EPOCH® and *e*PRISM®: A Web-Based Translational Framework for Bridging Outcomes Research and Clinical Practice

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Abstract

In an era where novel clinical, biochemical, genetic and imaging determinants impacting patient outcomes are being continuously discovered, the field of outcomes research offers clinicians and patients the potential to make better informed health care decisions through the use of sophisticated risk-adjustment models that incorporate patients' unique clinical characteristics.

EPOCH® *and e*PRISM® *comprise a novel application suite for delivering complex risk-adjustment models to the bedside and are currently in use at multiple medical centers. An intuitive visual interface for building models allows outcomes researchers to rapidly translate prediction models into web-based decision support and reporting tools. A flexible XML web services architecture facilitates integration with existing clinical information systems, allows for remote access to the modeling engine, and allows models to be exported across systems via the Predictive Model Markup Language standard.*

1. Introduction

The past decade of health services research has witnessed an explosion of prognostic models to help physicians and patients better understand the prognosis associated with specific disease states as well as the risks and benefits of proposed treatments. However, the application of such models to clinical practice has been limited by their complexity and the lack of a practical mechanism for making them available at the bedside.

The emergence of the internet and mobile computing devices has created new opportunities for researchers to translate their evidenced-based predictive models into clinical decision aids. However, a number of barriers continue to prevent researchers from taking advantage of these technologies, including: (1) a requisite expertise in computer programming; (2) the challenge of creating a system that can adapt to a broad range of clinical practice settings and work-flow constraints; (3) the need to update predictive models in a timely fashion; and (4) the difficulty of integrating with existing IT infrastructures and disparate clinical information systems.

To help outcomes researchers overcome these obstacles, we developed EPOCH® and *e*PRISM®, which comprise an application suite designed to facilitate the rapid translation of evidenced-based predictive models into robust web-based tools that can deliver real-time decision support and patient-specific reporting services to a broad range of clinical environments. Herein, we provide a general overview of this system and its clinical applications. Additional information, including a live demonstration, is available at http://www.HealthOutcomesSciences.com.

2. System architecture and design

We used Microsoft®'s (MS) .NET® platform to create EPOCH®, a unified web portal and services application framework; and *e*PRISM®, a plug-in module for EPOCH® that encompasses all of the functionality necessary for deploying clinical risk models as decision-support tools or embedding them within document templates.

EPOCH® features a complete set of web-based management and content authoring tools that facilitate the rapid creation of web sites for delivering content and tools to physicians and patients, including a built-in WYSIWYG HTML editor and several pre-defined content modules. A role-based access control system, coupled with support for group membership, Forms and Windows® authentication, as well as multiple modes of user registration, offers authors and site administrators a broad range of options for creating and managing user accounts and controlling access to portal content.

EPOCH® utilizes MS Internet Information Services (IIS) and MS SQL Server for web services and data

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storage, respectively. A multi-tier system architecture offers the ability to scale each component as needed to meet the specific demands of a particular deployment. In addition, EPOCH®'s modular design and API facilitates the incorporation of new functionality through the creation of custom modules (*e.g.*, *e*PRISM®) and makes the system highly extensible.

A tightly integrated XML web services infrastructure allows for the management of web services and portal access through a single administrative interface, and provides a mechanism by which third-party developers and IT staff can gain easy access to Web Services Description Language (WSDL) contracts and other online documentation in order to rapidly develop web service clients.

EPOCH® makes full use of MS Code Access Security (CAS) model [1] to protect data and vital system resources from unauthorized access, blocking all read/write operations to the system registry, event log, and file system outside of the application root directory on the host server. Additional restrictions are placed on access to OLE data sources, Microsoft message queuing services, unmanaged code assemblies, and serviced components (COM+).

A managed code-based cryptography class provides those modules handling protected health information (PHI) with access to encryption algorithms implementing the Advanced Encryption Standard (AES), supporting 128-, 192-, and 256-bit ciphers. All cryptographic ciphers are dynamically generated from composite key values that are unique to each user and each EPOCH® deployment, substantially reducing the chances of PHI becoming vulnerable even if the underlying SQL data store is compromised. Additional security features include the encryption and hashing of all application query strings to prevent tampering, and the use of stored procedures in the SQL data access tier to mitigate the risk of SQL injection attacks.

2.1. *e*PRISM® model building interface

*e*PRISM® employs a general regression model framework for expressing predictions, encompassing all major types of prognostic models including linear, generalized linear, cumulative multinomial, generalized multinomial, proportional hazard and other custom model types. Full details of *e*PRISM®'s modeling framework have been presented elsewhere [2].

Briefly, models are defined in terms of a *coefficient vector* and an optional *covariance matrix* in a format consistent with the outputs of most major statistical packages [3]:

Coefficient vector: $\mathbf{b}' = \begin{pmatrix} \mathbf{b}'_{0\cdot} & \mathbf{b}'_{1\cdot} & \cdots & \mathbf{b}'_{r\cdot} \end{pmatrix}$

Covariance matrix:

$$\mathbf{V} = \mathrm{Var}(\mathbf{b}) = \begin{bmatrix} \mathbf{V}_{1\cdot1\cdot} & \mathbf{V}_{1\cdot2\cdot} & \cdots & \mathbf{V}_{1\cdot r\cdot} \\ \mathbf{V}_{2\cdot1\cdot} & \mathbf{V}_{2\cdot2\cdot} & \cdots & \mathbf{V}_{2\cdot r\cdot} \\ \vdots & \vdots & & \vdots \\ \mathbf{V}_{r\cdot1\cdot} & \mathbf{V}_{r\cdot2\cdot} & \cdots & \mathbf{V}_{r\cdot r\cdot} \end{bmatrix}$$

where

$$\mathbf{V}_{i\cdot j\cdot} = \mathrm{Cov}(\mathbf{b}_{i\cdot}, \mathbf{b}_{j\cdot}) = \begin{bmatrix} v_{i1j1} & v_{i1j2} & \cdots & v_{i1js} \\ v_{i2j1} & v_{i2j1} & \cdots & v_{i2js} \\ \vdots & \vdots & & \vdots \\ v_{isj1} & v_{isj2} & \cdots & v_{isjs} \end{bmatrix}$$

In the definitions above, $\mathbf{b}_i' = (b_{i1}\ b_{i2} \cdots b_{is})$ is the vector of coefficients associated with the i^{th} predictor, one coefficient for each state s; and $v_{ikjl} = \mathrm{Cov}(b_{ik}, b_{jl})$ denotes the covariance between the (i^{th} predictor, k^{th} state) and (j^{th} predictor, l^{th} state) coefficients.

The *Linear Predictor* is then calculated as

$$\hat{\boldsymbol{\eta}}' = \begin{pmatrix} \hat{\eta}_1 & \hat{\eta}_2 & \cdots & \hat{\eta}_s \end{pmatrix} = \begin{pmatrix} \mathbf{x}'(\mathbf{e}_1 \circ \mathbf{b}) & \mathbf{x}'(\mathbf{e}_2 \circ \mathbf{b}) & \cdots & \mathbf{x}'(\mathbf{e}_s \circ \mathbf{b}) \end{pmatrix}$$

where $\mathbf{x}'$ is the *predictor vector* comprised of patient specific data elements (*e.g.*, systolic blood pressure), and where each $\mathbf{e}_i$ is an extraction vector derived from the appropriate *Extraction Matrix* that identifies the relevant sub-vector of $\mathbf{b}$ and the sub-matrix of $\mathbf{V}$ needed to predict the i^{th} independent parameter of $\hat{\boldsymbol{\eta}}'$ [2].

The *Prediction Vector* containing the outcome point-estimate(s) is then given by

$$\hat{\boldsymbol{\mu}} = g^{-1}(\hat{\boldsymbol{\eta}})$$

where g^{-1} is the appropriate inverse link function [2]. The *Linear Predictor Variance Vector* is given by

$$\hat{\boldsymbol{\sigma}}'^2 = \begin{pmatrix} \mathbf{x}'(\mathbf{e}_1 \circ \mathbf{V})\mathbf{x} & \mathbf{x}'(\mathbf{e}_2 \circ \mathbf{V})\mathbf{x} & \cdots & \mathbf{x}'(\mathbf{e}_s \circ \mathbf{V})\mathbf{x} \end{pmatrix}$$

from which confidence intervals can be calculated as

$$(\hat{\mu}_{\mathrm{LO}}, \hat{\mu}_{\mathrm{HI}}) = g^{-1}\left(\hat{\eta} \pm F_v^{-1}(1-\alpha/2)\sqrt{\hat{\varphi}^2 + \hat{\sigma}^2}\right)$$

where F_v^{-1} is the inverse t-distribution function with v degrees of freedom at confidence level α and $\hat{\varphi}^2$ is the mean square error ($\hat{\varphi}^2$ is only defined for linear models).

Model building in *e*PRISM® centers around a visual editing environment that provides dynamic on-screen instructions and rendering of prediction formulae as well as robust validation services (Figure 1).

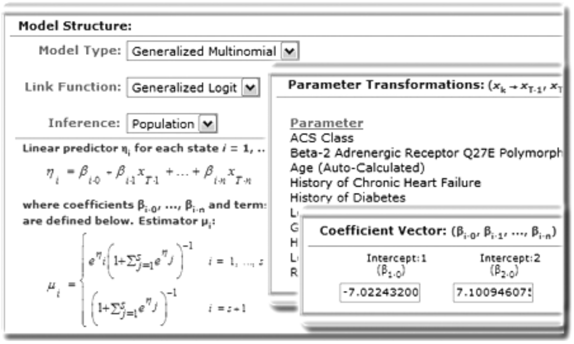

Figure 1. Composite screen shot of the model building interface, showing the on-screen rendering of a model.

The first steps in building a model involve specifying the general type and structure of the model *via* the *e*PRISM® visual designer. The parameters that serve as model inputs are then defined; these can be created *de novo* or selected from an existing parameter library, thereby allowing for standardization of parameter definitions across all models.

Once parameters have been defined, one or more data transformations can be assigned to each. A broad array of built-in transformation types are available, and custom transformation types can be readily defined allowing *e*PRISM® to handle a wide range of complex formulae.

The final steps in the model building process involve defining main effects and interaction terms derived from the parameters and their transformations, and providing regression coefficients for calculating point estimates for the outcome of interest and optional covariance estimates for computing confidence intervals. Once a model's definition has been validated and published, it is instantly available to all users *via* *e*PRISM®'s *Model Execution Interface* and *Web Services*.

Advanced features of the *Model Building Interface* include: (1) the ability to define parameter relationships for automatic value computations (*e.g.*, calculation of body surface area from height and weight); (2) the ability to map multiple models to a common outcome (*e.g.*, predicted survival with treatment A *versus* B) in order to allow for side-by-side comparisons of results; (3) a robust scripting engine that allows for the creation of custom data transformations, model structures, and rules such as imputation of missing data elements; and (4) a *Report Template Manager* featuring an MS Word®-like text editing environment that allows for the creation of highly structured document templates containing embedded modeling results (*e.g.*, an informed consent document that contains models projecting the risks and benefits of different treatments).

2.2. *e*PRISM® model execution interface

*e*PRISM®'s *Model Execution Interface* allows clinical users to browse model definitions and select individual models or groups of models for execution; alternatively, users can select one or more report templates (each containing a collection of one or more models) for concurrent execution.

The *Model Execution Interface* dynamically generates a data entry screen based on the parameters required by the selected model(s) or document templates(s). If a patient record has been selected, the data form is pre-populated with any stored values that are available for that patient, along with timestamps for each value (*see section 2.3*). All redundant data elements are automatically eliminated from the data entry form, and any derived parameter values (*e.g.*, body surface area) are automatically calculated.

Model outputs can be rendered in a variety of graphical and non-graphical formats, including solid bar plots, gradient bar plots, whisker line plots, pie charts, and digital LED-style displays (Figure 2). Output from multiple models can be grouped onto a single plot to facilitate inter-model comparisons (*e.g.*, stroke risk with angioplasty *versus* bypass surgery). In addition, the user can easily customize the output in terms of plot style, which models to include in the final output and the display of confidence intervals (if model covariance data has been provided). Finally, reports containing patient specific model-outputs can be readily printed or exported as Portable Document Format (PDF) files.

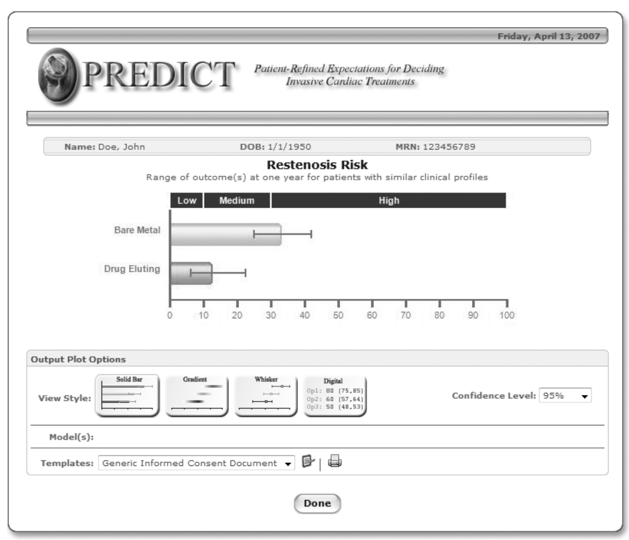

Figure 2. Screen shot of the output generated by the PREDICT™ Clinical Tool (created using *e*PRISM®).

2.3. *e*PRISM® web services

*e*PRISM® offers a number of integrated XML web services that expose many of its core modeling and data access functions to remote web clients through the industry standard Simple Object Access Protocol.

Data Integration Service: Offers a flexible mechanism for linking *e*PRISM® to existing clinical information systems, with single and bulk transactional support. A separate relay server application, *e*PRISM® Connect, provides a secure mechanism for transmitting patient data to *e*PRISM® installations from remote sites utilizing both message-level and transport-level encryption. When coupled with a third party HL7 gateway such as HL7Connect [4], *e*PRISM® Connect can accept incoming HL7-compliant feeds over a variety of transport layers including TCP/IP, HTTP, FTP, and email.

Library Publishing Service: Provides functions for publishing all models and supporting parameter definitions as Predictive Model Markup Language (PMML)-compliant documents. Exported definitions can be used in data mining applications that support the PMML standard or for collaborative sharing of model and parameter definitions across different *e*PRISM® installations.

Remote Modeling Service: Provides third-party developers easy access to *e*PRISM®'s modeling engine. Remote clients can request a list of models that are available for remote execution, as well as the complete collection of parameters needed to run those models. Patient data can then be anonymously submitted to the service for execution against a specified set of models, with results returned directly to the requesting client.

3. Clinical applications

EPOCH® and *e*PRISM® can be used to create powerful evidence-based tools that deliver decision support and patient-specific documentation services at the point-of-care. The visual model editing capabilities built into *e*PRISM® allow outcomes researchers to rapidly translate their work into clinical applications with minimal effort and without the need for programming skills or services. The ability to readily integrate *e*PRISM® with existing clinical information systems, coupled with a streamlined data collection mechanism that automatically eliminates redundant user inputs across groups of disparate models, facilitates the integration of *e*PRISM® into busy clinical environments and gives physicians and patients access to objective outcomes projections based on the most up-to-date body of evidence.

Studies of EPOCH® and *e*PRISM® in clinical use are currently ongoing at several sites. Decker and colleagues recently presented findings assessing the impact of using *e*PRISM® to deliver patient-specific informed consent documents containing validated multivariable risk models on a cohort of nearly 200 patients undergoing cardiac catheterization and/or angioplasty [5]. Risk models used in the documents came from a broad range of sources, including the Mid America Heart Institute of Kansas City, Missouri, the Blue Cross Blue Shield of Michigan Cardiovascular Consortium, and the Northern New England Cardiovascular Disease Study Group. Among the major findings of the study were improved patient comprehension of the procedures and their associated risks, decreased patient anxiety, and an enhanced sense of shared decision making and improved physician-patient communication. Future studies will address the impact of having risk models available *via* EPOCH® and *e*PRISM® at the time of medical decision making on outcomes such as treatment selection, resource utilization, and patient compliance.

4. Conclusions

EPOCH® and *e*PRISM® provide a novel framework for translating evidenced-based prognostic models into clinical tools that are readily available at the bedside. These tools offers a seamless link between health care providers, clinical information systems, and outcomes researchers, and offer a mechanism for meeting the Institute of Medicine's (IOM) vision of a health care system that is more evidence-based, transparent and patient centered.

References

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