: Computer-Aided Diagnosis of Abdominal Pain at Ormskirk & District General Hospital, 1988-1993. South Lancashire Health Authority 1993:12-15.

[5] Adams ID, Chan M, Clifford PC et al. Computer Aided Diagnosis of Abdominal Pain: A Multi-Centre Study. British Med J. 1986, 293:800-804.

[6] Weed, Lawrence L., (1991), Knowledge Coupling. New Premises and New Tools for Medical Care and Education. New York, Springer-Verlag.p1.

[7] Profitt, W.R. (1993). Contemporary Orthodontics, 2nd Edition, Mosby Year Book, Section III, Diagnosis and Treatment Planning, pp. 137 -264.

[8] Evidence Based Working Group. Evidence-Based Medicine: A New Approach to Teaching the Practice of Medicine. JAMA, 1992;268:2420-2425.

[9] Wyatt, J.; Spiegelhalter, D.. Evaluatiing Medical Expert Systems: What to Test and How? . Medical Informatics, 1990;5,3:205-217.

[10] Lundsgaarde, H.P. Evaluating Medical Expert Systems. Soc.Sci..Med. 1987;24:805-819.

APPENDICES

APPENDIX A Parameter Choices and Classifications

List of Figures

APPENDIX A - Figure A1

SUMMARY of PARAMETERS and CHOICES

ORTHO1 PROGRAM

	PARAMETER	CHOICES
I.	**GENERAL INFORMATION**	
1	Gender	male female
2	Age (Category)	growing female 0 to 15 yrs non-growing female 15+ yrs growing male 0 to 18 yrs non-growing male 18+ yrs
3	Race	Caucasiod Negroid Mongoloid Other
4	Medical Status	significant finding -please specify non-significant finding
5	Patient Objective(s) - Improved Function	yes no
6	Patient Objective(s) - Improved Dental Esthetics	yes no
7	Patient Objective(s) - Improved Facial Esthetics	yes no
8	Psychological Status	no psychological issues noted contraindications to ortho treatment or surgery psychological contraindications to surgery only requires psychological support through treatment
9	Psychological Effect of Malocclusion	neutral negatively - mild negatively - moderate negatively - severe
10	Patient Motivation Regarding Treatment	very weak motivation weak motivation moderate motivation strong motivation very strong motivation
11	Reported Habits	none digit sucking - active tongue thrust - active bruxing other oral habit - active other oral habit - historic
II.	**EXTRA - ORAL FINDINGS**	
12	Facial Form (Frontal View) -transverse	symmetric asymmetric - maxilla asymmetric - mild mand. deviation (1-2 mm) asymmetric - moderate mand. deviation (2.1-4mm) asymmetric - severe mand. deviation (4.1 + mm)
13	Facial Proportions (Frontal View) -vertical Mid-Face	decreased normal increased
14	Facial Proportions (Frontal View) -Lower Face Height	decreased normal increased
15	Facial Form (Lateral View)	convex flat
16	Facial Form (Lateral View) - Nasolabial Angle	obtuse normal (approx. 110 degrees) acute

APPENDIX A - Figure A1

SUMMARY of PARAMETERS and CHOICES

ORTHO1 PROGRAM

	PARAMETER	CHOICES
17	Facial Form (Lateral View) - Labiomental Angle	obtuse normal (approx. 130 degrees) acute
18	Nose - Length	small average large
19	Nose - Other	none asymmetric significant deviation wide
20	Facial Type	mesiofacial dolicofacial brachiofacial
21	Lip Posture (upper to lower)	competent incompetent
22	Lip Posture (lower)	everted not everted
23	Lip Length (upper)	short adequate long
24	Temporomandibular disorder	TMJ internal derangement - symptomatic TMJ internal derangement - asymptomatic Degenerative joint disease - active Degenerative joint disease - stable other no significant findings
25	Muscle Pain (TMD)	no pain mild - moderate pain moderate - severe pain
III.	INTRA - ORAL FINDINGS	
26	Oral Hygiene	acceptable unacceptable
27	Gingival Attachment - mandibular anterior	acceptable unacceptable
28	Periodontal Disease	none (PSR = 0) mild (PSR = 1 - 2) moderate (PSR = 3) severe (PSR = 4)
29	Teeth Present	full permanent dentition missing teeth (please specify)
30	Bolton Relationship	normal Bolton discrepancy
31	Bolton Discrepancy (Mandibular Overall Excess)	mandibular excess (6 to 6) 0mm - 4 mm mandibular excess (6 to 6) >4 mm
32	Bolton Discrepancy (Mandibular Anterior Excess)	mandibular excess (3 to 3) 0mm - 4 mm mandibular excess (3 to 3) >4 mm
33	Bolton Discrepancy (Maxillary Overall Excess)	maxillary excess (6 to 6) 0mm - 4 mm maxillary excess (6 to 6) >4 mm
34	Bolton Discrepancy (Maxillary Anterior Excess)	maxillary excess (3 to 3) 0mm - 4 mm maxillary excess (3 to 3) >4 mm

APPENDIX A - Figure A1

SUMMARY of PARAMETERS and CHOICES

ORTHO1 PROGRAM

	PARAMETER	CHOICES
	OCCLUSION	
35	Molar relationship - Right	Class I Class II - end : end Class II - full cusp Super Class II
36	Molar relationship - Left	Class I Class II - end : end Class II - full cusp Super Class II
37	Cuspid relationship - Right	Class I End:End Class II Super Class II
38	Cuspid relationship - Left	Class I End:End Class II Super Class II
39	Curve of spee	mild (0 - 2 mm.) moderate (2 - 4 mm.) severe (4+ mm.)
40	Overjet (millimeters)	mild (0 - 2 mm.) moderate (2 - 4 mm.) severe (4+ mm.)
41	Incisor position in Class II Cases	division I division II
52	Overbite - palatal impingement	yes no
43	Overbite (millimeters)	negitive (openbite) shallow (0 - 2 mm.) normal (2.1 - 4 mm.) deep (4.1 - 6 mm.) severe (6 - 7 mm.) excessive (> 7 mm)
44	Incisal Display at Rest (millimeters)	minimal (< 3 mm) normal (3.1 - 5 mm) excessive (> 5 mm)
45	Gingival Display on Smiling (millimeters)	none normal (< 3 mm) moderately severe (3.1 - 5 mm) excessive (> 5 mm)
46	CR : CO Discrepancy	no yes
47	CR : CO Shift - Transverse	0 - 2 mm > 2 mm
48	CR : CO Shift - AP	0 - 2 mm > 2 mm
49	Perimeter - Maxillary Excess	no excess mild excess (0 - 3 mm.) moderate excess (3.1 - 6 mm.) severe excess (> 6 mm.)
50	Perimeter - Maxillary Deficiency	no deficiency mild deficiency (0 - 4 mm.) moderate deficiency (4.1 - 8 mm.) severe deficiency (> 8 mm.)

APPENDIX A - Figure A1

SUMMARY of PARAMETERS and CHOICES

ORTHO1 PROGRAM

	PARAMETER	CHOICES
51	Perimeter - Mandibular Excess	no excess mild excess (0 - 3 mm.) moderate excess (3.1 - 6 mm.) severe excess (> 6 mm.)
52	Perimeter - Mandibular Deficiency	no deficiency mild deficiency (0 - 4 mm.) moderate deficiency (4.1 - 8 mm.) severe deficiency (> 8 mm.)
53	Parafunctional Habits	No Habits Habit - clenching Habit - grinding Habit - other
IV.	RADIOGRAPHIC EXAMINATION	
54	Panorex	no significant findings or not available high risk root morphology congenitally missing teeth impacted 8's impacted teeth (other than 8's) other - please specify
55	Tomograms	no significant findings evidence of Degenerative Joint Disease (stable) evidence of Degenerative Joint Disease (potentially active) significant findings - other
56	Other Imaging	available not available
V.	CEPHALOMETRICS	
57	*Facial Form* *facial angle* *(FH - NPg)*	very low (< 82 degrees) moderately low (82.1 - 84.9 degrees) normal (85 - 91 degrees) moderately high (91.1 - 95 degrees) very high (> 95 degrees)
	Mandible to Cranium:	
58	SNB	very retrusive (0 - 72 degrees) mildly retrusive (72.1 - 76.9 degrees) normal (77 - 83 degrees) mildly prognathic (83.1 - 87 degrees) severely prognathic (> 87 degrees)
59	SNPg	very low (< 72 degrees) moderately low (72.1 - 76.9 degrees) normal (77 - 83 degrees) moderately high (83.1 - 87 degrees) severe (>87 degrees)
60	Mandibular Body Length (mm.)	short (< 66 mm.) average (66.1 - 75.9 mm.) long (>76 mm.)
61	Ramus Height	short (< 39 mm.) average (39 - 49 mm.) long (> 49 mm.)
	Maxilla to Cranium:	
62	SNA	very retrusive (< 76 degrees) mildly retrusive (76.1 - 79.9 degrees) normal (80 - 83.9 degrees) mildly protrusive (84 - 86 degrees) severely protrusive (> 86 degrees)

APPENDIX A - Figure A1

SUMMARY of PARAMETERS and CHOICES

ORTHO1 PROGRAM

	PARAMETER	CHOICES	
63	SN Length	very short	(< 66 mm.)
		moderately short	(66.1 - 68 mm.)
		normal	(68.1 - 72 mm.)
		slightly long	(72.1 - 74 mm.)
		very long	(> 74 mm.)
	Mandible to Maxilla:		
64	ANB angle	Class I	(0 - 3.9 degrees)
		mild Class II	(4 -6 degrees)
		moderate Class II	(6.1 - 8.4 degrees)
		severe Class II	(> 8.5 degrees)
65	Wits	very low	(< 0 mm.)
		moderately low	(0.1 - 1.0 mm.)
		normal	(1.1 - 2.0 mm.)
		moderate high	(2.1 - 3.0 mm.)
		very high	(3.1 + mm.)
66	*Facial Proportions:* Y-axis (FH to SGn)	very flat	(> 53 degrees)
		moderately flat	(53 - 57 degrees)
		normal	(57.1 - 61 degrees)
		moderate steep	(61.1 - 65 degrees)
		severely steep	(> 65 degrees)
	Dental relationships		
67	[illegible] to NA (mm)	very low	(< - 2 mm.)
		moderately low	(-2 mm - +2 mm.)
		normal	(2.1 - 5 mm.)
		moderately high	(5.1 - 8.0 mm.)
		severely high	(> 8 mm.)
68	[illegible] to NPg (mm)	very low	(2 - 4 mm)
		moderately low	(4.1 - 6 mm.)
		normal	(6.1 - 8 mm.)
		moderately high	(8.1 - 10 mm.)
		severely high	(> 10 mm.)
69	interincisal angle	severely acute	(< 125 degrees)
		moderately acute	(125 - 134.9 degrees)
		normal	(135 - 145 degrees)
		moderately obtuse	(145.1 - 155 degrees)
		severely obtuse	(> 155 degrees)
70	mandibular plane angle (FH - GoMe)	very flat	(< 17 degrees)
		moderately flat	(17.1 - 22 degrees)
		normal	(22.1 - 27 degrees)
		moderately steep	(27.1 - 30 degrees)
		severely steep	(> 30 degrees)
71	mandibular plane to SN	very flat	(< 22 degrees)
		moderately flat	(22.1 - 26 degrees)
		normal	(26.1 - 31 degrees)
		moderately steep	(31.1 - 36 degrees)
		severely steep	(> 36 degrees)
72	upper face height (Na-ANS)	short	(< 48 mm.)
		average	(48 - 52 mm.)
		long	(> 52.0 + mm.)
73	lower anterior face height (ANS-Me)	short	(< 61 mm.)
		average	(61 - 65 mm.)
		long	(> 65 mm.)
74	lower face ht. : total face ht.	low	(- 55%)
		moderate	(55 %)
		severe	(55% +)

APPENDIX A - Figure A1

SUMMARY of PARAMETERS and CHOICES

ORTHO1 PROGRAM

	PARAMETER	CHOICES
	Soft Tissue	
75	nasolabial angle	obtuse (< 105 degrees) average (105 - 115 degrees) acute (> 115 degrees)
76	labiomental angle	obtuse (< 125 degrees) average (125 - 135 degrees) acute (> 135 degrees)
77	Upper lip relative to E Plane	moderately protrusive (> -2 mm.) slightly protrusive (- 3 to - 2 mm.) average (-3 to -5 mm.) moderately retrusive (-4 to - 6 mm.) severely retrusive (< -6 mm)
78	Lower lip relative to E Plane	protrusive (> 0 mm.) slightly protrusive (-1 to -2 mm.) average (-2 to 0 mm.) slightly retrusive (-2 to -4 mm.) severely retrusive (< -4 mm)
	PROPOSED TREATMENT	
79	Extractions Required	no extractions maxillary & mandibular 1st bicuspids maxillary & mandibular 2nd bicuspids maxillary 1st bicuspids & mandibular 2nd bicuspids maxillary 2nd bicuspids & mandibular 1st bicuspids maxillary 1st bicuspids maxillary 2nd bicuspids maxillary 2nd molars mandibular 1st or 2nd bicuspids maxillary and/or mandibular wisdom teeth other extractions - please specify
80	Orthodontics Only	yes no
81	Orthodontics & Surgery	no surgery mandibular advancement maxillary surgery genioplasty
82	No Treatment	no yes

APPENDIX A - Figure A2

SUMMARY of PARAMETERS by CLASSIFICATION

- ORTHO1 PROGRAM -

PARAMETER	OBJECTIVE	SUBJECTIVE	CONCEPT	CATEGORY	CLUSTER
Mandible to Cranium:					
58 SNB	+		"	"	"
59 SNPg	+		"	"	"
60 Mandibular Body Length (mm.)	+		"	"	"
61 Ramus Height	+		"	"	"
Maxilla to Cranium:					
62 SNA	+		"	"	"
63 SN Length	+		"	"	"
Mandible to Maxilla:					
64 ANB angle	+		"	"	"
65 Wits	+		"	"	"
Facial Proportions:					
66 Y-axis (FH to SGn)	+		"	"	"
Dental relationships					
67 Upper Incisor to NA (mm)	+		"	"	"
68 Upper Incisor to NPg (mm)	+		"	"	"
69 interincisal angle	+		"	"	"
70 mandibular plane angle (FH - GoMe)	+		"	"	"
71 mandibular plane to SN	+		"	"	"
72 upper face height (Na-ANS)	+		"	"	"
73 lower anterior face height (ANS-Me)	+		"	"	"
74 lower face ht. : total face ht.	+		"	"	"
Soft Tissue					CEPHALOMETRICS - Soft Tissue Relationships
75 nasolabial angle	+		"	"	"
76 labiomental angle	+		"	"	"
77 Upper lip relative to E Plane	+		"	"	"
78 Lower lip relative to E Plane	+		"	"	"
			PROPOSED TREATMENT	PROPOSED TREATMENT	PROPOSED TREATMENT
79 Extractions Required		+	"	"	"
80 Orthodontics Only		+	"	"	"
81 Orthodontics & Surgery		+	"	"	"
82 No Treatment		+	"	"	"

APPENDIX A - Figure A2

SUMMARY of PARAMETERS by CLASSIFICATION

- ORTHO1 PROGRAM -

PARAMETER	OBJECTIVE	SUBJECTIVE	CONCEPT	CATEGORY	CLUSTER
29 Teeth Present	+		MODEL ANALYSIS	"	OCCLUSION
30 Bolton Relationship		+	"	"	BOLTON ANALYSIS
31 Bolton Discrepancy (Mandibular Overall Excess)		+	"	"	"
32 Bolton Discrepancy (Mandibular Anterior Excess)		+	"	"	"
33 Bolton Discrepancy (Maxillary Overall Excess)		+	"	"	"
34 Bolton Discrepancy (Maxillary Anterior Excess)		+	"	"	"
					OCCLUSION
35 Molar relationship - Right		+	"	"	"
36 Molar relationship - Left		+	"	"	"
37 Cuspid relationship - Right		+	"	"	"
38 Cuspid relationship - Right		+	"	"	"
39 Curve of spee		+	"	"	"
40 Overjet (millimeters)		+	"	"	"
41 Incisor position in Class II Cases		+	"	"	"
42 Overbite - palatal impingement		+	"	"	"
43 Overbite (millimeters)		+	"	"	"
44 Incisal Display at Rest (millimeters)		+	CLINICAL ASSESSMENT	"	"
45 Gingival Display on Smiling (millimeters)		+	"	"	"
46 CR : CO Discrepancy	+		"	"	"
47 CR : CO Shift - Transverse	+		"	"	"
48 CR : CO Shift - AP	+		"	"	"
					PERIMETER
49 Perimeter - Maxillary Excess		+	MODEL ANALYSIS	"	"
50 Perimeter - Maxillary Deficiency		+	"	"	"
51 Perimeter - Mandibular Excess		+	"	"	"
52 Perimeter - Mandibular Deficiency		+	"	"	"
53 Parafunctional Habits		+	CLINICAL ASSESSMENT	"	OCCLUSION
54 Panorex		+	DIAGNOSTIC IMAGING	DIAGNOSTIC IMAGING	DIAGNOSTIC IMAGING
55 Tomograms		+	"	"	"
56 Other Imaging		+	"	"	"
				CEPHALOMETRICS	CEPHALOMETRICS - Skeletal Relationships
57 *Facial Form*			"	"	
facial angle			"	"	"
(FH - NPg)	+		"	"	"

APPENDIX A - Figure A2

SUMMARY of PARAMETERS by CLASSIFICATION

- ORTHO1 PROGRAM -

PARAMETER	OBJECTIVE	SUBJECTIVE	CONCEPT	CATEGORY	CLUSTER
			DEMOGRAPHICS / PERSONAL INFORMATION	GENERAL INFORMATION	GENERAL INFORMATION
1 Gender	+		"	"	"
2 Age (Category)	+		"	"	"
3 Race	+		"	"	"
			PATIENT HISTORY		MEDICAL / HEALTH INFORMATION
4 Medical Status		+	"	"	
					PATIENT OBJECTIVES
5 Patient Objective(s) - Improved Function		+	"	"	"
6 Patient Objective(s) - Improved Dental Esthetics		+	"	"	"
7 Patient Objective(s) - Improved Facial Esthetics		+	"	"	"
					PSYCHOLOGICAL STATUS
8 Psychological Status		+	"	"	"
9 Psychological Effect of Malocclusion		+	"	"	"
10 Patient Motivation Regarding Treatment		+	"	"	"
11 Reported Habits		+	"	"	"
			CLINICAL ASSESSMENT	EXTRA-ORAL FINDINGS - Clinical Assessment	EXTRA-ORAL FINDINGS - Clinical Assessment
12 Facial Form (Frontal View) -transverse		+	"	"	"
13 Facial Proportions (Frontal View) -vertical Mid-Face		+	"	"	"
14 Facial Proportions (Frontal View) -Lower Face Height		+	"	"	"
15 Facial Form (Lateral View)		+	"	"	"
16 Facial Form (Lateral View) - Nasolabial Angle		+	"	"	"
17 Facial Form (Lateral View) - Labiomental Angle		+	"	"	"
18 Nose - Length		+	"	"	"
19 Nose - Other		+	"	"	"
20 Facial Type		+	"	"	"
21 Lip Posture (upper & lower)		+	"	"	"
22 Lip Posture (lower)		+	"	"	"
23 Lip Length (upper)		+	"	"	"
24 Temporomandibular disorder		+	"	"	TEMPOROMANDIBULAR JOINT
25 Muscle Pain (TMD)	+	+	"	"	"
				INTRA-ORAL FINDINGS - Clinical Assessment	PERIODONTAL ASSESSMENT
26 Oral Hygiene		+		"	"
27 Gingival Attachment - mandibular anterior		+	"	"	"
28 Periodontal Disease		+	"	"	"

APPENDIX B Example of Literature Support in ORTHO1 System

List of Figures

APPENDIX B - Figure B1 Structured Literature Review

Formby, W.A., Nanda, R.S., Currier, G.F.. Longitudinal Changes In The Adult Facial Profile. American Journal of Orthodontics and Dentofacial Orthopedics, 105; 5: 464 - 476.

PURPOSE
- to evaluate growth changes of the adult face and the impact of these changes on treatment planning.

LITERATURE REVIEW
- Studies have shown that growth changes of the facial tissues occur predominantly before the age of 18, but are not complete at that time.
- growth changes that occur after 18 years of age show notable differences between males & females.
- The effects of growth changes must be understood in the adult patient as well as the younger patient, as these changes can still impact on the results of orthodontic treatment.

METHODS AND MATERIALS
- longitudinal cephalometric radiographs of 47 patients between the ages of 18 and 42 years all had Class I or end to end molar relationships and no excessive protrusions or retrusions
- both soft and hard tissue landmarks were used, and likewise located on the lateral cephalometric radiographs .... 21 soft tissue and 16 hard tissue (skeletal) landmarks were used
- the landmarks were traced and digitized, and all projected points were made perpendicular to the pterygomaxillary vertical reference plane

RESULTS
- average S-N length increased 0.68mm / females 0.44
- average posterior face length increased 2.68 mm / females 1.21
- anterior face height increased 1.88 mm / females 1.49
- Y- axis increased length 2.67 mm, corpus length increased 2.81 mm, skeletal depth at pogonion increased 2.29mm, skeletal depth at point A increased I .07mm
- mandibular plane angle did not change significantly after age 10 in either males or females
- sella-nasion to mandibular p lane, -mand ibular plane an decreased progressively throughout the period of the study in all groups, however the male deepbite group showed an accelerated decrease from age 4 - 10 yrs.
- gonial angle - both deep bite and openbite groups tended toward a progressive decrease in mean gonial angle from age 4 - 18 yrs.
- palatomandibular angle - highly significant differences between facial types in both male and female samples throughout the entire study period ... female openbite subjects showed a very large increase in this angle (exceeded the males, thus showing a sexual dimorphism)

SUMMARY
- there are large individual variations in the positional planes of the face during development, regardless of vertical dysplasia
- the decrease in the mandibular plane, palatomandibular plane, occlusal plane, and gonial angles will have specific effects on patients with vertical dysplasia
- in openbite patients, the magnitude of dysplasia will decrease
- in deepbite patients, the magnitude of the vertical problem will increase with the vertical changes noted
- the anterioposterior inclination of the palatal plane is stable (despite vertical displacement) and is established at an early age.
- note the importance of the palatal plane inclination in establishing a positional rotation of the mandible and increased lower face height
- the magnitude of the gonial angle and the inclinations of the occlusal and mandibular planes were not significantly different between the two skeletal types.
- the palatal plane angle may be influencing development of other facial plane angles
- no close correlation exists between the cranial base angle and vertical dysplasias of the face, though there are sexually related differences.

APPENDIX B - Figure B2

Example of Supporting Literature Provided by ORTHO1 System

No	PARAMETER	REFERENCE
1	Gender	Kiyak (1981) Katai (1990) Love (1990)
2	Age_Category	Grave (1976) Greulich (1959) Foley (1990) Behrets (1985a) Behrets (1985b) Hagg (1982)
3	Race	Cotton (1951) Richardson (1990)
4	Medical Status	CPS (1996)
5	Patient Objective(s)_Improved Function	
6	Patient Objective(s)_Improved Dental Esthetics	Kryshtalskyj (1989) Sarver (1993) Ostler (1991) Pogrel (1991)
7	Patient Objective(s)_Improved Facial Esthetics	Kryshtalskyj (1989) Sarver (1993) Ostler (1991) Pogrel (1991)
8	Psychological Status	Auerbach(1984) Kiyak (1991 Kiyak (1984) Pogrel (1991)
9	Psychological Effect of Malocclusion	Shaw (1981) Helm (1985) MacGregor (1979) Kinealy (1989)
10	Patient Motivation Regarding Treatment	Flannary (1985) Heldt (1982) McKiernan (1992) Ostler (1991) Ronis (1994)
11	Reported Habits	Haryette (1970)
12	Facial Form (Frontal View)_Transverse	Downs (1948)
13	Facial Proportions (Frontal View)_Vertical Mid Face	Farkas (1987) Sassouni (1969)
14	Facial Proportions (Frontal View) _Low Face Height	Farkas (1987) Sassouni (1969)
15	Facial Form (Lateral View)	Formby (1994) Abe (1990)
16	Facial Form (Lateral View)_Nasolabial Angle	Eales (1994) Hayes (1994) Lundstrom (1993)
17	Facial Form (Lateral View)_Labiomental Angle	Eales (1994) Hayes (1994) Lundstrom (1993)
18	Nose Length	Schendel (1991) O'Ryan (1989) Peck (1987)
19	Nose-Other	Schendel (1991)
20	Facial Type	Farkas (1987) Sassouni (1969)
21	Lip Posture(upper & lower)	Holdaway (1984)
22	Lip Posture(lower)	Holdaway (1984)
23	Lip Length(upper)	Holdaway (1984)
24	Temporomandibular disorder	McNiel (1994) Major(1995)
25	Muscle Pain(TMD)	McNiel (1994)
26	Oral Hygiene	Boyd (1991) Artun (187) Kennedy (1985) Vehkalahi (1989) Am. Assoc.Perio (1992)
27	Gingival Attachment_mandibular anterior	Boyd (1991)
28	Periodontal Disease	Polson (1987) Boyd (1991) Westram (1987) Newman (1994)
29	Teeth Present	Proffit (1989)
30	Bolton Relationship	Bolton (1962) Proffit (1989) Broadbent (1975)
31	Bolton Discrepancy(Mandibular Overall Excess)	Bolton (1962) Proffit (1989) Broadbent (1975)

APPENDIX B - Figure B2

Example of Supporting Literature Provided by ORTHO1 System

No	PARAMETER	REFERENCE		
32	Bolton Discrepancy(Mandibular Anterior Excess)	Bolton (1962)	Proffit (1989)	Broadbent (1975)
33	Bolton Discrepancy(Maxillary Overall Excess)	Bolton (1962)	Proffit (1989)	Broadbent (1975)
34	Bolton Discrepancy(Maxillary Anterior Excess)	Bolton (1962)	Proffit (1989)	Broadbent (1975)
35	Molar Relationship_Right	Ackerman (1969)	Anderson (1972)	Proffit (1989)
36	Molar Relationship_Left	Ackerman (1969)	Anderson (1972)	Proffit (1989)
37	Cuspid Relationship_Right	Ackerman (1969)	Anderson (1972)	Proffit (1989)
38	Cuspid Relationship_Left	Ackerman (1969)	Anderson (1972)	Proffit (1989)
39	Curve of Spee	Ackerman (1969)	Anderson (1972)	Proffit (1989)
40	Overjet (millimeters)	Ackerman (1969)	Anderson (1972)	Proffit (1989)
41	Incisor position in Class II Cases	Ackerman (1969)	Anderson (1972)	Proffit (1989)
42	Overbite_palatal impingement	Ackerman (1969)	Anderson (1972)	Proffit (1989)
43	Overbite (millimeters)	Ackerman (1969)	Anderson (1972)	Proffit (1989)
44	Incisal Display at Rest (millimeters)	Legan (1980)	Pogrel (1991)	
45	Gingival Display on Smiling (millimeters)	Legan (1980)	Pogrel (1991)	
46	CR : CO Discrepancy	Williamson (1980)	Okeson (1992)	
47	CR : CO shift AP	Williamson (1980)	Okeson (1992)	
48	CR : CO shift Transverse	Williamson (1980)	Okeson (1992)	
49	Perimeter_Maxillary Excess	Hickson (1972)	Tanaka (1985)	
50	Perimeter_Maxillary Deficiency	Hickson (1972)	Tanaka (1985)	
51	Perimeter_Mandibular Excess	Hickson (1972)	Tanaka (1985)	
52	Perimeter_Mandibular Deficiency	Hickson (1972)	Tanaka (1985)	
53	Parafunctional Habits	Okeson (1992)		
54	Panorex	Kantor (1987)		
55	Tomograms	McNiel (1994)		
56	Other Imaging	Christiansen (1990)	Nance (1990)	
57	Facial Form_Facial Angle FH_NPg	McNamara (1988)		
58	Mandible to Cranium_SNB	McNamara (1988)		
59	Mandible to Cranium_SNPg	McNamara (1988)	Nanda (1994)	
60	Mandibular Body Length (mm)	Jarabak (1985)		
61	Ramus Height	Jarabak (1985)		
62	Maxilla to Cranium_SNA	Jarabak (1985)	Jacobson (1975)	

APPENDIX B - Figure B2

Example of Supporting Literature Provided by ORTHO1 System

No	PARAMETER	REFERENCE
63	SN Length	Jarabak (1985)
64	Mandible to Maxilla_ANB angle	Jacobson (1975) Chandra (1990) Oktay (1991)
65	Wits	Jacobson (1975) Chandra (1990) Oktay (1991)
66	Facial Proportions_Y axis (FH to SGn)	Ricketts (1968) Arnett (1993)
67	Dental relationship_II to NA (mm)	Washington Analysis (1975)
68	Dental relationship_II to NPg (mm)	Washington Analysis (1975)
69	Interincisal angle	Washington Analysis (1975)
70	Mandibular plane angle (FH-GoMe)	Washington Analysis (1975)
71	Mandibular plane to SN	Washington Analysis (1975)
72	Upper face height(Na-ANS)	Washington Analysis (1975)
73	Lower anterior face height(ANS-Me)	Washington Analysis (1975)
74	Lower face ht/total face ht	Washington Analysis (1975)
75	Nasolabial angle	Legan (1980) Nanda (1990) Abe (1990) Holdaway (1984)
76	Labiomental angle	Legan (1980) Nanda (1990)
77	Upper lip relative to E PLane	Holdaway (1984) Earles (1994) Hack (1993) Ricketts (1968) Holdaway (1984)
78	Lower lip relative to E Plane	Holdaway (1984) Earles (1994) Hack (1993) Ricketts (1968)
79	Treatment_Extractions Required	
80	Treatment_Orthodontics Only	
81	Treatment_Orthodontics & Surgery	Proffit (1991) Huang (1982) Snow (1991) Tucker (1982) Neal (1991) Osler (1991)
82	Treatment_No Treatment	Jacobson (1990) Pogrel (1991) MacGregor (1970)

APPENDIX C Example of Case Work-up

List of Figures

APPENDIX C - Figure C1

GENERAL INFORMATION

CASE #003

General
- Age 39-0 years
- Gender female

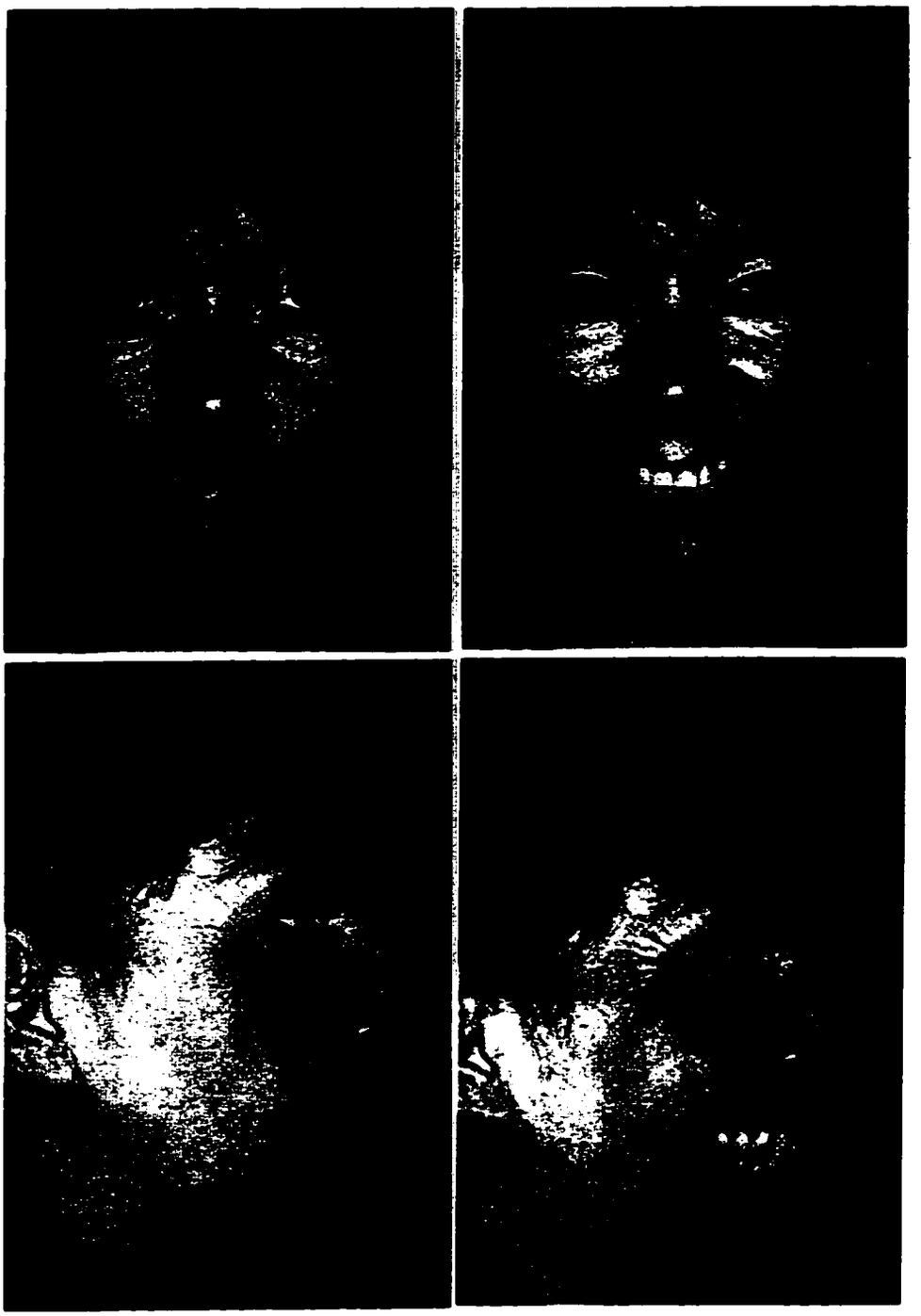
Chief Complaint
- "front teeth stick out and are flared"

Medical / Psych History
- No significant findings

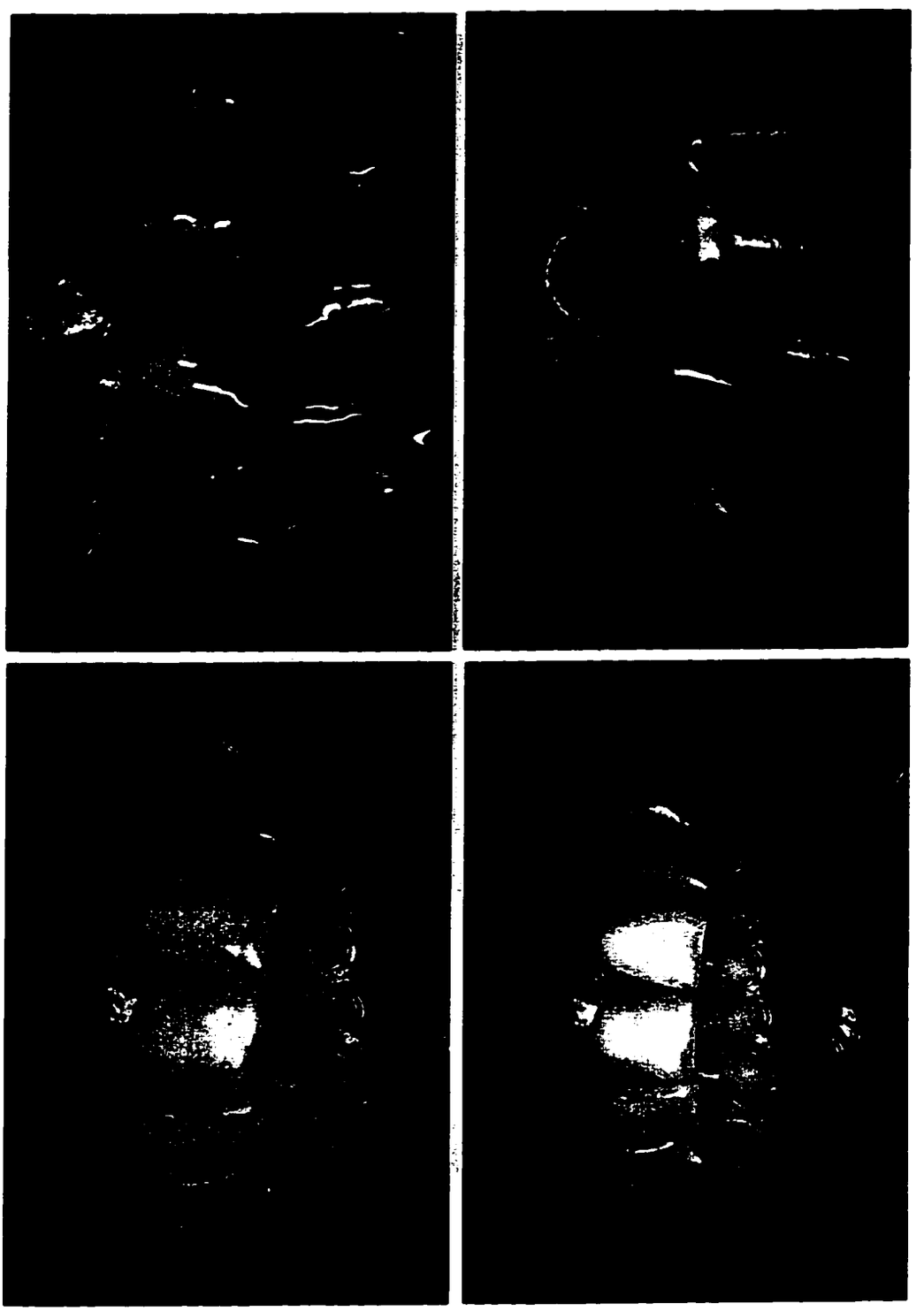
Social History
- married
- full time employment
- 2 teenage children
- good family support system

Dental History
- routine dental care (yearly)
- perio status (psr = 2)
- heavily restored posterior dentition
- history of moderate trauma to maxillary central incisors (hit cupboard door)
- No history of TMD

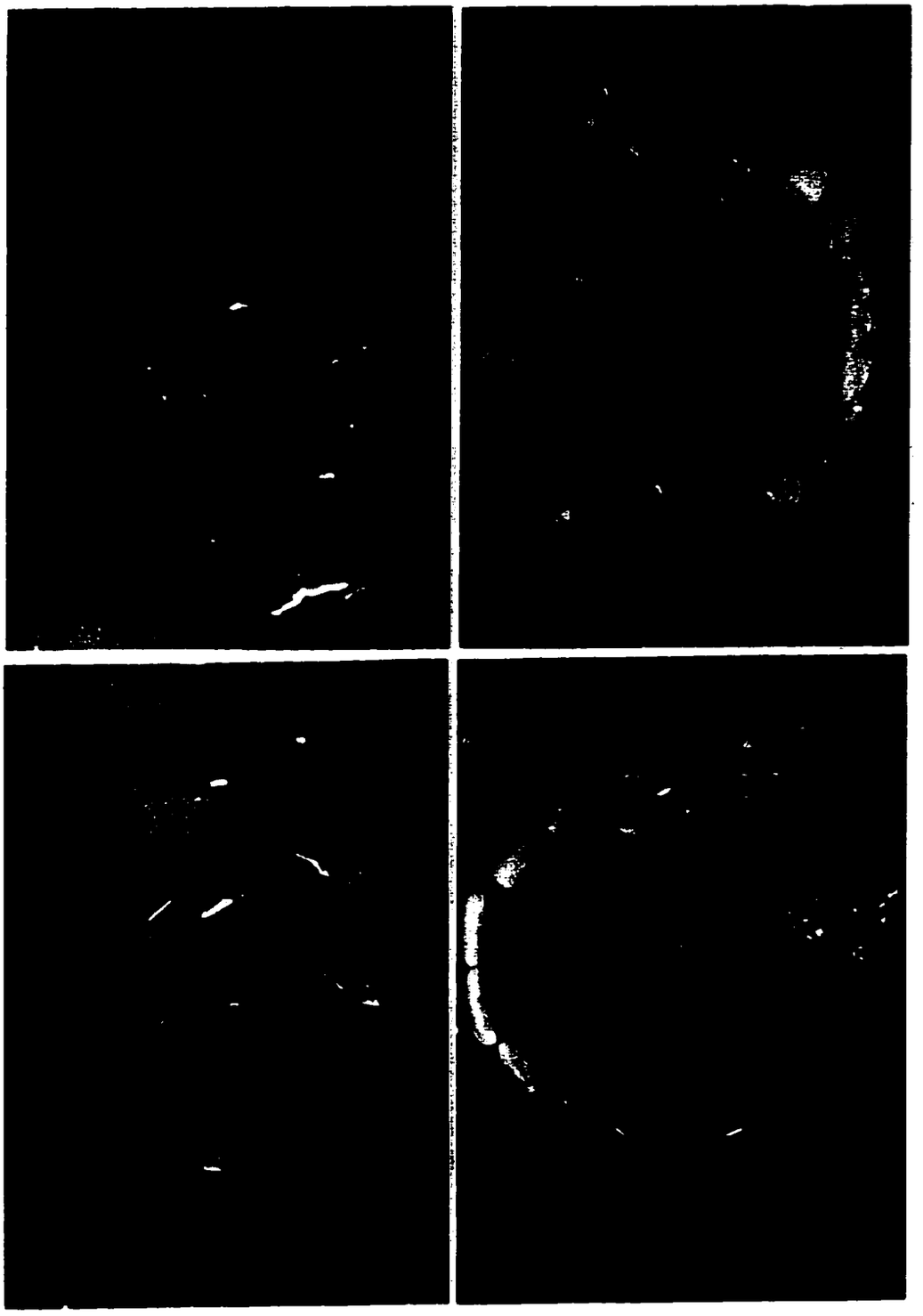
APPENDIX C - Figure C2.1
Clinical Photographs : Extraoral Photos



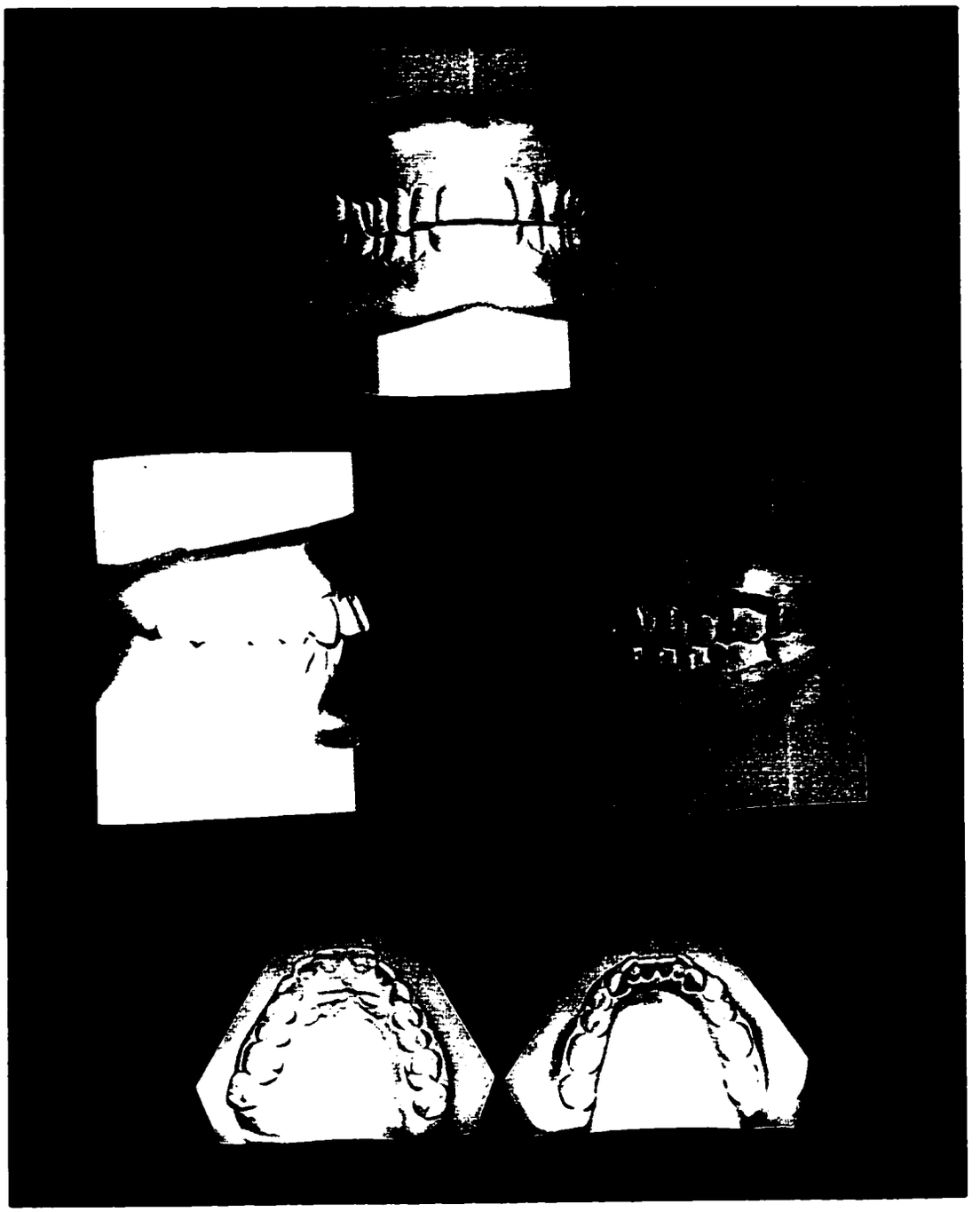
APPENDIX C - Figure C2.2
Sample Case Work-up - Intraoral Photos (Set A)



APPENDIX C - Figure C2.3
Sample Case Work-up - Intraoral Photos (Set B)



APPENDIX C - Figure C3
Sample Case Work-up - Model Photos



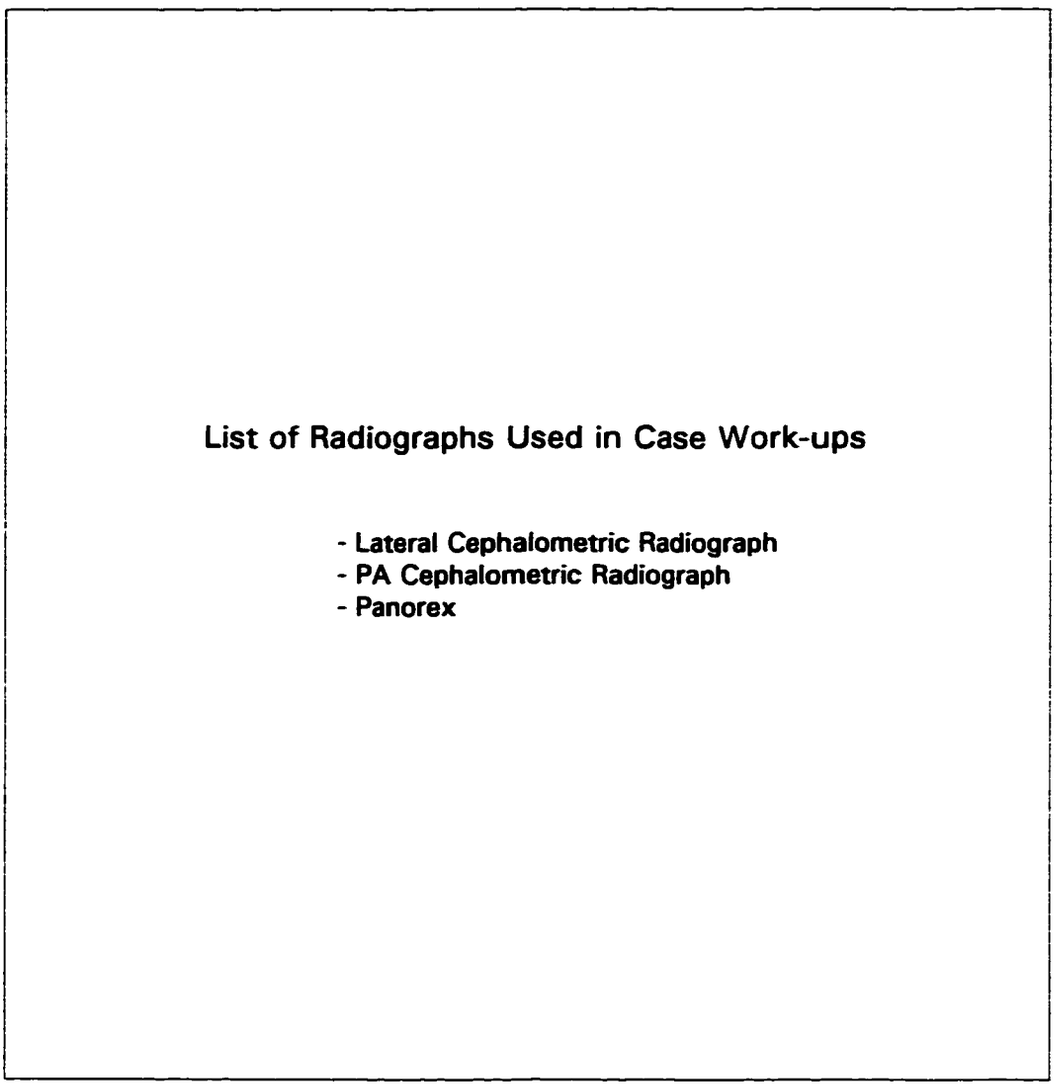
APPENDIX C - Figure C4
Bolton Analysis Patient #003

SIZE (mm)	TOOTH				
10.70	#16				
6.20	#15				
6.50	#14				
7.40	#13				
6.60	#12				
8.90	#11				
8.80	#21				
7.00	#22				
7.50	#23	sum max. "6"	46.20		
6.60	#24				
6.40	#25			sum max. "R"	46.30
10.70	#26	sum max. "12"	93.30	sum max. "L"	47.00
10.60	#36				
7.20	#35				
6.10	#34				
6.50	#33				
6.10	#32				
5.10	#31				
5.10	#41				
6.40	#42				
6.60	#43	sum mand. "6"	35.80		
6.50	#44				
6.60	#45			sum mand. "L"	41.60
10.70	#46	sum mand. "12"	83.50	sum mand. "R"	41.90

ANALYSIS

Overall Ratio	=	sum mand. "12" / sum max. "12"	=	83.50 / 93.30	89.5%
(<91.3 %)	act. max. "12" - 93.30	corr. max."12" 91.46	=	1.84	ax."12" excess
Anterior Ratio	=	sum mand. "6" / sum max. "6"	=	35.80 / 46.20	77.5%
(>77.2 %)	act. mand "6" - 35.80	corr. mand."6" 35.67	=	0.13	nd."6" excess

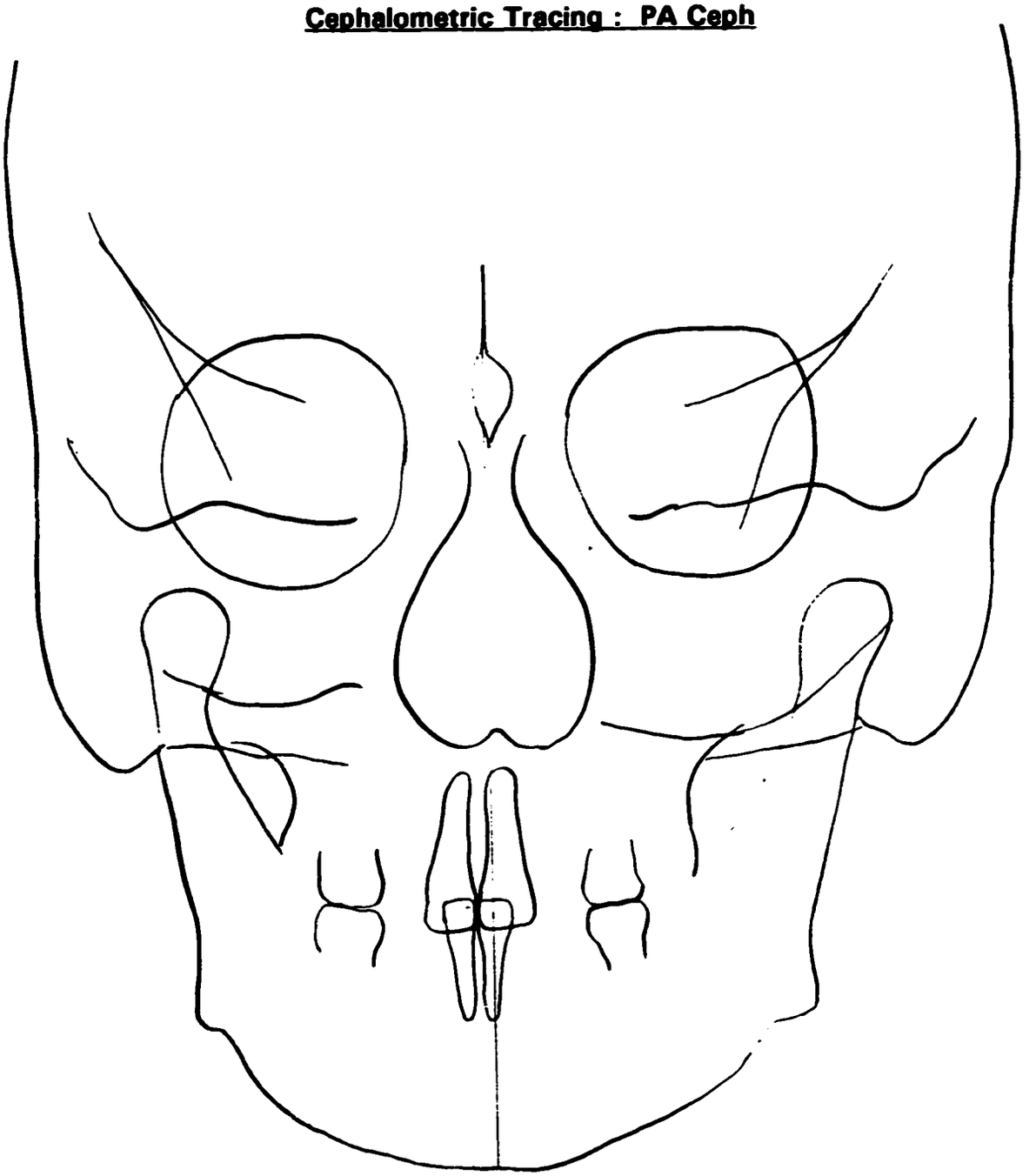
APPENDIX C - Figure C5



APPENDIX C - Figure C6.1
Cephalometric Tracing : Lateral Ceph

Patient Identification	..... #003
Date of Radiograph.	..... June 8, 1995
Date of Birth	..... June 5, 1956
Age at time of Radiograph	..... 39 years 0 months

APPENDIX C - Figure C6.2
Cephalometric Tracing : PA Ceph



Patient Identification	.....#003
Date of Radiograph.	..... June 8, 1995
Date of Birth	.....June 5, 1956
Age at time of Radiograph	.....39 years 0 months

APPENDIX C - Figure C7 Cephalometric Analysis ALBERTA ANALYSIS (summary)

PATIENT: # 003

			Range	Mean	PATIENT	Patient Relative to Range
Mandible to Cranium Maxilla to Cranium		Facial Angle	82 - 95°	87°	82.8	
		SNB	72 - 87°	79°	74.6	
		SNPg	72 - 88°	80°	74.5	
		SNA	75 - 87°	81°	80.2	
		NA to FH	84 - 96°	90°	88.4	
Mandible to Maxilla		ANB	-1 - 5°	2°	5.5	high
		AB to NPg	0 - (-9°)	-4.5°	8.1	high
		Angle Convex	-8.5 - 10°	0°	5.7	
Mandibular Denture to Maxillary Denture		1/ to /1	130-150°	135°	117.1	low
		Occl Plane-FH	1 - 14°	9°	3.0	
		Occl Plane-SN	8 - 21°	16°	11.3	
		OB	1 - 6 mm	3 mm	3	
		OJ	1 - 4 mm	1 - 2 mm	4	
		Molar Class			Class I	
Chin Button		/1 to NB	1 - 10 mm	4 mm	5.9	
		Pg to NB	2 - 5 mm	3 mm	-.2	low
		Ratio		1 : 1		
Axial Inclination of Teeth		1/ to FH	105 - 117°		117.7	high
	M	1/ to SN	92 - 114°		109.4	
	A	1/ to NA°	3 - 31°		29.6	
	X	1/ to NA (mm)	-2 - 8 mm		6.66	
		1/ to Npg (mm)	2 - 10 mm		14.8	high
		/1 to MPl	82 - 97°		99.8	high
	M	/1 to OPl	70 - 87°		57.8	high
	A	/1 to NB°	8 -40°		28.3	
	N	/1-NBmm	1 - 10mm		5.9	
	D	/1-APgmm	-2 - 3mm		2.1	
		FMIA	52 - 78°		54.73	

APPENDIX C - Figure C7 Cephalometric Analysis ALBERTA ANALYSIS (summary)

Facial Proportions	Y-Axis to FH	53 - 66°	59°	62.2	
	Y-Axis to SN	60 - 72°	66°	70.5	
	Mand Pl to FH	17 -28°	22°	25.5	
	Mand Pl to SN	22 - 36°	29°	33.8	
	% Nasal Height		43%	44	
	UFH (Na - ANS)	48 - 52 mm		55.2	high
	LFH (ANS - Me)	61 - 65 mm		65.7	
	E to LL	+/-2mm	-2mm	1.2	high
	E to UL	+/-2mm	-4mm	-5.3	
	S-N Length	+/-3mm	71mm	84.2	high
	N-S-Ar	+/-5°	123°	124.5	
	FH-SN		8°	8.3	

APPENDIX C - Figure C7 Cephalometric Analyses

JARABAK ANALYSIS

Measurement Type		Normal Range		Low	Patient	High
Saddle Angle N-S-Ar	deg	118.00-	128.00		124.52	
Articulare Angle S-Ar-Go	deg	137.00-	149.00		151.20	2.20
Gonial Angle Ar-Go-Me	deg	123.00-	137.00	4.94	118.06	
Sum total	deg					
Anterior Cranial Base S-N	mm	68.00-	74.00		74.15	0.15
Posterior Cranial Base S-Ar	mm	29.00-	35.00		29.35	
Ramus Height Ar-Go	mm	39.00-	49.00		51.11	2.11
Mn body length (Go-Me)	mm	66.00-	76.00		71.80	
Mn body length:S-N length	%	98.00-	102.00	1.16	96.84	
Post Cranial Base:Ramus Hgt	%	75.00-	75.00	17.57	57.43	
Lower Ant:Total Face Height	%	55.00-	55.00	1.38	53.62	

McNAMARA ANALYSIS

Measurement Type		Normal Range		Low	Patient	High
A Pt to N Vertical	mm	-1.90-	2.70		-1.68	
Mandibular Length	mm	81.10-	90.10	4.94	76.16	
Midface Length	mm	52.40-	58.80		61.22	2.42
LAFH	mm	57.80-	76.60		68.76	
Mandibular Plane Angle	deg	18.50-	27.50		25.51	
Facial Axis	deg	86.50-	93.50		87.12	
Pogonion to Nasion Vertical	mm	-6.30-	2.70	8.37	-14.67	
Upper 1 to A Vertical	mm	3.70-	7.10		6.04	
Lower 1 to A Pogonion	mm	1.00-	4.40		2.12	

WITS ANALYSIS

Measurement Type		Normal Range		Low	Patient	High
Jaw Disharmony	mm	-0.50-	0.50		8.72	8.22

APPENDIX C - Figure C7 Cephalometric Analyses

RICKETTS ANALYSIS

Measurement Type		Normal Range	Low	Patient	High
Facial axis (Ba-N to Pt-Gn)	deg	87.00- 93.00		87.12	
Mn Plane angle (FH-GoMe)	deg	23.00- 31.00		25.51	
Lower Face Height (ANS-Xi-Pm)	deg	43.00- 49.00		52.15	3.15
Palatal Plane (FH-ANS-PNS)	deg	-2.50- 2.50		2.44	
Convexity at A Pt. (A to NPg)	mm	1.80- 5.80		5.99	0.19
Lower Incisor to A-Pg	mm	-1.50- 3.50		2.12	

Measurement Type		Normal Range	Low	Patient	High
Molar Relation	mm	-6.00- 0.00		1.94	1.94
Incisor Overjet	mm	0.00- 5.00		8.36	3.36
Incisor Overbite	mm	0.50- 4.50		3.21	
Lower Incisor Extrusion	mm	-0.70- 3.30		1.60	
Interincisal Angle	deg	124.00- 136.00	6.94	117.06	
Convexity at A Pt.	mm	0.00- 4.00		5.99	1.99
Lower Facial Height	deg	43.00- 51.00		48.38	
Lip Protrusion	mm	-2.00- 2.00		1.06	
Upper Lip Length	mm	22.00- 26.00		30.64	4.64
Embrasure-Occclusal Plane	mm	-3.50- -1.50		3.41	4.91
Upper Molar Position	mm	15.00- 21.00		15.81	
Lower Incisor to A-Pg	mm	-1.50- 3.50		2.12	
Maxil. Incisor Protrusion	mm	1.20- 5.80		10.94	5.14
Mandib. Incisor Inclination	deg	18.00- 26.00		21.99	
Maxil. Incisor Inclination	deg	24.00- 32.00		40.95	8.95
Occlusal Plane to Ramus	mm	-7.00- -1.00		0.43	1.43
Occlusal Plane Inclination	deg	22.00- 30.00		28.29	
Facial Plane	deg	87.00- 93.00	4.24	82.76	
Facial Axis	deg	86.50- 93.50		87.12	
Facial Taper	deg	64.50- 71.50		71.82	0.32
Mandibular Plane Angle	deg	18.50- 27.50		25.51	
Maxillary Depth	deg	87.00- 93.00		88.41	
Maxillary Height	deg	53.00- 59.00		58.71	
Palatal Plane	deg	-2.50- 4.50		2.44	
Cranial Deflection	deg	24.00- 30.00		24.35	
Cranial Length-Anterior	mm	52.50- 57.50		59.80	2.30
Posterior Facial Height	mm	51.70- 58.30		67.96	9.66
Ramus Position	deg	73.00- 79.00		73.07	
Porion Location	mm	-41.20- -36.80		-37.35	
Corpus Length	mm	77.30- 82.70	8.02	69.28	

APPENDIX C - Figure C7 Cephalometric Analyses

COGS ANALYSIS

Measurement Type		Normal Range		Low	Patient	High
Convexity	mm	-2.40-	9.00		5.65	
A to Nasion Vertical	mm	-4.70-	2.70		-1.68	
B to Nasion Vertical	mm	-11.60-	-0.60	0.91	-12.51	
Pg to Nasion Vertical	mm	-12.30-	1.30	2.37	-14.67	
Nasion- ANS	mm	49.50-	55.10		55.18	0.08
ANS- Gnathion	mm	61.70-	68.30		63.49	
Facial Height Ratio	%	74.50-	86.50		86.90	0.40
Mand Plane to Horiz.	deg	18.10-	29.10		25.51	
Upper 1 to NF	mm	27.10-	30.90		27.12	
Lower 1 to MP	mm	40.90-	44.90		42.52	
Upper 6 to NF	mm	22.90-	26.30	2.91	19.99	
Lower 6 to MP	mm	31.80-	36.20	0.21	31.59	
A-B along OP (Wits)	mm	-3.00-	1.40		8.36	6.96
Upper 1 to NF	deg	106.70-	116.70		115.23	
Lower 1 to MP	deg	90.50-	101.30		99.76	

APPENDIX D Case Data Produced by ORTHO1 Decision Support System

List of Figures

APPENDIX D - Case Data Produced by ORTHO1 Decision Support System

An example, for one of the 10 cases used in the study, of the output produced by the ORTHO1 decision support system is shown in this Appendix. As explained in Section 2.13, System Design, the Current Case and Reference Case Modules are data input modules (Figure 2.11). The Current Case is entered by the novice orthodontist and the Reference Case which represents the consensus opinion of the three experts.

In the Comparison Module (Figure 2.12), the data from the current case and all reference cases are compared, and the best matched reference case is selected for more detailed comparison. From this module the current case and selected reference case parameter, choice, and weight summary is printed, as shown in this Appendix D, Figure D1.

In the Learning Module a printout, as shown in Appendix D, Figure D3, can also be produced. As described in Section 2.13, System Design, the user enters the rationale section of the Learning Module and can then select from; "What-if", "What Best", "Question", or "Outcome". The "What-if" section provides output related to two cycles of analysis: cycle one is the Initial Case Analysis, cycle two is the "What-if" Case Analysis. In cycle one the analysis is based on the initial input. Printouts containing the following information are produced from the Initial Case Analysis:

Figure D1	Comparison of Current Case to Reference Case (Case Matching by Parameter, Weight and Outcome)
Figure D2	Summary of Treatment Recommendations by Experts and Novice
Figure D3	Current Case Versus Reference Case (Summary of Parameter Choices and Weights Made by Expert and Novice Orthodontists)
Figure D4	Concept, Category, Cluster, Subjective - Objective Parameter Analysis Summaries
Figure D5	What Best Scenario (Summary of Differences in Choice Between Experts and Novice)

In cycle two, the cases are analyzed based on changes the novice has made to the current case during the "What-if" section of the computer system. In this section, the novice reviews the experts comments about why they made the choice (for each parameter) and is provided with supporting literature pertaining to the parameter being analyses. The

novice can repeat the "What-if" section as many times as desired. As shown in Section 2.13 Figure 2.15. When satisfied with their treatment decision, parameter choices and weightings, the novice is then provided with output as listed for cycle one, however the data used in the analyses is that which is produced in the "What-if" section. See Figures D6-D10.

The "What Best" section produces a printout which summarizes the non-matching parameters which result from the comparison of the current case and the selected reference case. Appendix D, Figure D5 shows the What Best report for the Initial Case Assessment and Figure 10 shows the report for the What-if Case Assessment.

The "Outcome" section (Figure 2.19) produces a printout (Appendix D, Figure D2) from the Initial Case Assessment and Appendix D, Figure D7 from the What-if Case Assessment.

APPENDIX D - Figure D1 Initial Case Assessment
Comparison of Current Case to Reference Case
(Case Matching by Parameter, Weight, and Outcome)

Current Case # 1407

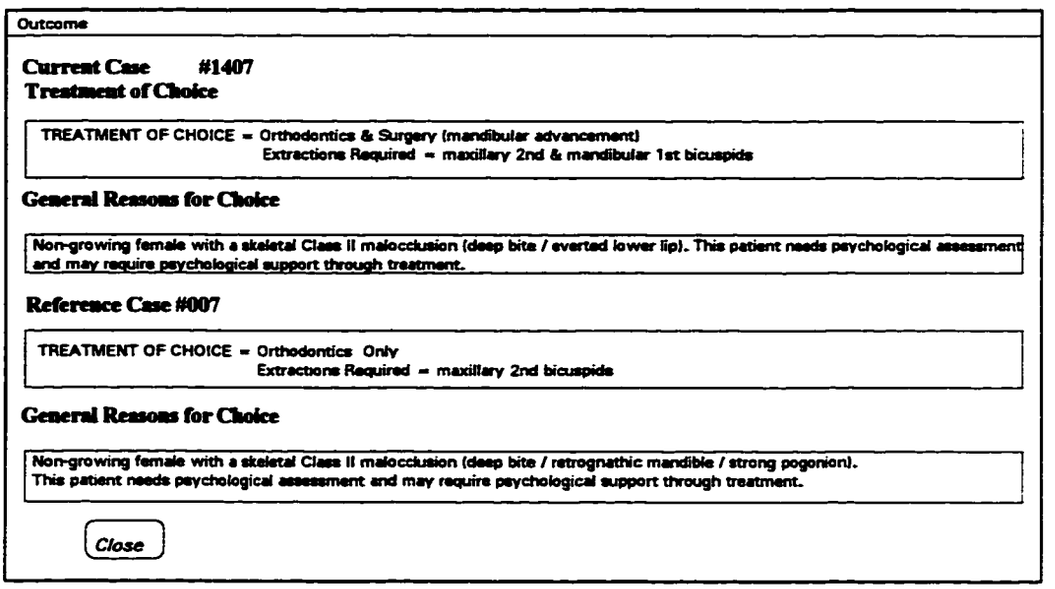
Parameter	Result	Weight
Gender	female	4
Age	non-growing (15+ yrs.)	5
Race	Caucasoid	5
Medical Status	non-significant findings - please specify	3
Patient Objective(s) -Improved Function)	yes	1
Patient Objective(s)- Improved Dental Esthetics	yes	4

Comparison to Reference Case

case no	parameter match	weight match	outcome match	interpretation
006	33	46	3	
005	35	37	3	
008	37	41	3	
010	38	54	1	
003	40	55	1	
001	40	66	1	
004	44	79	1	
002	46	55	1	
009	51	73	1	
007	54	80	1	the current case is best related (by parameter) to ref. case 007

Parameter | *Weight* | *Outcome* | *Detail* | *Close*

APPENDIX D - Figure D2 Initial Case Assessment
Summary of Treatment Recommendations by Experts and Novice



APPENDIX D - Figure D3 Initial Case Assessment
Current Case versus Reference Case
(Summary of Parameter Choices and Weights Made by Expert and Novice Orthodontists)

Gender

Current result:	female	wt. 1
Expert result :	female	wt. 5

Age (Category)

Current result:	15 + yrs . wt. 2	
Expert result :	15 + yrs . wt. 5	

Race

Current result:	Caucasoid	wt. 1
Expert result :	Caucasoid	wt. 3

Medical Status

Current result:	non-significant findings	wt. 1
Expert result :	non-significant findings	wt. 1

Patient Objectives - Improved Function

Current result:	yes. wt. 1
Expert result :	yes. wt. 4

Patient Objectives - Improved Dental Esthetics

Current result:	yes. wt. 5
Expert result :	yes. wt. 5

Patient Objectives - Improved Facial Esthetics

Current result:	yes. wt. 1
Expert result :	yes. wt. 4

Psychological Status

Current result:	requires psychological support through treatment	wt. 3
Expert result:	requires psychological assessment before treatment	wt. 5

Psychological Effect of Malocclusion

Current result is:	negatively - severe	wt. 1
Expert result is:	negatively - moderate	wt. 4

Patient Motivation Regarding Treatment

Current result:	moderate motivation	wt.2
Expert result is:	moderate motivation	wt.5

Reported Habits

Current result:	none	wt. 1
Expert result is:	none	wt. 1

Facial Form (Frontal View) - Transverse

Current result:	symmetric	wt. 1
Expert result is:	symmetric	wt. 2

APPENDIX D - Figure D4

CONCEPT / CATEGORY / CLUSTER / SUBJECTIVE-OBJECTIVE PARAMETER ANALYSIS SUMMARIES

NOVICE #4 -- CASE #007 - INITIAL CASE ASSESSMENT

CONCEPT

GROUP	PARMETER No	PARAMETER COUNT	WEIGHT SCORE	INTERPRETATION
Proposed Treatment	4	1	0	your assessment is : fair
Clinical Assessment	23	16	14	your assessment is : good
Parient History	8	6	11	your assessment is : excellent
Model Analysis	19	16	36	your assessment is : excellent
Diagnostic Imaging	25	22	32	your assessment is : excellent
Demographics / Personal Information	3	3	4	your assessment is : excellent

CATEGORY

GROUP	PARMETER No	PARAMETER COUNT	WEIGHT SCORE	INTERPRETATION
Proposed Treatment	4	1	0	your assessment is : good
Extra-Oral Findings	14	9	8	your assessment is : good
Diagnostic Imaging	3	2	0	your assessment is : good
General Information	11	9	15	your assessment is : excellent
Intra-Oral Findings	28	23	42	your assessment is : excellent
Cephalometrics	22	20	32	your assessment is : excellent

CLUSTER

GROUP	PARMETER No	PARAMETER COUNT	WEIGHT SCORE	INTERPRETATION
Proposed Treatment	4	1	0	your assessment is : fair
Perimeter Assessment	5	2	0	your assessment is : fair
Cephalometrics_Soft Tissue	4	2	8	your assessment is : good
ExtraOral Findings_Clinical Assessment	12	7	8	your assessment is : good
Medical Health Information	5	3	4	your assessment is : good
Diagnostic Imaging	3	2	0	your assessment is : good
Occlusion	12	10	30	your assessment is : excellent
Temporomandibular Joint	2	2	0	your assessment is : excellent
Patient Objectives	3	3	7	your assessment is : excellent
IntraOral Findings_Periodontal Considerations	4	4	5	your assessment is : excellent
IntraOral Findings_Bolton Assessment	5	5	5	your assessment is : excellent
General Information	3	3	4	your assessment is : excellent
Esthetic Assessment of Dentition	2	2	2	your assessment is : excellent
Cephalometrics_Skeletal	18	18	24	your assessment is : excellent

SUBJECTIVE / OBJECTIVE

GROUP	PARMETER NO.	RAMETER COU	EIGHT SCO	INTERPRETATION
Subjective	28	0	0	your assessment is : poor
Objective	54	2	1	your assessment is : poor

APPENDIX D - Figure D5 Initial Case Assessment
What Best Scenario
(Differences in Choice Between Novice and Expert Orthodontists)

Psychological Satus
Current result is: requires psychological support through treatment
Expert result is: requires psychological assessment before treatment

Psychological Effect of Malocclusion
Current result is: negitively - severe
Expert result is: negatively - moderate

Facial Form (Lateral View)_ Nasolabial Angle
Current result: acute
Expert result is: normal (approx. 130 degrees)

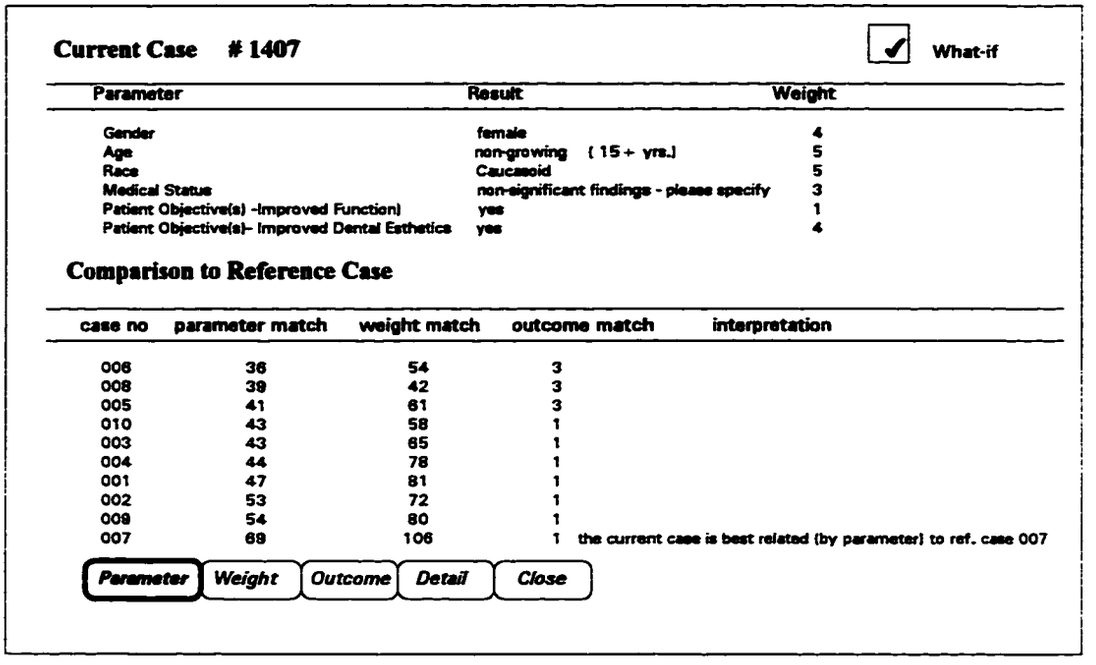
Facial Form (Lateral View)_ Labiomental Angle
Current result: acute
Expert result is: normal (approx. 130 degrees)

Overjet (millimeters)
Current result: mild (0 - 2 mm.)
Expert result is: moderate (2.1 - 4 mm)

CR : CO Discrepancy
Current result: yes
Expert result is: no

Perimeter - Maxillary Deficiency
Current result: mild deficiency (0-4 mm.)
Expert result is: moderate (4.1-8 mm.)

APPENDIX D - Figure D6 **What - if Case Case Analysis**
Comparison of Current Case to Reference Case
(Case Matching by Parameter, Weight, and Outcome)



Current Case # 1407 ☑ What-if

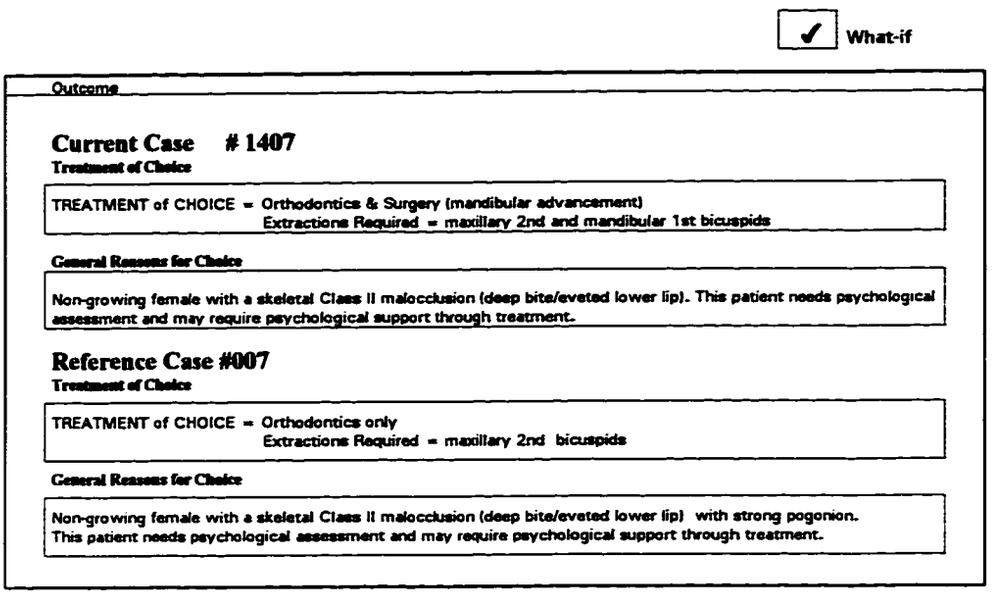
Parameter	Result	Weight
Gender	female	4
Age	non-growing (15 + yrs.)	5
Race	Caucasoid	5
Medical Status	non-significant findings - please specify	3
Patient Objective(s) -Improved Function)	yes	1
Patient Objective(s)- Improved Dental Esthetics	yes	4

Comparison to Reference Case

case no	parameter match	weight match	outcome match	interpretation
006	36	54	3	
008	39	42	3	
005	41	61	3	
010	43	58	1	
003	43	65	1	
004	44	78	1	
001	47	81	1	
002	53	72	1	
009	54	80	1	
007	69	106	1	the current case is best related (by parameter) to ref. case 007

Parameter *Weight* *Outcome* *Detail* *Close*

APPENDIX D - Figure D7 What - if Case Assessment
Summary of Treatment Recommendations by Expert and Novice Orthodontists



APPENDIX D - Figure D8 **What - if Case Analysis**
Current Case versus Reference Case
(Summary of Parameter Choices and Weights Made by Expert and Novice Orthdontists)

☑ What-if

Gender
Current result : female wt. 1
Expert result : female wt. 5

Age (Category)
Current result : 15 + yrs . wt. 2
Expert result : 15 + yrs . wt. 5

Race
Current result : Caucasoid wt. 1
Expert result : Caucasoid wt. 3

Medical Status
Current result : non-significant findings wt. 1
Expert result : non-significant findings wt. 1

Patient Objectives - Improved Function
Current result : yes. wt. 1
Expert result : yes. wt. 4

Patient Objectives - Improved Dental Esthetics
Current result : yes. wt. 5
Expert result : yes. wt. 5

Patient Objectives - Improved Facial Esthetics
Current result : yes. wt. 1
Expert result : yes. wt. 4

Psychological Status
Current result: requires psychological support through treatment wt. 3
Expert result: requires psychological assessment before treatment wt. 5

Psychological Effect of Malocclusion
Current result is: negatively - severe wt. 1
Expert result is: negatively - moderate wt. 4

Patient Motivation Regarding Treatment
Current result: moderate motivation wt.2
Expert result is: moderate motivation wt.5

Reported Habits
Current result: none wt. 1
Expert result is: none wt. 1

Facial Form (Frontal View) - Transverse
Current result: symmetric wt. 1
Expert result is: symmetric wt. 2

APPENDIX D - Figure D9
CONCEPT / CATEGORY / CLUSTER / SUBJECTIVE-OBJECTIVE PARAMETER
ANALYSIS SUMMARIES

NOVICE #4 -- CASE #007 - WHAT if ASSESSMENT

☑ What-if

CONCEPT

GROUP	PARMETER No	PARAMETER COUNT	WEIGHT SCORE	INTERPRETATION
Proposed Treatment	4	1	0	your assessment is : fair
Clinical Assessment	23	20	18	your assessment is : excellent
Parient History	8	6	11	your assessment is : excellent
Model Analysis	19	17	38	your assessment is : excellent
Diagnostic Imaging	25	23	24	your assessment is : excellent
Demographics / Personal Information	3	3	4	your assessment is : excellent

CATEGORY

GROUP	PARMETER No	PARAMETER COUNT	WEIGHT SCORE	INTERPRETATION
Proposed Treatment	4	1	0	your assessment is : good
Extra-Oral Findings	14	12	11	your assessment is : excellent
Diagnostic Imaging	3	2	0	your assessment is : excellent
General Information	11	9	15	your assessment is : excellent
Intra-Oral Findings	28	25	45	your assessment is : excellent
Cephalometrics	22	21	34	your assessment is : excellent

CLUSTER

GROUP	PARMETER No	PARAMETER COUNT	WEIGHT SCORE	INTERPRETATION
Proposed Treatment	4	1	0	your assessment is : fair
Perimeter Assessment	12	7	8	your assessment is : good
Cephalometrics_Soft Tissue	4	3	10	your assessment is : good
ExtraOral Findings_Clinical Assessment	3	2	0	your assessment is : good
Medical Health Information	5	3	4	your assessment is : good
Diagnostic Imaging	3	2	0	your assessment is : good
Occlusion	12	11	31	your assessment is : excellent
Temporomandibular Joint	2	2	0	your assessment is : excellent
Patient Objectives	3	3	7	your assessment is : excellent
IntraOral Findings_Periodontal Considerations	4	4	5	your assessment is : excellent
IntraOral Findings_Bolton Assessment	5	5	5	your assessment is : excellent
General Information	3	3	4	your assessment is : excellent
Esthetic Assessment of Dentition	2	2	2	your assessment is : excellent
Cephalometrics_Skeletal	18	18	24	your assessment is : excellent

SUBJECTIVE / OBJECTIVE

GROUP	PARMETER No	PARAMETER COUNT	WEIGHT SCORE	INTERPRETATION
Subjective	28	0	0	your assessment is : poor
Objective	54	2	1	your assessment is : poor

APPENDIX D - Figure D10 Best Scenario
Following What if Changes Made by Novice Orthodontist
(Differences In Choice Between Novice and Expert Orthodontists)

☑ What-if

Psychological Satus
Current result is: requires psychological uspport through treatment
Expert result is: requires psychological assessment before treatment

Psychological Effect of Malocclusion
Current result is: negitively - severe
Expert result is: negatively - moderate

Facial Form (Lateral View)_ Nasolabial Angle
Current result: acute
Expert result is: normal (approx. 130 degrees)

Facial Form (Lateral View)_ Labiomental Angle
Current result: acute
Expert result is: normal (approx. 130 degrees)

Overjet (millimeters)
Current result: mild (0 - 2 mm.)
Expert result is: moderate (2.1 - 4 mm)

Perimeter - Maxillary Deficiency
Current result: mild deficiency (0-4 mm.)
Expert result is: moderate (4.1-8 mm.)

APPENDIX E Hardware and Software Requirements for ORTHO1 Decision Support System

APPENDIX E Hardware and Software Requirements for the ORTHO1 Decision Support System

Hardware

- standard personal computer with 486 Mhz processor
- 10 M harddrive
- 16 M RAM
- VGA monitor
- enhanced keyboard
- MS Serial Mouse

Software

- Windows 3.x or Windows 95
- Microsoft Access 2.0

APPENDIX F Technical System - Flow of Data Within the ORTHO1 Decision Support System

APPENDIX F Technical System - Flow of Data Within the ORTHO1 Decision Support System

As discussed in the section 2.13, systems design, the ORTHO1 decision support system has four modules; Reference Case, Current Case, Comparison, and Learning (Figure 2.10.)

The Current Case and Reference Case Modules are data input modules. (Figure 2.11). The novice orthodontists enter each case in the Current Case Module. The data is stored in a database table titled "current case event". The expert consensus is entered in the Reference Case Module and the data is stored in the "reference case event" table. Both the novice and expert consensus data is entered by parameter, of which there are 82. A summary of the parameters and possible choices used in each case assessment is contained in Appendix A, Figure A1. One of several choices pertaining to the specific parameter is entered by the user and a weight from zero to five is selected. A section for comments is also available.

In the Comparison Module each current case is compared separately to all reference cases. The current case is compared by matching parameters, weights, and treatment choice. The results of the comparison are stored in the database "comparison" table and displayed in the "comparison result" form. The user can select the parameter, weight, or outcome sort options. The program will sort and rank, in ascending order, each reference case and the number of matched parameters, weights, or treatment choice accordingly. The user can then select any one of the reference cases for comparison, parameter by parameter, with the current case. A printout which lists the parameter choices and weights recorded for the reference case and the current case can now be produced.

In the Learning Module a case comparison and matching process identical to that of the Comparison Module is done initially. The user can then select any one of the reference cases for further comparative analysis with the current case. Typically this will be the reference case which has the most matches. Once a reference case has been selected, the user can proceed to the Rationale section of the program where the parameter, weight, and outcome results of the "current case event" are compared with those in the "reference case event". The results of the comparison are stored in the "Wicurrent case event" table. In the rationale section, three options for analysis are available; "What Best", "What if", and

"Outcome". The "What Best" option will select from the "comparison results" table , the non-matching parameters resulting from the comparison of the current case and the reference case. The data can be printed using the "What Best " form.

The "What-if" option leads to an interactive section of the ORTHO1 system. The user can first cycle through the analysis using the data that was initially entered and stored in the "current case event" and "reference case event" tables. As outlined in section 2.13, system design, this is referred to as the Initial Case Assessment. For the purposes of this analysis, the data is stored in the "tempcurrent case event" table and displayed in the "What-if " form (WIF). The flaw option can be selected which activates the flaw analysis. This compares the current case to the reference case by classification of parameter. As explained in Section 2.08, Selection and Classification of Parameters, the parameters are classified into four groups: concept, category, cluster, and subjective/objective. At the end of the initial cycle through the "What-if" analysis, a printout of the matches by parameter and weight plus an interpretation of these matches is produced for each group. The results of the flaw analysis are stored in the "Fcomparison" table. On the second and subsequent cycles through the "What-if" analysis, the user is given the opportunity to change input related to any of the 82 parameters. The parameter choice , weight, and rationale for these selections, as determined by the expert consensus, ("reference case event" form), is displayed simultaneously with the novice parameter choice , weight, and rationale ("current case event"). During this cycle, the user is prompted to change parameter choice and weight, if desired. The "What-if" form (WIF) is updated and the "What-if" analysis by group is displayed and printed on command. As outlined in the Systems Overview section, this is referred to as the What-if Case Assessment. The results of the revisions made during each "What-if " cycle are stored in the "Wicomparison" table. Following the *"What-if"* cycle and analysis, the user can select: the *"What Best"* analysis to review the non-matching parameters, which are summarized based on the last "what-if" input made; the *"Outcome"* summary to review the treatment choice and general reasons for choice (which the user may have changed during "What-if" cycle); the *"What-if"* analysis to continue evaluating the user's parameter choices and weights and possibly change the input; *"Question"* to prompt the user which of the six questions is being addressed by the system or *"Close"* to exit the "What-if" cycle.

The "Outcome" option displays a written summary of the treatment choice and the general reasons , as reported by the novice and expert consensus.

Run time reports are generated at numerous points during the cycle through the ORTHO1 system. The design template is generated through the Crystal Report for Visual

Basic program. Here format, pattern, and fonts are designed. The template is then displayed on Visual Basic forms. The data required for each time run report is retrieved from the mdb files in the Microsoft Access tables or queries.

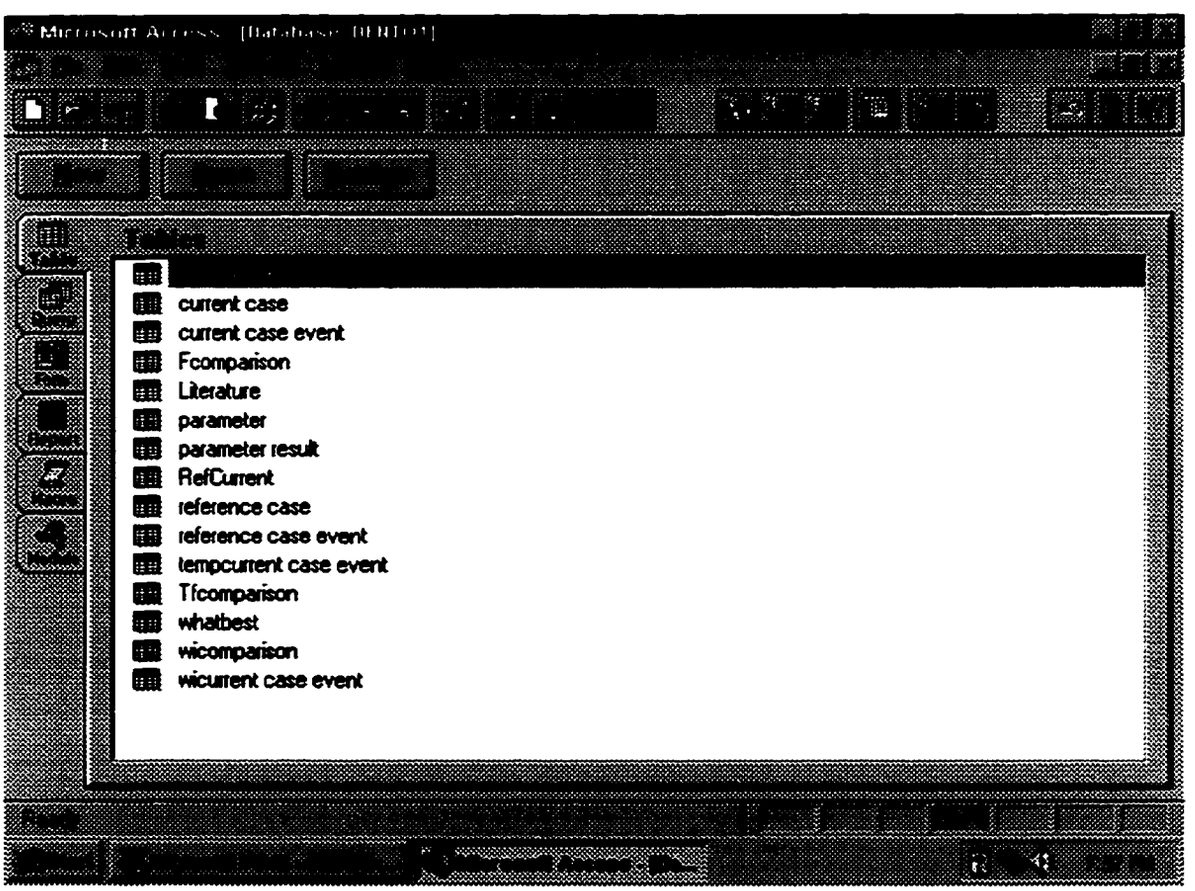
APPENDIX G Relational Database Files for ORTHO1 Decision Support System

List of Figures

APPENDIX G - Figure G1

RELATIONAL DATABASE FILES
(D:\MSOffice\Access\ORTHO1\dento.mbd)

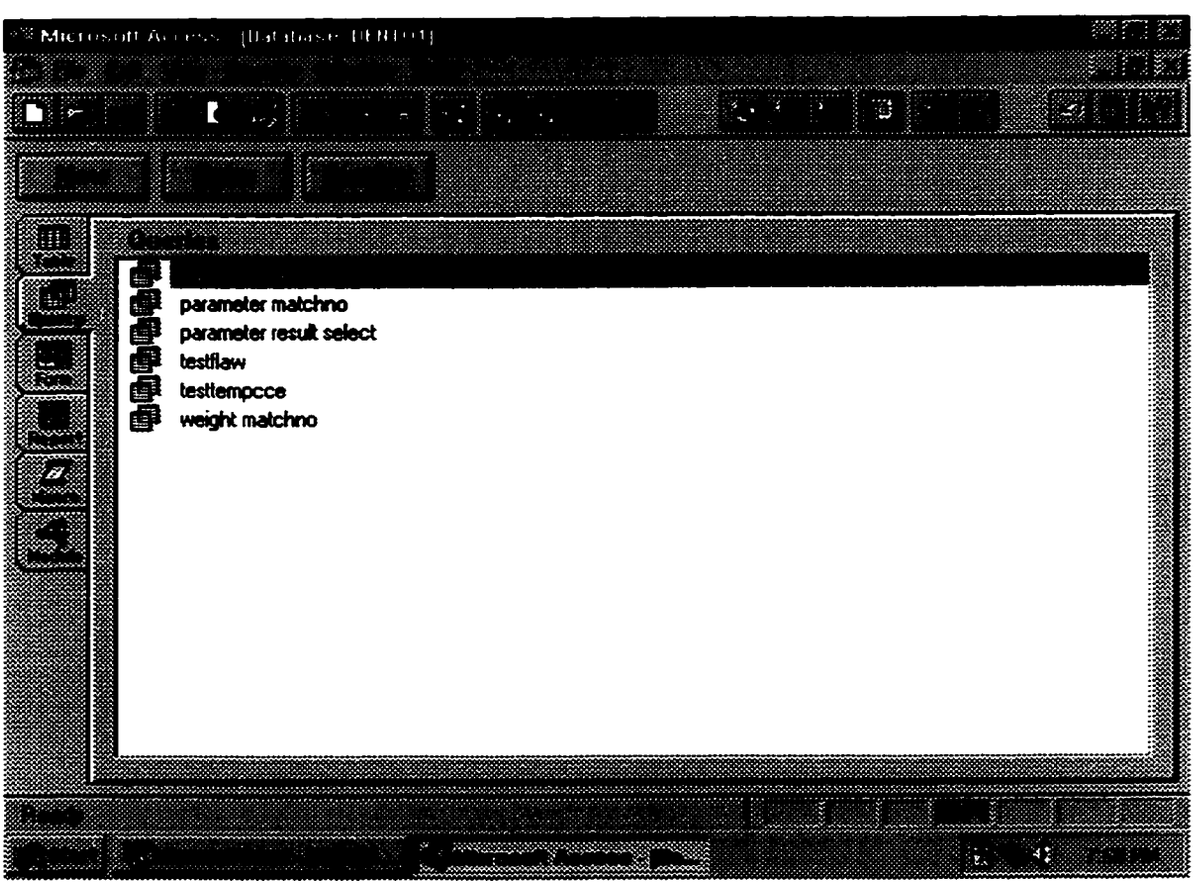
TABLES



APPENDIX G - Figure G2

RELATIONAL DATABASE FILES
(D:\MSOffice\Access\ORTHO1\dento.mbd)

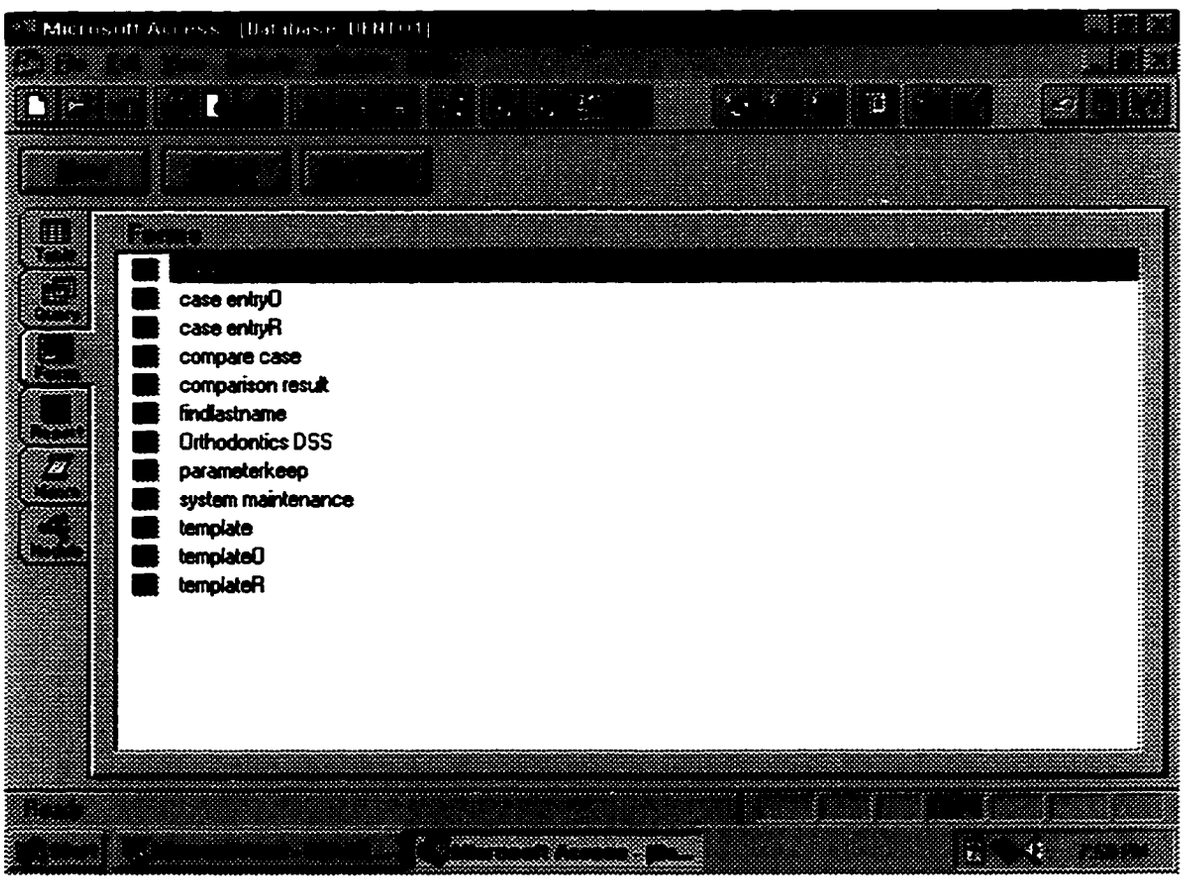
QUERIES



APPENDIX G - Figure G3

RELATIONAL DATABASE FILES
(D:\MSOffice\Access\ORTHO1\dento.mbd)

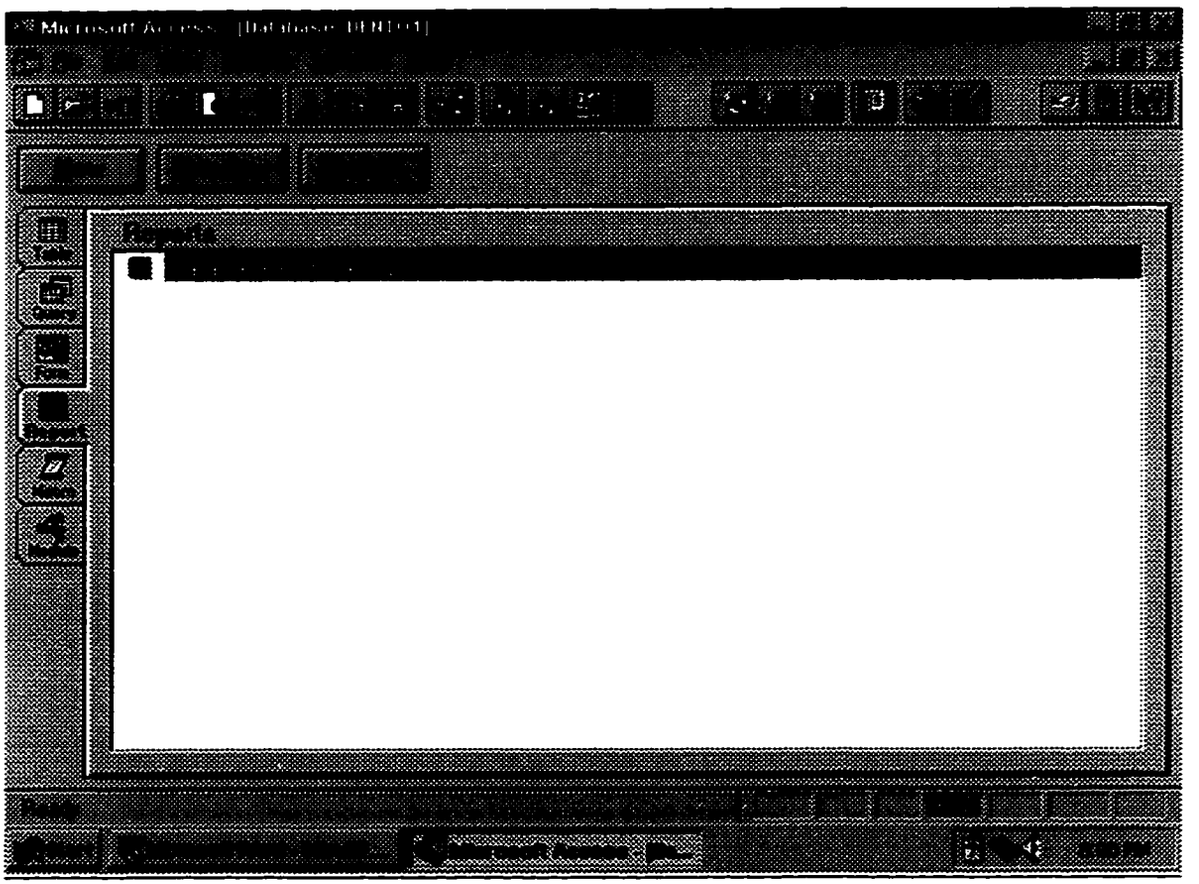
FORMS



APPENDIX G - Figure G4

RELATIONAL DATABASE FILES
(D:\MSOffice\Access\ORTHO1\dento.mbd)

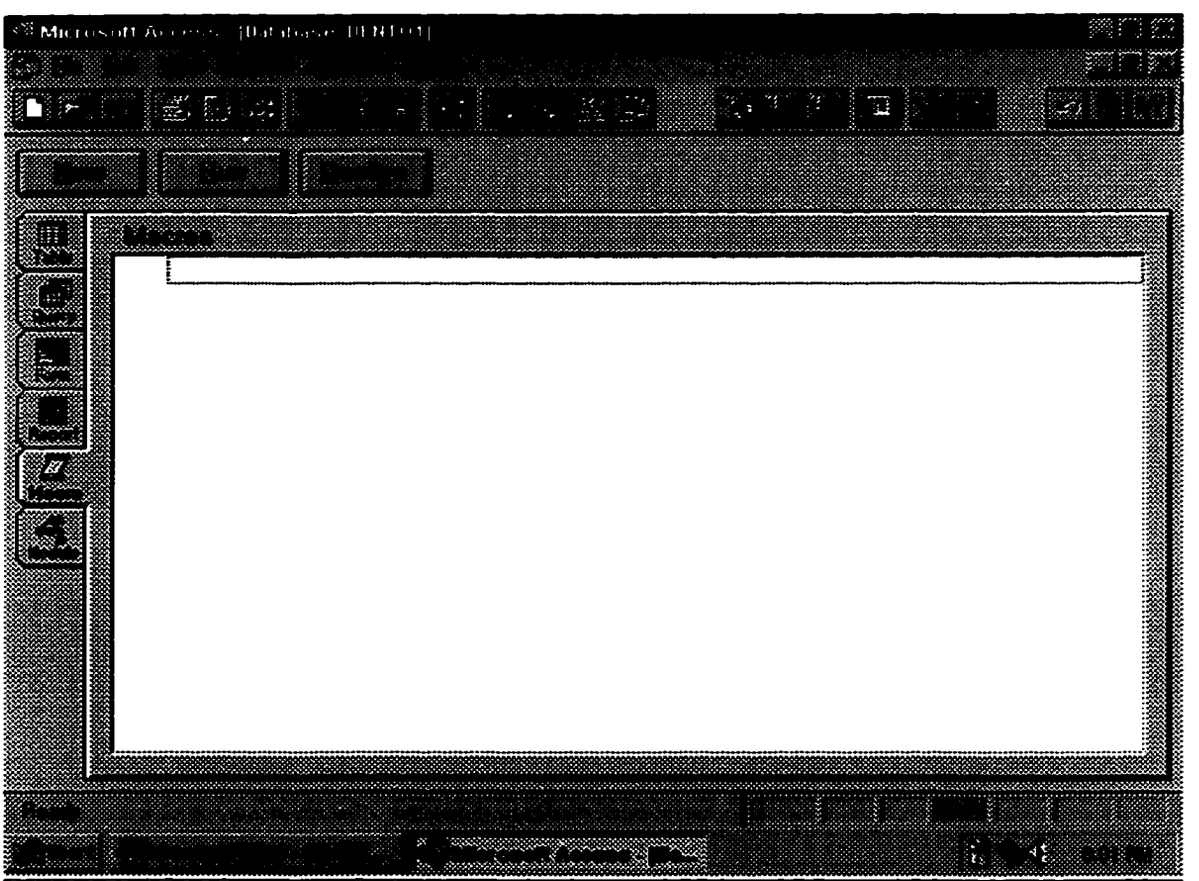
REPORTS



APPENDIX G - Figure G5

RELATIONAL DATABASE FILES
(D:\MSOffice\Access\ORTHO1\dento.mbd)

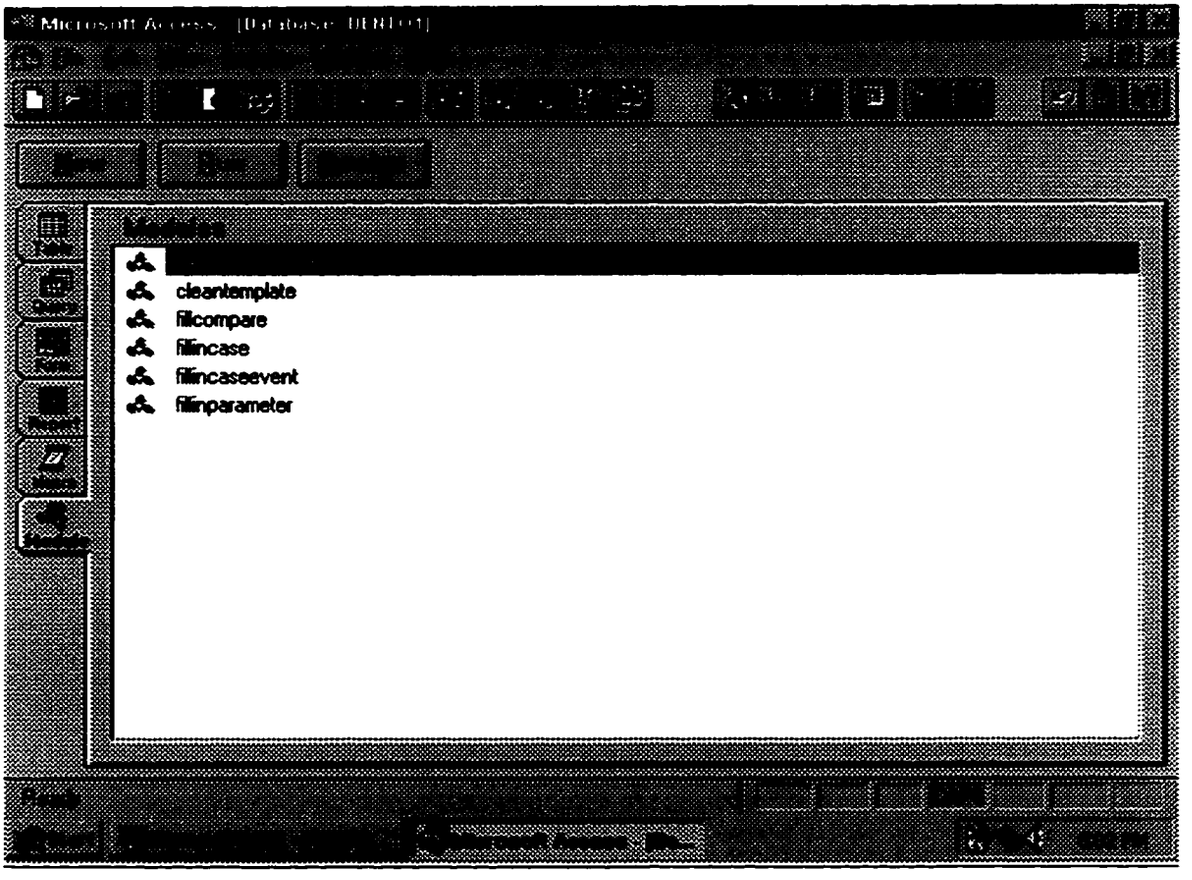
MACROS



APPENDIX G - Figure G6

RELATIONAL DATABASE FILES
(D:\MSOffice\Access\ORTHO1\dento.mbd)

MODULES



APPENDIX H User Performance Data - Initial Case Analyses

List of Figures

SUMMARY USER PERFORMANCE RECORD
APPENDIX H - Table H1
Summary of Matching Parameters by Novice User and Case
- Initial Case Analyses -

		CASE #1				CASE #2			
Group - CONCEPT		N1		N3		N1		N3	
SUBGROUPS	Parameters per Group	# of Matching Parameters	% of Subgrou	# of Matching Parameters	% of Subgroup	# of Matching Parameters	% of Subgrou	# of Matching Parameters	% of Subgroup
Demographics / Personal Info.	3	3	100.0%	3	100.0%	3	100.0%	3	100.0%
Patient History	8	6	75.0%	7	87.5%	7	87.5%	7	87.5%
Clinical Assessment	23	20	87.0%	21	91.3%	18	78.3%	16	69.6%
Model Analysis	19	16	84.2%	17	89.5%	17	89.5%	19	100.0%
Diagnostic Imaging	25	24	96.0%	24	96.0%	25	100.0%	25	100.0%
Proposed Treatment	4	1	25.0%	1	25.0%	3	75.0%	4	100.0%
	82	70	85.4%	73	89.0%	73	89.0%	74	90.2%

		CASE #1				CASE #2			
Group - CATEGORY		N1		N3		N1		N3	
SUBGROUPS	Parameters per Group	# of Matching Parameters	% of Subgrou	# of Matching Parameters	% of Subgroup	# of Matching Parameters	% of Subgrou	# of Matching Parameters	% of Subgroup
General Information	11	9	81.8%	10	90.9%	10	90.9%	10	90.9%
Extra-Oral Findings	14	12	85.7%	12	85.7%	10	71.4%	8	57.1%
Intra-Oral Findings	28	24	85.7%	26	92.9%	25	89.3%	27	96.4%
Diagnostic Imaging	3	2	66.7%	2	66.7%	3	100.0%	3	100.0%
Cephalometrics	22	22	100.0%	22	100.0%	22	100.0%	22	100.0%
Proposed Treatment	4	1	25.0%	1	25.0%	3	75.0%	4	100.0%
	82	70	85.4%	73	89.0%	73	89.0%	74	90.2%

		CASE #1				CASE #2			
Group - CLUSTER		N1		N3		N1		N3	
SUBGROUPS	Parameters per Group	# of Matching Parameters	% of Subgrou	# of Matching Parameters	% of Subgroup	# of Matching Parameters	% of Subgrou	# of Matching Parameters	% of Subgroup
Demographics / Personal Info.	3	3	100.0%	3	100.0%	3	100.0%	3	100.0%
Medical Health Information	5	4	80.0%	4	80.0%	4	80.0%	4	80.0%
Patient Objectives	3	2	66.7%	3	100.0%	3	100.0%	3	100.0%
ExtraOral Findings_Clinical Assess.	12	10	83.3%	10	83.3%	8	66.7%	6	50.0%
Temporomandibular Joint	2	2	100.0%	2	100.0%	2	100.0%	2	100.0%
IntraOral Findings_Periodontal Consid.	4	4	100.0%	4	100.0%	4	100.0%	4	100.0%
IntraOral Findings_Bolton Assess.	5	5	100.0%	5	100.0%	5	100.0%	5	100.0%
Esthetic Assessment of Dentition	2	2	100.0%	2	100.0%	2	100.0%	2	100.0%
Occlusion	12	9	75.0%	10	83.3%	10	83.3%	12	100.0%
Perimeter Assessment	5	4	80.0%	5	100.0%	4	80.0%	4	80.0%
Diagnostic Imaging	3	2	66.7%	2	66.7%	3	100.0%	3	100.0%
Cephalometrics_Soft Tissue	4	4	100.0%	4	100.0%	4	100.0%	4	100.0%
Cephalometrics_Skeletal	18	18	100.0%	18	100.0%	18	100.0%	18	100.0%
Proposed Treatment	4	1	25.0%	1	25.0%	3	75.0%	4	100.0%
	82	70	85.4%	73	89.0%	73	89.0%	74	90.2%

		CASE #1				CASE #2			
SUBJECTIVE / OBJECTIVE		N1		N3		N1		N3	
SUBGROUPS	Parameters per Group	# of Matching Parameters	% of Subgrou	# of Matching Parameters	% of Subgroup	# of Matching Parameters	% of Subgrou	# of Matching Parameters	% of Subgroup
Objective	30	29	96.7%	30	57.7%	30	100.0%	30	100.0%
Subjective	52	41	78.8%	43	82.7%	43	82.7%	44	84.6%
	82	70	85.4%	73	89.0%	73	89.0%	74	90.2%

SUMMARY USER PERFORMANCE RECORD
APPENDIX H - Table H1
Summary of Matching Parameters by Novice User and Case
- Initial Case Analyses -

		CASE #3				CASE #4			
Group - CONCEPT		N1		N2		N1		N2	
SUBGROUPS	Parameters per Group	# of Matching Parameters	% of Subgroup	# of Matching Parameters	% of Subgroup	# of Matching Parameters	% of Subgroup	# of Matching Parameters	% of Subgroup
Demographics / Personal Info.	3	3	100.0%	3	100.0%	3	100.0%	3	100.0%
Patient History	8	5	62.5%	6	75.0%	5	62.5%	6	75.0%
Clinical Assessment	23	18	78.3%	15	65.2%	19	82.6%	20	87.0%
Model Analysis	19	17	89.5%	17	89.5%	19	100.0%	19	100.0%
Diagnostic Imaging	25	24	96.0%	25	100.0%	25	100.0%	25	100.0%
Proposed Treatment	4	1	25.0%	4	100.0%	4	100.0%	4	100.0%
	82	68	82.9%	70	85.4%	75	91.5%	77	93.9%
Group - CATEGORY		N1		N2		N1		N2	
SUBGROUPS	Parameters per Group	# of Matching Parameters	% of Subgroup	# of Matching Parameters	% of Subgroup	# of Matching Parameters	% of Subgroup	# of Matching Parameters	% of Subgroup
General Information	11	8	72.7%	9	81.8%	8	72.7%	9	81.8%
Extra-Oral Findings	14	10	71.4%	9	64.3%	12	85.7%	12	85.7%
Intra-Oral Findings	28	25	89.3%	23	82.1%	26	92.9%	27	96.4%
Diagnostic Imaging	3	2	66.7%	3	100.0%	3	100.0%	3	100.0%
Cephalometrics	22	22	100.0%	22	100.0%	22	100.0%	22	100.0%
Proposed Treatment	4	1	25.0%	4	100.0%	4	100.0%	4	100.0%
	82	68	82.9%	70	85.4%	75	91.5%	77	93.9%
Group - CLUSTER		N1		N2		N1		N2	
SUBGROUPS	Parameters per Group	# of Matching Parameters	% of Subgroup	# of Matching Parameters	% of Subgroup	# of Matching Parameters	% of Subgroup	# of Matching Parameters	% of Subgroup
Demographics / Personal Info.	3	3	100.0%	3	100.0%	3	100.0%	3	100.0%
Medical Health Information	5	2	40.0%	3	60.0%	2	40.0%	3	60.0%
Patient Objectives	3	3	100.0%	3	100.0%	3	100.0%	3	100.0%
ExtraOral Findings_Clinical Assess.	12	8	66.7%	7	58.3%	10	83.3%	10	83.3%
Temporomandibular Joint	2	2	100.0%	2	100.0%	2	100.0%	2	100.0%
IntraOral Findings_Periodontal Consid.	4	4	100.0%	4	100.0%	4	100.0%	4	100.0%
IntraOral Findings_Bolton Assess.	5	5	100.0%	5	100.0%	5	100.0%	5	100.0%
Esthetic Assessment of Dentition	2	2	100.0%	1	50.0%	2	100.0%	2	100.0%
Occlusion	12	11	91.7%	9	75.0%	11	91.7%	11	91.7%
Perimeter Assessment	5	3	60.0%	4	80.0%	4	80.0%	5	100.0%
Diagnostic Imaging	3	2	66.7%	3	100.0%	3	100.0%	3	100.0%
Cephalometrics_Soft Tissue	4	4	100.0%	4	100.0%	4	100.0%	4	100.0%
Cephalometrics_Skeletal	18	18	100.0%	18	100.0%	18	100.0%	18	100.0%
Proposed Treatment	4	1	25.0%	4	100.0%	4	100.0%	4	100.0%
	82	68	82.9%	70	85.4%	75	91.5%	77	93.9%
SUBJECTIVE / OBJECTIVE		N1		N2		N1		N2	
SUBGROUPS	Parameters per Group	# of Matching Parameters	% of Subgroup	# of Matching Parameters	% of Subgroup	# of Matching Parameters	% of Subgroup	# of Matching Parameters	% of Subgroup
Objective	30	30	100.0%	29	96.7%	30	100.0%	29	96.7%
Subjective	52	38	73.1%	41	78.8%	45	86.5%	48	92.3%
	82	68	82.9%	70	85.4%	75	91.5%	77	93.9%

SUMMARY USER PERFORMANCE RECORD
APPENDIX H - Table H1
Summary of Matching Parameters by Novice User and Case
- Initial Case Analyses -

CASE #5

Group - CONCEPT		N1		N3	
SUBGROUPS	Parameters per Group	# of Matching Parameters	% of Subgroup	# of Matching Parameters	% of Subgroup
Demographics / Personal Info.	3	3	100.0%	3	100.0%
Patient History	8	7	87.5%	8	100.0%
Clinical Assessment	23	22	95.7%	22	95.7%
Model Analysis	19	17	89.5%	17	89.5%
Diagnostic Imaging	25	25	100.0%	25	100.0%
Proposed Treatment	4	3	75.0%	4	100.0%
	82	77	93.9%	79	96.3%

Group - CATEGORY		N1		N3	
SUBGROUPS	Parameters per Group	# of Matching Parameters	% of Subgroup	# of Matching Parameters	% of Subgroup
General Information	11	10	90.9%	11	100.0%
Extra-Oral Findings	14	13	92.9%	13	92.9%
Intra-Oral Findings	28	26	92.9%	26	92.9%
Diagnostic Imaging	3	3	100.0%	3	100.0%
Cephalometrics	22	22	100.0%	22	100.0%
Proposed Treatment	4	3	75.0%	4	100.0%
	82	77	93.9%	79	96.3%

Group - CLUSTER		N1		N3	
SUBGROUPS	Parameters per Group	# of Matching Parameters	% of Subgroup	# of Matching Parameters	% of Subgroup
Demographics / Personal Info.	3	3	100.0%	3	100.0%
Medical Health Information	5	4	80.0%	5	100.0%
Patient Objectives	3	3	100.0%	3	100.0%
ExtraOral Findings_Clinical Assess.	12	11	91.7%	11	91.7%
Temporomandibular Joint	2	2	100.0%	2	100.0%
IntraOral Findings_Periodontal Consid.	4	4	100.0%	4	100.0%
IntraOral Findings_Bolton Assess.	5	5	100.0%	5	100.0%
Esthetic Assessment of Dentition	2	2	100.0%	2	100.0%
Occlusion	12	12	100.0%	12	100.0%
Perimeter Assessment	5	3	60.0%	3	60.0%
Diagnostic Imaging	3	3	100.0%	3	100.0%
Cephalometrics_Soft Tissue	4	4	100.0%	4	100.0%
Cephalometrics_Skeletal	18	18	100.0%	18	100.0%
Proposed Treatment	4	3	75.0%	4	100.0%
	82	77	93.9%	79	96.3%

SUBJECTIVE / OBJECTIVE		N1		N3	
SUBGROUPS	Parameters per Group	# of Matching Parameters	% of Subgroup	# of Matching Parameters	% of Subgroup
Objective	30	30	100.0%	30	100.0%
Subjective	52	47	90.4%	49	94.2%
	82	77	93.9%	79	96.3%

SUMMARY USER PERFORMANCE RECORD
APPENDIX H - Table H1
Summary of Matching Parameters by Novice User and Case
- Initial Case Analyses -

Group - CONCEPT		CASE #6				CASE #7			
		N2		N4		N2		N4	
SUBGROUPS	Parameters per Group	# of Matching Parameters	% of Subgroup	# of Matching Parameters	% of Subgroup	# of Matching Parameters	% of Subgroup	# of Matching Parameters	% of Subgroup
Demographics / Personal Info.	3	3	100.0%	3	100.0%	3	100.0%	3	100.0%
Patient History	8	6	75.0%	7	87.5%	3	37.5%	6	75.0%
Clinical Assessment	23	18	78.3%	16	69.6%	18	78.3%	16	69.6%
Model Analysis	19	16	84.2%	17	89.5%	17	89.5%	16	84.2%
Diagnostic Imaging	25	22	88.0%	23	92.0%	24	96.0%	22	88.0%
Proposed Treatment	4	3	75.0%	3	75.0%	1	25.0%	1	25.0%
	82	68	82.9%	69	84.1%	66	80.5%	64	78.0%

Group - CATEGORY		CASE #6				CASE #7			
		N2		N4		N2		N4	
SUBGROUPS	Parameters per Group	# of Matching Parameters	% of Subgroup	# of Matching Parameters	% of Subgroup	# of Matching Parameters	% of Subgroup	# of Matching Parameters	% of Subgroup
General Information	11	9	81.8%	10	90.9%	6	54.5%	9	81.8%
Extra-Oral Findings	14	10	71.4%	8	57.1%	10	71.4%	9	64.3%
Intra-Oral Findings	28	24	85.7%	25	89.3%	25	89.3%	23	82.1%
Diagnostic Imaging	3	2	66.7%	3	100.0%	2	66.7%	2	66.7%
Cephalometrics	22	20	90.9%	20	90.9%	22	100.0%	20	90.9%
Proposed Treatment	4	3	75.0%	3	75.0%	1	25.0%	1	25.0%
	82	68	82.9%	69	84.1%	66	80.5%	64	78.0%

Group - CLUSTER		CASE #6				CASE #7			
		N2		N4		N2		N4	
SUBGROUPS	Parameters per Group	# of Matching Parameters	% of Subgroup	# of Matching Parameters	% of Subgroup	# of Matching Parameters	% of Subgroup	# of Matching Parameters	% of Subgroup
Demographics / Personal Info.	3	3	100.0%	3	100.0%	3	100.0%	3	100.0%
Medical Health Information	5	4	80.0%	4	80.0%	1	20.0%	3	60.0%
Patient Objectives	3	2	66.7%	3	100.0%	2	66.7%	3	100.0%
ExtraOral Findings_Clinical Assess.	12	8	66.7%	6	50.0%	8	66.7%	7	58.3%
Temporomandibular Joint	2	2	100.0%	2	100.0%	2	100.0%	2	100.0%
IntraOral Findings_Perio. Consid.	4	4	100.0%	4	100.0%	4	100.0%	4	100.0%
IntraOral Findings_Bolton Assess.	5	5	100.0%	4	80.0%	5	100.0%	5	100.0%
Esthetic Assessment of Dent.	2	2	100.0%	2	100.0%	2	100.0%	2	100.0%
Occlusion	12	10	83.3%	12	100.0%	12	100.0%	10	83.3%
Perimeter Assessment	5	3	60.0%	3	60.0%	2	40.0%	2	40.0%
Diagnostic Imaging	3	2	66.7%	3	100.0%	2	66.7%	2	66.7%
Cephalometrics_Soft Tissue	4	4	100.0%	4	100.0%	4	100.0%	2	50.0%
Cephalometrics_Skeletal	18	16	88.9%	16	88.9%	18	100.0%	18	100.0%
Proposed Treatment	4	3	75.0%	3	75.0%	1	25.0%	1	25.0%
	82	68	82.9%	69	84.1%	66	80.5%	64	78.0%

SUBJECTIVE / OBJECTIVE		CASE #6				CASE #7			
		N2		N4		N2		N4	
SUBGROUPS	Parameters per Group	# of Matching Parameters	% of Subgroup	# of Matching Parameters	% of Subgroup	# of Matching Parameters	% of Subgroup	# of Matching Parameters	% of Subgroup
Objective	30	30	100.0%	28	93.3%	30	100.0%	27	90.0%
Subjective	52	38	73.1%	41	78.8%	36	69.2%	37	71.2%
	82	68	82.9%	69	84.1%	66	80.5%	64	78.0%

SUMMARY USER PERFORMANCE RECORD
APPENDIX H - Table H1
Summary of Matching Parameters by Novice User and Case
- Initial Case Analyses -

Group - CONCEPT		CASE #8				CASE #9			
		N2		N4		N2		N4	
SUBGROUPS	Parameters per Group	# of Matching Parameters	% of Subgroup	# of Matching Parameters	% of Subgroup	# of Matching Parameters	% of Subgrou	# of Matching Parameters	% of Subgroup
Demographics / Personal Info.	3	3	100.0%	3	100.0%	3	100.0%	3	100.0%
Patient History	8	7	87.5%	8	100.0%	6	75.0%	4	50.0%
Clinical Assessment	23	20	87.0%	18	78.3%	19	82.6%	16	69.6%
Model Analysis	19	15	78.9%	18	94.7%	14	73.7%	19	100.0%
Diagnostic Imaging	25	24	96.0%	25	100.0%	23	92.0%	24	96.0%
Proposed Treatment	4	4	100.0%	4	100.0%	1	25.0%	4	100.0%
	82	73	89.0%	76	92.7%	66	80.5%	70	85.4%

Group - CATEGORY		N2		N4		N2		N4	
SUBGROUPS	Parameters per Group	# of Matching Parameters	% of Subgroup	# of Matching Parameters	% of Subgroup	# of Matching Parameters	% of Subgrou	# of Matching Parameters	% of Subgroup
General Information	11	10	90.9%	11	100.0%	9	81.8%	7	63.6%
Extra-Oral Findings	14	12	85.7%	11	78.6%	11	78.6%	8	57.1%
Intra-Oral Findings	28	23	82.1%	25	89.3%	22	78.6%	27	96.4%
Diagnostic Imaging	3	3	100.0%	3	100.0%	2	66.7%	3	100.0%
Cephalometrics	22	21	95.5%	22	100.0%	21	95.5%	21	95.5%
Proposed Treatment	4	4	100.0%	4	100.0%	1	25.0%	4	100.0%
	82	73	89.0%	76	92.7%	66	80.5%	70	85.4%

Group - CLUSTER		N2		N4		N2		N4	
SUBGROUPS	Parameters per Group	# of Matching Parameters	% of Subgroup	# of Matching Parameters	% of Subgroup	# of Matching Parameters	% of Subgrou	# of Matching Parameters	% of Subgroup
Demographics / Personal Info.	3	3	100.0%	3	100.0%	3	100.0%	3	100.0%
Medical Health Information	5	5	100.0%	5	100.0%	3	60.0%	3	60.0%
Patient Objectives	3	2	66.7%	3	100.0%	3	100.0%	1	33.3%
ExtraOral Findings_Clinical Assess.	12	10	83.3%	9	75.0%	9	75.0%	6	50.0%
Temporomandibular Joint	2	2	100.0%	2	100.0%	2	100.0%	2	100.0%
IntraOral Findings_Perio. Consid.	4	4	100.0%	3	75.0%	4	100.0%	4	100.0%
IntraOral Findings_Bolton Assess.	5	4	80.0%	5	100.0%	5	100.0%	5	100.0%
Esthetic Assessment of Dent.	2	2	100.0%	2	100.0%	1	50.0%	1	50.0%
Occlusion	12	8	66.7%	10	83.3%	9	75.0%	12	100.0%
Perimeter Assessment	5	5	100.0%	5	100.0%	3	60.0%	5	100.0%
Diagnostic Imaging	3	3	100.0%	3	100.0%	2	66.7%	3	100.0%
Cephalometrics_Soft Tissue	4	3	75.0%	4	100.0%	4	100.0%	3	75.0%
Cephalometrics_Skeletal	18	18	100.0%	18	100.0%	17	94.4%	18	100.0%
Proposed Treatment	4	4	100.0%	4	100.0%	1	25.0%	4	100.0%
	82	73	89.0%	76	92.7%	66	80.5%	70	85.4%

SUBJECTIVE / OBJECTIVE		N2		N4		N2		N4	
SUBGROUPS	Parameters per Group	# of Matching Parameters	% of Subgroup	# of Matching Parameters	% of Subgroup	# of Matching Parameters	% of Subgrou	# of Matching Parameters	% of Subgroup
Objective	30	28	93.3%	29	96.7%	29	96.7%	29	96.7%
Subjective	52	45	86.5%	47	90.4%	37	71.2%	41	78.8%
	82	73	89.0%	76	92.7%	66	80.5%	70	85.4%

SUMMARY USER PERFORMANCE RECORD
APPENDIX H - Table H1
Summary of Matching Parameters by Novice User and Case
- Initial Case Analyses -

CASE #10

Group - CONCEPT		N2		N4	
SUBGROUPS	Parameters per Group	# of Matching Parameters	% of Subgroup	# of Matching Parameters	% of Subgroup
Demographics / Personal Info.	3	3	100.0%	3	100.0%
Patient History	8	5	62.5%	7	87.5%
Clinical Assessment	23	19	82.6%	18	78.3%
Model Analysis	19	15	78.9%	17	89.5%
Diagnostic Imaging	25	25	100.0%	24	96.0%
Proposed Treatment	4	4	100.0%	4	100.0%
	82	71	86.6%	73	89.0%

Group - CATEGORY		N2		N4	
SUBGROUPS	Parameters per Group	# of Matching Parameters	% of Subgroup	# of Matching Parameters	% of Subgroup
General Information	11	8	72.7%	10	90.9%
Extra-Oral Findings	14	11	78.6%	9	64.3%
Intra-Oral Findings	28	23	82.1%	26	92.9%
Diagnostic Imaging	3	3	100.0%	2	66.7%
Cephalometrics	22	22	100.0%	22	100.0%
Proposed Treatment	4	4	100.0%	4	100.0%
	82	71	86.6%	73	89.0%

Group - CLUSTER		N2		N4	
SUBGROUPS	Parameters per Group	# of Matching Parameters	% of Subgroup	# of Matching Parameters	% of Subgroup
Demographics / Personal Info.	3	3	100.0%	3	100.0%
Medical Health Information	5	4	80.0%	5	100.0%
Patient Objectives	3	1	33.3%	2	66.7%
ExtraOral Findings_Clinical Assess.	12	9	75.0%	7	58.3%
Temporomandibular Joint	2	2	100.0%	2	100.0%
IntraOral Findings_Perio. Consid.	4	3	75.0%	2	50.0%
IntraOral Findings_Bolton Assess.	5	4	80.0%	5	100.0%
Esthetic Assessment of Dent.	2	2	100.0%	2	100.0%
Occlusion	12	10	83.3%	11	91.7%
Perimeter Assessment	5	4	80.0%	5	100.0%
Diagnostic Imaging	3	3	100.0%	3	100.0%
Cephalometrics_Soft Tissue	4	4	100.0%	4	100.0%
Cephalometrics_Skeletal	18	18	100.0%	18	100.0%
Proposed Treatment	4	4	100.0%	4	100.0%
	82	71	86.6%	73	89.0%

SUBJECTIVE / OBJECTIVE		N2		N4	
SUBGROUPS	Parameters per Group	# of Matching Parameters	% of Subgroup	# of Matching Parameters	% of Subgroup
Objective	30	30	100.0%	29	96.7%
Subjective	52	41	78.8%	44	84.6%
	82	71	86.6%	73	89.0%

APPENDIX I User Performance Data -Sensitivity Analysis

List of Figures

APPENDIX I - TABLE I1
CHANGES IN NOVICE PERFORMANCE RATINGS FOR INITIAL CASE ANALYSIS
WITH 3 LEVELS OF ACCEPTABILITY >75% - >80% - >85%

Group A - Cases #1 - # 5

Group - CONCEPT

SUBGROUPS	Parameters per Group	N1 A >75%	N1 B >80%	N1 C >85%	N1 Change (B-A)	N1 Change (C-A)	N3 A >75%	N3 B >80%	N3 C >85%	N3 Change (B-A)	N3 Change (C-A)
Demographics / Personal Info.	3	5	5	5	0	0	5	5	5	0	0
Patient History	8	2	2	2	0	0	3	3	3	0	0
Clinical Assessment	23	5	3	2	-2	-3	3	3	3	0	0
Model Analysis	19	5	5	4	0	-1	5	5	5	0	0
Diagnostic Imaging	25	5	5	5	0	0	5	5	5	0	0
Proposed Treatment	4	1	1	1	0	0	4	4	4	0	0
	82										

Group - CATEGORY

SUBGROUPS	Parameters per Group	N1 A >75%	N1 B >80%	N1 C >85%	N1 Change (B-A)	N1 Change (C-A)	N3 A >75%	N3 B >80%	N3 C >85%	N3 Change (B-A)	N3 Change (C-A)
General Info.	11	3	3	2	0	-1	5	5	3	0	-2
Extra-Oral Findings	14	3	3	3	0	0	3	3	3	0	0
Intra-Oral Findings	28	5	5	5	0	0	5	5	4	0	-1
Diagnostic Imaging	3	3	3	3	0	0	4	4	4	0	0
Cephalometrics	22	5	5	5	0	0	5	5	5	0	0
Proposed Treatment	4	1	1	1	0	0	4	4	4	0	0
	82										

Group - CLUSTER

SUBGROUPS	Parameters per Group	N1 A >75%	N1 B >80%	N1 C >85%	N1 Change (B-A)	N1 Change (C-A)	N3 A >75%	N3 B >80%	N3 C >85%	N3 Change (B-A)	N3 Change (C-A)
Demographics / Personal Info.	3	5	5	5	0	0	5	5	5	0	0
Medical Health Information	5	3	0	0	-3	-3	3	1	1	-2	-2
Patient Objectives	3	4	5	4	1	0	5	5	5	0	0
ExtraOral Findings_Clinical Assess	12	3	3	1	0	-2	3	3	1	0	-2
Temporomandibular Joint	2	5	5	5	0	0	5	5	5	0	0
IntraOral Findings_Perio. Consid.	4	5	5	5	0	0	5	5	5	0	0
IntraOral Findings_Bolton Assess.	5	5	5	5	0	0	5	5	5	0	0
Esthetic Assessment of Dentition	2	5	5	5	0	0	4	4	4	0	0
Occlusion	12	4	4	3	0	-1	4	4	3	0	-1
Perimeter Assessment	5	3	1	0	-2	-3	4	2	2	-2	-2
Diagnostic Imaging	3	3	3	3	0	0	4	4	4	0	0
Cephalometrics_Soft Tissue	4	5	5	5	0	0	5	5	5	0	0
Cephalometrics_Skeletal	18	5	5	5	0	0	5	5	5	0	0
Proposed Treatment	4	1	1	1	0	0	4	4	4	0	0
	82										

SUBJECTIVE / OBJECTIVE

SUBGROUPS	Parameters per Group	N1 A >75%	N1 B >80%	N1 C >85%	N1 Change (B-A)	N1 Change (C-A)	N3 A >75%	N3 B >80%	N3 C >85%	N3 Change (B-A)	N3 Change (C-A)
Objective	30	5	5	5	0	0	4	4	4	0	0
Subjective	52	4	3	2	-1	-2	5	4	2	-1	-3
	82										

APPENDIX I - TABLE I1
CHANGES IN NOVICE PERFORMANCE RATINGS FOR INITIAL CASE ANALYSIS
WITH 3 LEVELS OF ACCEPTABILITY >75% - >80% - >85%

Group B - Cases #6 - #10

Group - CONCEPT

SUBGROUPS	Parameters per Group	N2 A >75%	N2 B >80%	N2 C >85%	N2 Change (B-A)	N2 Change (C-A)	N4 A >75%	N4 B >80%	N4 C >85%	N4 Change (B-A)	N4 Change (C-A)
Demographics / Personal Info.	3	5	5	5	0	0	5	5	5	0	0
Patient History	8	1	1	1	0	0	3	1	3	-2	0
Clinical Assessment	23	5	3	1	-2	-4	2	0	0	-2	-2
Model Analysis	19	4	2	1	-2	-3	5	5	4	0	-1
Diagnostic Imaging	25	5	5	5	0	0	5	5	5	0	0
Proposed Treatment	4	2	2	2	0	0	3	3	3	0	0
	82										

Group - CATEGORY

SUBGROUPS	Parameters per Group	N2 A >75%	N2 B >80%	N2 C >85%	N2 Change (B-A)	N2 Change (C-A)	N4 A >75%	N4 B >80%	N4 C >85%	N4 Change (B-A)	N4 Change (C-A)
General Info.	11	3	3	1	0	-2	4	4	3	0	-1
Extra-Oral Findings	14	3	1	1	-2	-2	1	0	0	-1	-1
Intra-Oral Findings	28	5	4	3	-1	-2	5	5	4	0	-1
Diagnostic Imaging	3	2	2	2	0	0	3	3	3	0	0
Cephalometrics	22	5	5	5	0	0	5	5	5	0	0
Proposed Treatment	4	2	2	2	0	0	3	3	3	0	0
	82										

Group - CLUSTER

SUBGROUPS	Parameters per Group	N2 A >75%	N2 B >80%	N2 C >85%	N2 Change (B-A)	N2 Change (C-A)	N4 A >75%	N4 B >80%	N4 C >85%	N4 Change (B-A)	N4 Change (C-A)
Demographics / Personal Info.	3	5	5	5	0	0	5	5	5	0	0
Medical Health Information	5	3	1	1	-2	-2	3	2	2	-1	-1
Patient Objectives	3	1	2	1	1	0	3	3	3	0	0
ExtraOral Findings_Clinical Assess	12	1	2	0	1	-1	0	0	0	0	0
Temporomandibular Joint	2	5	5	5	0	0	5	5	5	0	0
IntraOral Findings_Perio. Consid.	4	4	4	4	0	0	3	3	3	0	0
IntraOral Findings_Bolton Assess.	5	5	3	3	-2	-2	5	4	4	-1	-1
Esthetic Assessment of Dentition	2	4	4	4	0	0	4	4	4	0	0
Occlusion	12	3	4	1	1	-2	5	5	3	0	-2
Perimeter Assessment	5	2	1	1	-1	-1	3	3	3	0	0
Diagnostic Imaging	3	2	2	2	0	0	4	4	4	0	0
Cephalometrics_Soft Tissue	4	4	4	4	0	0	3	3	3	0	0
Cephalometrics_Skeletal	18	5	5	5	0	0	5	5	5	0	0
Proposed Treatment	4	2	2	2	0	0	3	3	3	0	0
	82										

SUBJECTIVE / OBJECTIVE

SUBGROUPS	Parameters per Group	N2 A >75%	N2 B >80%	N2 C >85%	N2 Change (B-A)	N2 Change (C-A)	N4 A >75%	N4 B >80%	N4 C >85%	N4 Change (B-A)	N4 Change (C-A)
Objective	30	5	5	5	0	0	5	5	5	0	0
Subjective	52	2	1	1	-1	-1	4	2	1	-2	-3
	82										

APPENDIX J User Feedback

List of Figures

APPENDIX J - User Feedback

The objective of the "before-use" and "after-use" feedback forms , designed for administration to the novice orthodontists, was to look, very generally, at evaluation of the ORTHO1 decision support program. The feedback forms have been used to help determine, via feedback from the users, if the program met the objectives of the project. The objectives of the project were as follows:

- to identify areas within the diagnosis and treatment planning process where novice orthodontist's decisions vary significantly from a group of experts,
- to categorize and analyze areas identified within the novice orthodontist's decision making process that differ from the experts, and
- to provide structured feedback related to the identified variations in decision making between the group of experts and the novice orthodontist.

The "Before-Use" questionnaire was designed to find out:

- About the individual's computer background.
- If the individual knows anything about computer based decision support.
- What the individual thinks about the concept of computer based decision support.
- About the individual's protocol for case analysis in diagnosis and treatment planning.

The "After-Use" questionnaire was designed to find out:

- What the user's impressions of the computer based decision support system which has been developed.
- If the user's feels that the objectives of the computer system were met.
- If the user's has any suggestions for improvement of the computer system
- If the user's thinks the system prototype might be useful in his/her diagnosis and treatment planning process.

<u>Administration of Questionnaires</u>

1. The concept of computer supported decision making was outlined.
2. The "Before-Use" feedback form was administered.
3. The objectives of the computer program were explained.
4. The workings of the decision support computer program were explained.
5. The novice orthodontist used the program.
6. The "After-Use" feedback form was administered.

APPENDIX J - Figure J2

NOVICE ORTHODONTIST FEEDBACK FORM

"BEFORE - USE"

1. Do you have any formal computer training?
   Please elaborate

2. Are you consider a frequent user of a computer?
   yes
   no
   If yes, please list the types of computer applications you use.

3. When diagnosing and treatment planning an orthodontic case, what is the process you use for case analysis?
   Please outline the stages of your diagnosis and treatment planning process.

4. Do you use any computer applications when diagnosing and treatment planning?
   yes
   no
   If yes, please specify.
   If no, are you considering using computer applications to assist you in diagnosis and treatment planning?

5. Are you familiar with computer supported decision making?
   yes
   no
   If yes, please elaborate
   If no, what do you think of the concept of computer assisted decision making?

APPENDIX J - Figure J3

NOVICE ORTHODONTIST FEEDBACK FORM

"AFTER - USE"

1. Has the computer system affected your diagnosis and treatment planning process?

   Please elaborate

2. Do you think the objectives of the project have been met?

   yes
   no
   Please elaborate

3. Do you think that a computer system similar to the one developed for this project would

   be useful in your diagnosis and treatment planning process?

   yes
   no
   Please elaborate

4. Do you have any comment about the computer system system?

   yes
   no
   Please elaborate

APPENDIX K Stead's System Development and Evaluation

List of Figures

APPENDIX K - Table K1 Relationship of System Development Stage to Level of Evaluation

	EVALUATION / SYSTEM DEVELOPMENT	I. DEFINITION	II. LABORATORY	III. LABORATORY	IV. REMOTE FIELD	V. FIELD
			Bench	Field	Validity	Efficacy
A	SPECIFICATION	→	↓			
B	COMPONENT DEVELOPMENT		↓			
C	COMBINATION OF COMPONENTS INTO A SYSTEM		↓→	↓→	↓	
D	INTEGRATION OF SYSTEM INTO ENVIRONMENT		→	↓→	↓→	↓
E	ROUTINE USE			→	→	→

Rows = stages of system development
Columns = levels of evaluation
Note:

- an arrow in a column indicates that the level of evaluation indicated by the column heading is appropriate for the stage of development represented by the row.
- a horizontal arrow indicates that it is appropriate to proceed to the next level of evaluation while the system development stage is unchanged.
- a vertical arrow indicates that it is appropriate to proceed to the next stage of development without changing evaluation level.
- a double arrow indicates that it is appropriate to proceed to either the next stage of development or the next stage of evaluation.

From:

Stead, W.W., Haynes, R.B., Fuller, S., Travis, L.E., Beck, J.R., Fenichel, C.H. et al. Designing Medical Informatics Library and Research Projects to Increase What is Learned. Vanderbilt University, 1993 (unpublished).