Implementing Broad Scale Childhood Immunization Decision Support as a Web Service

Vivienne J. Zhu, MD, MS[1,2], Shaun J. Grannis, MD, MS[1,2], Marc B. Rosenman, MD, MS[1,2], Stephen M. Downs, MD, MS[1,2]
Regenstrief Institute and Indiana University School of Medicine, IN

ABSTRACT

Timely vaccinations decrease a child's risk of contracting vaccine-preventable disease and prevent disease outbreaks. Childhood immunization schedules may represent the only clinical guideline for which there is official national consensus. So an immunization clinical decision support system (CDSS) is a natural application. However, immunization schedules are complex and change frequently. Maintaining multiple CDSS's is expensive and error prone. Therefore, a practical strategy would be an immunization CDSS as a centralized web service that can be easily accessed by various electronic medical record (EMR) systems. This allows centralized maintenance of immunization guidelines. We have developed a web service, based on Miller's tabular model with modifications, which implements routine childhood immunization guidelines. This immunization web service is currently operating in the Regenstrief Institute intranet and system evaluations are ongoing. We will make this web service available on the Internet. In this paper, we describe this web service -based immunization decision support tool.

INTRODUCTION

Immunizations are one of the most successful and effective public health tools for preventing disease, disability, and death from preventable disease. Timely vaccinations decrease a child's risk of contracting vaccine-preventable disease and prevent disease outbreaks. ***Healthy People 2010***, the national health promotion and disease prevention initiative, states that immunization is one of ten leading health indicators that reflect the major health concerns in the United States at the beginning of the 21st century.[1]

The American Academy of Pediatrics (AAP) and the Advisory Committee on Immunization Practices (ACIP) of the Centers for Disease Control and Prevention (CDC) have provided national standard guidelines for immunization and have constantly updated the modifications since 1997.[2] Standards for child and adolescent vaccination practices have been published frequently to assist with implementing vaccination programs and maximizing their benefits.[3]

A well-defined Computerized Decision Support System (CDSS) for physicians can improve adherence to clinical practice guidelines.[4,5] Computerized reminders can advise clinicians regarding which of the dizzying array of vaccines is needed for a particular child.[6] Currently, regional Immunization Information System (IIS) and immunization CDSS in clinics are increasingly used as decision making tools by immunization programs and health care providers.[7] However, providers still encounter numerous barriers to deliver immunizations.[8] In addition to patients' receiving vaccines at multiple sites with scattered paper-based immunization records, the standard immunization guidelines change frequently. As a result, different information systems must update their computerized guidelines separately. This results in inefficiencies, inconsistencies, and a higher error rate.

A more efficient, practical approach to implementing and maintaining immunization guidelines would be a centralized CDSS made available via the Internet and endorsed by CDC, AAP or the Health Information Technology Standards Panel (HITSP). Web services are commonly used as a unified means to access disparate systems in computer industries.[9] This approach assembles software components in a modular way to facilitate reuse and standardize interfaces.[10] A centralized web service for immunization forecasting can be easily accessed by various EMR systems and CDSS's in different settings and can provide vaccine recommendations for any child. In addition, the clinical logic in the immunization web service can be easily implemented through different platforms including various window applications and web applications. More importantly, it would allow centralized maintenance and updating of immunization guidelines.

In order to provide an immunization scheduler CDSS to our local clinics and demonstrate the feasibility of using this technology to disseminate this CDSS in broader scale, we have developed a web service based on Miller's tabular model that implements the standardized routine childhood immunization guidelines.[11,12] Using the patient's date of birth and immunization history, this web service first validates the patient historic immunization data.

Then it generates patient specific recommendations about which vaccines should be given at a particular clinic visit. It also provides appropriate time frames for the next vaccinations.

METHODS

This childhood immunization forecasting web service is designed for generating vaccination recommendations for different local CDSS's. When a child presents to a clinic, the local CDSS can send patient's date of birth and immunization history to our web service. Our web service processes these data, generates recommendations, and then sends the recommendations back to the local CDSS using appropriate standards. Three modules accomplish this goal. They are vaccine term mapping, immunization guidelines translation, and clinical logic implementation.

Vaccine Term Mapping

In many EMR systems, patient immunization data were recorded and transferred via the Health Level 7 standard (HL7).[13] However, the HL7 standard vaccine terms, including various combination vaccines, were not suitable for evaluation against the CDC immunization schedule.[14] In order to facilitate our immunization forecasting web service, we first mapped HL7 vaccine terms to corresponding CDC standard childhood routine vaccine terms for nine vaccine series. We also mapped two local medical record resources, the Regenstrief Medical Record System (RMRS) and the Marion County Health Department at Indiana (MCHD) immunization database, to CDC standard terms.[15] Terms for combination vaccines were decomposed and mapped to related CDC standard single vaccine terms. The original terms and mapped terms were stored in a SQL table.

Translation of Standard Immunization Guidelines

The CDC published childhood immunization guidelines for *Haemophilus influenzae* type b (Hib), Diphtheria-Tetanus-Pertussis (DTaP), Inactive Poliovirus (IPV), Pneumococc (PCV), Measles-Mumps-Rubella (MMR), Hepatitis B (Hep B), Hepatitis A (Hep A), Rotavirus (Rota), and Varicella (Var). The CDC immunization schedule specifies a minimum and maximum acceptable age for each vaccine and the minimum interval between two sequential doses in a series. [16]

Our immunization schedule web service produced recommendations for the nine CDC recommended childhood vaccination series (a total of 29 shots): 4 Hip, 5 DTaP, 4 IPV, 4 PCV, 2 MMR, 3 Hep B, 2 Hep A, 3 Rota, and 2 Var. We used a logic lookup table to translate the standard childhood immunization schedule for the year 2008 for these nine immunization series. Using this logic lookup table, our web service could assess the patient immunization status and generate reminders for clinicians. In addition to the CDC based variables, date of birth, minimum age (the youngest age a vaccine should be given), maximum age (the oldest age a vaccine should be given), minimum interval (the shortest waiting time between sequential vaccines in a vaccine series), we added three variables: prior vaccine (the previous vaccine in a series), prior vaccine dose (the dose number for the previous vaccine), live vaccine status (if a vaccine is a live virus vaccine or not). The date of forecasting (the clinic visit date) was automatically generated by an SQL built-in function. Table 1 shows a portion of the lookup table using the HepB, DTaP, MMR and Rota vaccine series. Ages and time interval units in days.

Implementation of Clinical Decision Support

Our main focus for this project was to develop a generalized CDSS to implement the logics of the

Table 1. Sample vaccinations look up table by HepB, DTap, MMR, Rota series (- = Not Specified)

Vaccine	Dose	Minimum Age	Maximum Age	Minimum Interval	Prior Vaccine	Prior Vaccine Dose	Live Vaccine Status
Hep B	1	0	-	0	-	-	no
Hep B	2	30	-	30	Hep B	1	no
Hep B	3	126	-	61	Hep B	2	no
DTaP	1	42	-	0	-	-	no
DTaP	2	70	-	28	DTaP	1	no
DTaP	3	126	-	28	DTaP	2	no
DTaP	4	365	-	42	DTaP	3	no
DTaP	5	1460	-	42	DTaP	4	no
MMR	1	365	-	0	-	-	yes
MMR	2	1460	-	30	MMR	1	yes
Rota	1	42	84	0	-	-	yes
Rota	2	70	224	30	Rota	1	yes
Rota	3	126	224	30	Rota	2	yes

immunization guidelines. Based on the patient date of birth and immunization history data, this system generated recommendations for (1) the vaccines and dose that should be given on the current date, and (2) the next vaccinations and their appropriate time frames. We used SQL stored procedures along with the lookup table to implement the logic of immunization schedule guidelines.

The input data for this CDSS include the patient's date of birth, vaccines administered, and dates administered. Because vaccine doses usually were not recorded in immunization data, we first validated the patient's historic immunization data and then assigned the dose numbers for each valid vaccine. Because vaccines that are given earlier than the minimum age or earlier than the minimum waiting interval are thought not to contribute much to the protective effect of immunization series, we marked these vaccinations as invalid. We applied this validation approach using SQL stored procedures to both live vaccines and non-live vaccines. Duplicate records also were eliminated by this process.

The logic implemented in this algorithm fulfilled four criteria: (1) live vaccines, such as MMR, Var, and Rota, should be given at least 28 days apart from each other or administered on the same day, (2) two sequential vaccines should be given no closer than the minimum waiting interval, (3) any vaccine should be given only after the minimum age for that vaccine, and (4) do not administer a vaccine if the patient's age is greater than the maximum acceptable age if it was defined. These four criteria were implemented with SQL stored procedures and four tables that temporarily store the patient input and output data. By iterating through the lookup table, we applied these criteria for all uncompleted vaccine series and identified which vaccines should be given in a particular patient clinic visit (Figure 1).

```
IF (Live Vaccine Status = yes and (interval with
    last live vaccine >=28 or =0)) or
    (Live Vaccine Status = no) THEN
        check the Prior Vaccine
        IF (have no Prior Vaccine) THEN
            check current age
            IF (Minimum  Age<current
                age< Maximum Age)
                THEN issue vaccine
            END IF
        ELSE IF (have Prior Vaccine) THEN
            retrieve Given Date of Prior Vaccine
            IF (Minimum  Age<current
                age< Maximum Age) and
                (interval >Minimum Interval)
                THEN issue vaccine
            END IF
        END IF
END IF
```

Figure 1. Pseudo-code that determines which vaccines should be given on patient visit date.

In order to avoid unnecessary clinic visits and needle sticks for vaccination, our web service also provided suggestions for the next vaccinations and their time frames, if recommended vaccines were given at the visit date. Providers could schedule the child's next well care visit at a time that accommodates these recommended time frames (Figure 2).

Language and Platform

We used the Microsoft ASP.NET and SQL Server 2005 to develop the immunization web service.

RESULTS

In total, we mapped 84 distinct routine childhood vaccine terms to nine CDC standard childhood vaccine terms, 42 from HL7, 30 from RMRS and 12 from the MCHD immunization database. Using four SQL stored procedures and two tables for storing clinical knowledge base, we implemented guidelines for nine vaccine series with a total of 29 shots. With five web methods to interact with consumers, our

```
IF (Maximum Age not specified) or
   ((prior vaccine Given Date + Minimum Interval) < (Date of Birth + Maximum Age))
        THEN (check Live Vaccine Status)
          IF (is not a live vaccine) THEN
                next vaccine Given Date = GREATEST (Date of Birth + Minimum Age,
                                          prior vaccine Given Date + Minimum Interval,
                                          Date of Birth + Maximum Age)
             ELSE IF (is a live vaccine) THEN
                next vaccine Given Date = GREATEST (Date of Birth + Minimum Age,
                                          prior vaccine Given Date + + Minimum Interval,
                                          latest live vaccine Given Date + 28,
                                          Date of Birth + Maximum Age)
          END IF
END IF
```

Figure 2. Pseudo-code for the clinical logics generating the next vaccinations and their appropriate time frames.

immunization web service could receive the immunization input data in either XML or delimited text file formats. In addition, after validating patient's historic immunization data, this web service delivered recommendations in a dataset format for both vaccines that should be given at the current visit and the recommended time frames for future vaccinations. Figure 3 illustrates an example of the input and output for the immunization forecasting web service. This web service is currently available in the Regenstrief Institute intranet and is under evaluation. We will expose this immunization web service for broader consumption as a next step.

(a) Forecasting date: 03/09/2009
Input data:

Date_of_Birth	2007-12-01
DTap-Hib	2008-06-01
Hib-Hep B	2008-07-01
Hep B, NOS	2008-09-01
Hep B, NOS	2008-09-04
MMRV	2008-10-01
MMR	2008-12-10
rotavirus, NOS1	2008-12-10

(b) Mapped and validated input data:

Mapped_Term	Given_Date	Validated_Dose
DTaP	2008-06-01	1
Hep B	2008-07-01	1
Hep B	2008-09-01	2
Hep B	2008-09-04	Invalid
Hib	2008-06-01	1
Hib	2008-07-01	2
MMR	2008-10-01	Invalid
MMR	2008-12-10	1
Rota	2008-12-10	Invalid
Var	2008-10-01	Invalid

(c) The following vaccine(s) are due on 03/09/2009:

Vaccine	Dose
DTaP	2
Hep A	1
Hep B	3
Hib	3
IPV	1
PCV	1
VAR	1

(d) The following vaccine(s) will be due:

Vaccine	Dose	After_Date	Before_Date
DTaP	3	2009-04-08	--
Hep A	2	2009-09-07	--
Hib	4	2009-05-09	--
IPV	2	2009-04-08	--
MMR	2	2011-11-30	--
PCV	2	2009-04-08	--
VAR	2	2011-11-30	--

Figure 3. (a) An example of immunization history data, (b) mapped and validated input data with CDC vaccine terms and doses, (c) and (d) the recommendations for the input dataset. (-- = Not Specified)

DISCUSSION

This project demonstrated that childhood immunization guidelines can be computerized and centralized by a web service. A commercial rule-based immunization CDSS application has been developed,[17] but our system differs in a number of ways. Our web service for the vaccination scheduler provided an efficient approach. First, we mapped immunization terms from the HL7 standard and two local resources, which results a broad coverage of current users. In addition, mapping information is stored in a table, which allows us to add additional mapping term when needed. Since the number of terms needed is relatively small (9 vaccine series, 29 doses), the mapping task will not be overwhelming. Second, we translated and implemented complex immunization knowledge into basic SQL tables and stored procedures in a relatively small number of steps. Third, this web service could be easily accessed by different applications either through a local class or a web reference. The client systems need to implement relatively simple interfaces including: an interface sending basic patient demographics and immunization data, and an interface for receiving forecasting recommendations. Fourth, because we modularized the clinical logic, it is easy for us to add new functionalities during the development process. Finally and most importantly, when immunization guidelines change or new vaccines are added, we only need to update the variable values in the tables to reflect the changes.

This project has several limitations. First, we did not address the child's hepatitis B exposure status, vaccine contraindications, or recommend the various vaccine products that are available in combination. Although this clinical knowledge could be interpreted with little additional programming, a successful computerized guideline should be simple, straightforward and able to resolve recognized clinical problems rather than merely translating detailed clinical knowledge to programming.[18] For this web service, our goal was to develop an informatics tool to simplify the process of vaccination scheduling in the busy clinical practice and to provide a mechanism to handle rapid changes in immunization guidelines. Second, we did not implement the catch up schedule for children behind on immunizations. To make our immunization service more sophisticated and practical, we will develop modules to implement guidelines for this sub-area in future work.

It is important to note that any CDSS should be formally evaluated and validated before its deployment in order to ensure usability and accurate recommendations. We are currently evaluating the accuracy of our immunization forecasting web service using childhood immunization data generated from the Regenstrief Medical Record System, comparing our system's predictions to recommendations by a human expert. We will also pilot and evaluate this web service in our local operational CDSS's, such as CHICA, Gopher and Docs4Docs.[19-21] These evaluations will provide information for future improvements.

CONCLUSION

Our model builds on work by Miller and colleagues,[12] moving vaccine forecasting into a web service that will be widely available on the Internet. Ideally, the CDC, the AAP, the HITSP and other authoritative sources of vaccination guidelines will adopt this approach to making accurate, consistent and up-to-date vaccine recommendations available to various CDSS's.

ACKNOWLEDGEMENTS

This project was performed at the Regenstrief Institute, Indianapolis, IN. We would like to thank Jane Wang at Regenstrief Institute, Inc.; Vibha Anand and Tammy Dugan in Children's Health Services Research, Department of Pediatrics, Indiana. Dr. Zhu is supported by grant 5T15LM007117 from the National Library of Medicine.

REFERENCES

1. US Department of Health and Human Service. Health People 2010. 2000;15. Washington, DC.

2. Richard Kent Zimmerman. AAFP, AAP and ACIP Release 1998 Recommended Childhood Immunization Schedule.

3. Vaccination and Immunization. CDC Available at: http://www.cdc.gov/vaccines/

4. Clement J. McDonald. Protocol_based computer reminders, the quality of care and the non-perfection of man. New England Journal of Medicine. 1976;295(4):1351-1355.

5. Marc J. Overhage, William M. Tierney, Xiao-Hua (Andrew) Zhou, Clement J. McDonald. A randomized trial of "corollary orders" to prevent errors of omission. J Am Med Inform Assoc 1997;4(5):364-375.

6. Committee TNVA. Strategies to sustain success in childhood immunizations. JAMA 1999;282:7.

7. CDC. Immunization information systems progress--United States, 2006. 2008 Mar 21(11):289-91.

8. Noam H. Arzt. Immunization information system interoperability. AIRA pre-conference Workshop 42nd National Immunization Conference. 2008

9. Scott Mitchell. An extensive examination of web services: part 1. Rolla.com 2008.

10. Susan M. Salkowitz, Noam H. Arzt, Roth Gubernick. Immunization information systems and healthcare systems interoperability. APHA 136th Annual Meeting and Exposition. 2008.

11. Miller PL. Tools for Immunization Guideline Knowledge Maintenance. Computer and Biomedical Research 1998;31:16.

12. Miller PL. Combining Tabular, Rule-based, and Procedural Knowledge in Computer-Based Guidelines for Childhood Immunization. Computer and Biomedical Research 1997;30:20.

13. Schadow G, Russian DC, Mead CN, McDonald CJ. Integrating medical information and knowledge in the HL7 RIM. AMIA Symp. 2000:764-768.

14. Health Level Seven (HL7) Standard Code Set: CVX – Vaccines Administered. CDC. 2008 .

15. McDonald CJ, Overhage JM, Tierney WM, Dexter PR, Martin DK, Suico JG, et al. Medical Record System: a quarter century experience. Int J Med Inform. 1999 Jun;54(3):225-53.

16. CDC. Recommended Immunization Schedule for Persons Aged 0–6 Years—UNITED STATES • 2008. MMWR Morb Motal Wkly. 2008.

17. Software Partners Vaccine Forecasting Module. http://www.matchmerge.com/en/vaccine-forecast-decision-supportservice.html. 08/29/2009

18. William M. Tierney, Marc J. Overhage, Clement J. McDonald. Computerizing guidelines: factors for success. AMIA Annu Symp. 1996:459-62.

19. Vibha Anand, Paul G. Biondich, Gilbert Liu, Marc Rosenman, Stephen M. Downs. Child Health Improvement through Computer Automation: The CHICA System. Stud Health Technol Inform. 2004;107:187-91.

20. McDonald CJ, Tierney WM. The medical gopher - a mocro-computer system to help find, organize and decide about patient data. Western J of Med. 1986;145:823-29.

21. Michael Barnes. Lessons learned from the implementation of clinical messaging systems. AMIA Annu Symp. 2007:36-40.