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TELEMEDICINE SYSTEM FOR EARLY ASSESSMENT OF OBSTRUCTIVE SLEEP APNEA

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ABSTRACT
This paper describes a telemedicine system for early assessment of obstructive sleep apnea (OSA) based on clinical prediction rules and simple tests, such as nocturnal pulse oximetry. The Web-based system provides support for general practitioners working in remote rural areas with limited access to in-clinic overnight polysomnography tests (PSGs) and specialized sleep disorders clinics. The system has three major functions: (1) collecting patient data and test results, (2) supporting the analysis of OSA risk factors to expedite diagnosis and treatment for the serious cases and to limit unnecessary tests for low-probability cases, and (3) preparing patient referrals to sleep disorders clinic and communicating with sleep specialists. The telemedicine system consists of four modules: (1) a Web-based interface for general health practitioners and sleep specialists, (2) a database with data acquisition, storage, and retrieval, (3) an adaptive decision support subsystem based on a rule-based reasoning approach, and (4) rule learning subsystems using data mining techniques for refinement of the clinical decision rules.

KEY WORDS
Underserviced communities and demand for telehealth, decision support systems, diagnostics, sleep medicine, obstructive sleep apnea, clinical decision rules

1. Introduction

Obstructive sleep apnea (OSA) is a common, serious respiratory disorder afflicting approximately 2-4% of the general population [1,2]. OSA is caused by collapse of the soft tissues in the throat as the result of the natural relaxation of the muscles during sleep. The sleeping person literally stops breathing ("apnea" means "without breath"). Since sleep apnea occurs only during sleep, it might go unnoticed for years. OSA is associated with hypertension, congestive heart failure, stroke, and coronary artery disease. Moreover, sleep deprivation caused by OSA may lead to motor vehicle accidents, job related injures, and, in general, a decreased quality of life [3,4]. The golden standard in diagnosis of OSA is an overnight in-laboratory polysomnography (PSG) involving continuous recording of EEG, ECG, EOG, EMG, airflow, breathing effort, and oxygen saturation. However, this is an expensive, labour-intensive, and not readily available test performed only in dedicated clinics. British Columbia has only five sleep clinics located in the major cities. A large segment of the population, especially from the rural areas, is not diagnosed because of the time factors, extensive travel required, and limited access to the overnight in-clinic diagnosis. Furthermore, many patients are waiting for 6-12 months for the PSG study required to initiate the treatment. However, an early treatment, especially for more severe OSA cases, significantly improves daytime sleepiness and the overall quality of life [5]. Therefore, a telemedicine system using a combination of predictive rules and simple home studies [6] will allow for prioritization for PSG testing, and, in some cases, an early treatment before formal diagnosis by PSG. The proposed system will be used for the initial evaluation of risk factors among patients complaining or suspected of having sleep disorders. It will support the diagnostic process in the remote rural locations, but, at the same time, it will not replace the proper diagnostic procedure.

This paper focuses on the overall framework of a Web-based system for early OSA assessment. Section 2 discusses the applications of the clinical prediction rules. Section 3 describes the use of overnight pulse oximetry tests and the inference system combining the predictive rules and oximetry results. Section 4 provides a brief overview of adaptive techniques for the clinical rules refinement. Section 5 provides the telemedicine system architecture. The last section describes the conclusions and future work.

2. Assessment of Apnea Using Clinical Prediction Rules

2.1 Initial Assessment

The typical complaints of OSA patients are excessive daytime sleepiness, fatigue, and snoring [7]. Typically, complaining patients are assessed by their family doctors based on several risk factors such as sleepiness, snoring, high blood pressure, high body mass index, witnessed breathing pauses, morning headaches, smoking, age, and gender. In our telemedicine system, the patient's data is entered into the system and is used by the rule-based decision support system.

2.2 Prediction Rules and Predictors

The clinical prediction rules are used by medical practitioners to expedite the diagnostic process and initiate early treatment. The rules are based on a limited number of factors (predictors) from medical history, physical examination, and tests. A predictor is an established or suspected symptom, sign, correlate, or co-morbid condition. Our rule-based reasoning system prototype, Hypnos, stores 14 predictors divided into six categories: (1) anatomical signs: obesity measured by body mass index (BMI) in kg/m2, large neck size, and craniofacial and upper airway abnormalities, (2) nocturnal symptoms: snoring, breathing pauses, and choking, (3) diurnal symptoms: excessive daytime sleepiness, (4) demographic factors: gender, age, and familial aggregation, (5) coexisting medical conditions: hypertension and coronary artery disease; and (6) lifestyle factors: smoking and alcohol use [8,9,10].

We define a clinical prediction rule (CPR) as an IF-THEN statement, a certainty factor, and usability. Hence, we define CPR as a triplet: < RS, CF, U >, where the rule statement, RS, represents the rule's syntax, the rule certainty factor, CF, is a part of the rule's semantics, and the usability, U, determines the rule's pragmatic value (rule validity and clinical usability).
For example, a diagnostic rule for a high-risk group: older male patients with morbid obesity (BMI > 40) is defined as follows: IF BMI>40 AND age>65 AND gender=male THEN OSA=yes (CF=0.9).

3. Assessment of Apnea using Overnight Pulse Oximetry

Pulse oximetry is a simple non-invasive method of monitoring the percentage of haemoglobin (Hb) which is saturated with oxygen. Repetitive drops in the blood oxygen saturation during sleep imply breathing obstruction. Numerous studies have explored the efficacy of pulse-oximetry for sleep disorder assessment [11,12]. The specificity and sensitivity of overnight oximetry has been studied with varying results [13]. The study by Ryan et al. [14] concluded that pulse oximetry criteria have a 100% specificity, but in patients with hypopneic episodes with little desaturation sensitivity is only 31%. Therefore, oximetry alone should not be used in identifying the absence of OSA and the patients with negative pulse oximetry results should undergo further investigation.

The oximetry results are analysed using three measures: (1) the commonly used Desaturation Index (DI) – a number of 4% saturation drops per hour of measurement, (2) the percentage of saturation below 90%, and (3) the minimum overnight oxygen level.

Nocturnal oximetry is easy to use and inexpensive; however, it is not sufficiently reliable. Therefore, we suggest a combination of the oximetry result and clinical predictors, based on patient's data (e.g. age, BMI, hypertension, and gender). Figure 1 illustrates a rule-based inference system calculating the overall risk of OSA, P_{os}, from a set of predictor values and oximetry measures: desaturation index (DI) and time below 90% (T below 90%).

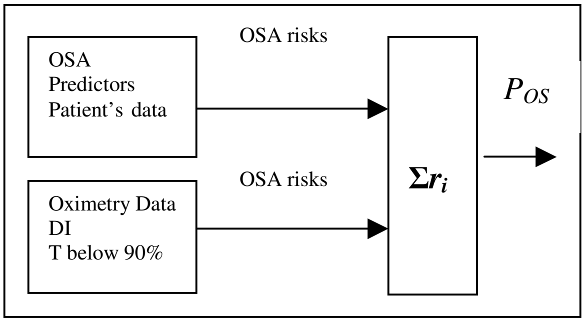


Fig. 1 Inference System for OSA Risk Evaluation

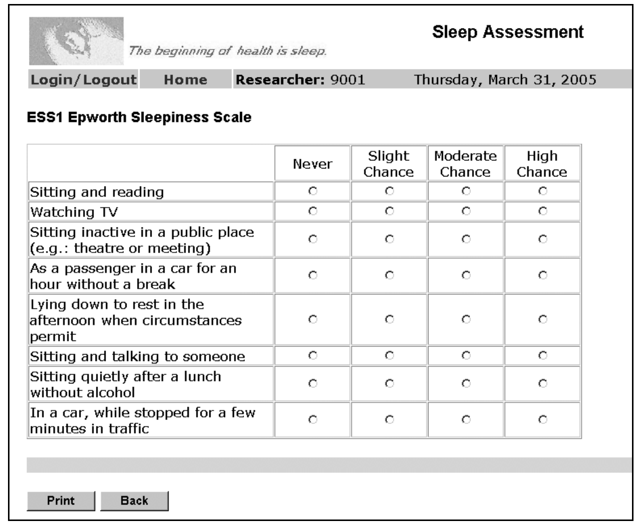
4. Adaptive Techniques for the Adjustment of the Clinical Prediction Rules

The system incorporates a rule refinement mechanism allowing (1) interactive modification of rules by the health practitioners and (2) automated augmentation of the rules based on the data mining techniques.

4.1 Interactive Modification of the Predictive Rule

Daytime sleepiness is a well-described symptom of sleep disorders; excessive daytime sleepiness (EDS) is the most important indicator of sleep deprivation and sleep disorders requiring further clinical evaluations. The Epworth Sleepiness Scale (ESS) [15] is the most often used self-administered questionnaire to measure excessive daytime sleepiness in eight everyday situations: 1) sitting and reading, 2) watching TV, 3) sitting inactive in public place (e.g. a theatre or a meeting, 4) as a passenger in a car for an hour without a break, 5) lying down to rest in the afternoon when circumstances permit, 6) sitting and talking to someone, 7) sitting quietly after lunch without alcohol, and 8) in a car, while stopped for a few minutes in traffic. Each item has a score between 0-3. The answers are 'never', 'slight chance', 'moderate chance', and 'high chance.' The maximum score is 24. Typically the score of 11 and above is recognized as excessive daytime sleepiness (EDS).

Figure 2 illustrates the Web interface for the standard Epworth Sleepiness Scale.



	Never	Slight Chance	Moderate Chance	High Chance
Sitting and reading	○	○	○	○
Watching TV	○	○	○	○
Sitting inactive in a public place (e.g.: theatre or meeting)	○	○	○	○
As a passenger in a car for an hour without a break	○	○	○	○
Lying down to rest in the afternoon when circumstances permit	○	○	○	○
Sitting and talking to someone	○	○	○	○
Sitting quietly after a lunch without alcohol	○	○	○	○
In a car, while stopped for a few minutes in traffic	○	○	○	○

Fig. 2 Web-based Interface for the Epworth Sleepiness Scale

Several studies [16,17,18,19] demonstrate that the ESS results might be considerably biased by gender, medical condition (depression), and occupation (truck drivers or police officers). The Multicenter Sleep Heart Health Study evaluated 6,440 participants (52% women) and reported that ESS is more likely to identify sleepiness among men than women [16]. Women tend to underreport their daytime sleepiness and, instead, report tiredness. The study of depressed patients [17] reported that the subjects overestimate their sleepiness. The study [19] of Italian police officers shows that they significantly underreport their sleepiness and that the threshold for ESD should be lowered to score above 9.

Therefore, the rule refinement subsystems provide an interactive mode for specific adjustments and modifications of the rules to reflect specificity of the subpopulations and the individual patients.

4.2 Automated Augmentation of Predictive Rules

The decision support system uses an initial set of rules derived, validated, and evaluated in sleep disorder clinics and approved by sleep specialists. However, the accuracy of clinical rules varies with different populations of patients. Therefore, our system provides a continuous re-evaluation of the initial set using the new data stored in the patients' database. The inference system has two types of refinement mechanisms: generalization and specialization. The generalization mechanism re-evaluates general clinical rules on incrementally growing data sets using statistical methods and traditional data mining techniques. The specialization mechanism uses a semio-fuzzy approach based on a combination of fuzzy logic and contextual adjustments of rules. For example, the clinical rules using general predictors, such as daytime sleepiness or depression, must be adjusted for the members of Northern British Columbia communities at risk of seasonal affective disorder (SAD) or shift workers suffering from circadian rhythm disorder.

5. Telemedicine System Architecture

The proposed telemedicine system for early assessment of OSA will provide remote medical services and consultations to all rural areas in British Columbia. The data will be collected at the patients' locations by regional health care providers and uploaded to a local computer. Since all areas in BC have fast Internet connection, the patient's data and test results will be sent to the central database server in Vancouver. The database will be accessed by the sleep specialists from the Respiratory Clinic at Vancouver General Hospital. The assessment results will be stored and appropriate messages will be sent back to the rural centers. Figure 3 illustrates the overall system architecture.

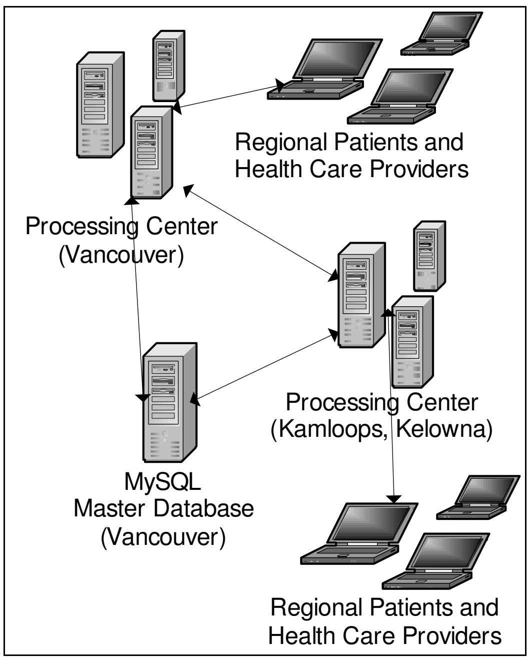


Fig. 3 Telemedicine System Architecture

The designed prototype uses open source software: Java Server Pages (JSP), JavaBeans, Apache Tomcat Web Server, and MySQL as an initial database system. This technology provides flexibility, low cost, and scalability. Figure 4 illustrates the connections between the technological components.

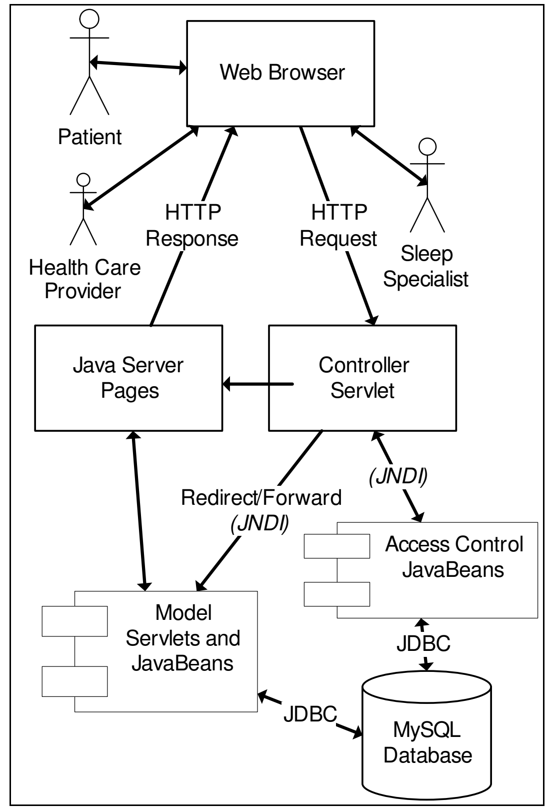


Fig. 4 Technological Components

6. Conclusions and Future Work

This paper presents the overall framework for the telemedicine system for the assessment of obstructive sleep apnea in a rural setting. The major purpose of the system is to provide earlier treatment for OSA sufferers and prioritize patients referred for PSG studies. The rule-based inference system provides support for the clinical diagnosis based on a combination of clinical predictors and home studies. Furthermore, the system incorporates a rule refinement mechanism allowing for (1) interactive modification of rules by the health practitioners and (2) automated augmentation of the rules based on the data mining techniques.

The authors are involved in the development of a first prototype of the telemedicine system for the Respiratory Clinic at Vancouver General Hospital. The prototype is scheduled for an initial clinical test in September 2005.
Although the current system is limited to risk factors specific to OSA, it can be expanded by additional predictors and rules for other sleep disorders, such as insomnia or circadian rhythm disorder. Furthermore, it can be used not only for assessment, but also for evaluation of treatment. Moreover, the rule-based decision support subsystem can be used in a different setting, for example in preoperative and postoperative care for screening of the undiagnosed OSA patients, who

may experience respiratory complications after receiving a general anaesthetic or opiate analgesia [20].

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