The field of ophthalmology has a number of unique features compared with other medical and surgical specialties regarding clinical workflow and data management. This has important implications for the design of electronic health record (EHR) systems that can be used intuitively and efficiently by ophthalmologists and that can promote improved quality of care. Ophthalmologists often lament the absence of these specialty-specific features in EHRs, particularly in systems that were developed originally for primary care physicians or other medical specialists. The purpose of this article is to summarize the special requirements of EHRs that are important for ophthalmology. The hope is that this will help ophthalmologists to identify important features when searching for EHR systems, to stimulate vendors to recognize and incorporate these functions into systems, and to assist federal agencies to develop future guidelines regarding meaningful use of EHRs. More broadly, the American Academy of Ophthalmology believes that these functions are elements of good system design that will improve access to relevant information at the point of care between the ophthalmologist and the patient, will enhance timely communications between primary care providers and ophthalmologists, will mitigate risk, and ultimately will improve the ability of physicians to deliver the highest-quality medical care.

Financial Disclosure(s): Proprietary or commercial interest disclosure may be found after the references.


Advances in information technology have transformed the industrialized world dramatically within the past several decades. Electronic health records (EHRs) have the potential to apply these same technologies toward improving the delivery, quality, and efficiency of health care. Despite these trends, EHR adoption by ophthalmologists, and by other physicians, has been slow. In 2006, the American Academy of Ophthalmology (the Academy) performed a survey of its members and found that the adoption rate was 12%. This compares with an overall adoption rate of 17% for basic or complete EHR systems among physicians in different specialties across the country. To promote adoption of EHRs by physicians and hospitals, the federal Health Information Technology for Economic and Clinical Health Act of 2009 allocates $27 billion in incentives. The federal government is relying on these incentives to help drive the adoption rate to 85% among physicians by the year 2014. Although recent follow-up surveys indicate that there are slow increases in EHR adoption related to these incentives, the low adoption rates suggest that ophthalmologists continue to be hesitant.

The Institute of Medicine has described key capabilities of EHR systems related to health care delivery, and the Centers for Medicare and Medicaid Services have defined specific so-called meaningful use criteria for EHRs. These basic functions are required of all EHR systems and include recording of problem lists and active diagnoses, electronic prescribing, computer-based provider order entry, and drug–drug interaction checks. Beyond these general functions, EHRs must meet additional special requirements to be useful to address the unique needs of ophthalmologists. These stem from the field’s constellation of medical and surgical care, heavy reliance on interpretation of diagnostic imaging, high-volume clinical practices with complex workflows, and documentation requirements involving a combination of numerical, text-based, and image-based data elements. By recognizing and accounting for these special requirements, EHR systems will be better able to help ophthalmologists provide higher-quality care, with improved safety and efficiency.

Among EHRs that are being used currently by ophthalmologists, many are large, comprehensive systems that originally were designed for other medical specialties or large enterprises (e.g., hospitals, health plans), and therefore pay little attention to the unique needs of ophthalmologists. Other systems that are more directly designed toward addressing ophthalmologist needs have been developed by smaller ophthalmology-specific vendors, who may have limited resources and may have difficulty developing features that would qualify for meaningful use. For these and other reasons, the authors believe that many current EHR systems do not meet the needs of ophthalmologists optimally.
The purposes of this article are to summarize the special EHR requirements and functionalities that are important for ophthalmology and to point out some shortcomings of current EHR products, with regard to these special ophthalmology requirements as well as the more general meaningful use regulations. These requirements were developed by consensus of the Academy’s Medical Information Technology Committee (MFC, MVB, KDE, MCL, CAM, SP, DES, FL) and additional collaborators with expertise in ophthalmic information science, biomedical informatics, and clinical data transmission standards (AB, MBH). Consensus was reached through 4 detailed face-to-face meetings, including subsets of coauthors and Academy leadership, weekly conference calls including subsets of coauthors for several months, and numerous e-mail exchanges.

The authors recognize that there are many EHR selection criteria and that the weighting of these criteria will vary across practices. Important factors that should be considered include ease of use, practice subspecialty mix, patient volume, workflow, clinical needs, number of office locations, data security and backup features, data exchange needs with health care organizations and other clinicians, image management needs, integration with image management systems, and integration of practice management software. Therefore, each practice must approach EHR selection independently and with due diligence in carefully defining and comparing their needs with the feature sets of the various EHR products available.

The authors hope that this article will help vendors to recognize and incorporate the appropriate functionalities into their ophthalmology products and that it will assist federal agencies to develop future meaningful use guidelines that are appropriate for ophthalmologists. The authors believe that this will promote efforts by ophthalmologists to optimize their practices; to adapt to the future of caring for an increasing number of patients, given the aging United States population; and to provide the highest-quality patient care. Finally, this paper is intended to complement the information contained in Centers for Medicare and Medicaid Services meaningful use regulations, rather than conflicting with them. These meaningful use regulations describe general functionalities involving patient demographics, electronic prescribing, clinical documentation, and communication that are intended to apply to all physicians and hospitals regardless of specialty, and the authors believe these should be satisfied by ophthalmology EHRs. This article is not intended to discuss the specific content of the EHR or to discuss issues that are handled by practice management and billing software.

**Unique Characteristics of Ophthalmology**

There are several characteristics of an ophthalmology practice that impact clinical workflow and data management requirements, all of which affect the optimal design of EHR systems. First, ophthalmology is both a medical and surgical specialty. Surgical procedures generally occur either in the office or in operating rooms, and medical clearance, if performed, usually are carried out by nonophthalmologists. Thus, EHRs must support documentation in, and transitions between, the office and operating room. They must be able to incorporate data from other healthcare providers who may not be part of the ophthalmology practice.

Second, ophthalmology is a visually intensive specialty, often incorporating sketches or formal imaging studies into the assessment of patients’ circumstances. As a result, ophthalmologists who trained before the era of the EHR frequently document clinical findings using hand-drawn sketches. Because of this, traditional paper-based ophthalmology examination forms often include anatomic drawing templates that are annotated by the physician. For this reason, many ophthalmologists are frustrated by current EHRs that rely primarily on keyboard-based or mouse-based data entry, without a useful mechanism for drawing or annotation.

Third, the use of traditional vital signs (e.g., blood pressure, height, weight) varies among different ophthalmic subspecialists, and these tests generally are performed infrequently for ophthalmic decision making and management. Instead, ophthalmologists rely on visual acuity and intraocular pressure (IOP) as routinely collected data that serve as the vital signs of the eye. To promote best practices, EHRs for ophthalmology must incorporate features to capture, track, and display these ophthalmic vital signs. Future meaningful use criteria that incorporate specialty-specific practice patterns and requirements would further encourage development and adoption of EHRs tailored to ophthalmologists’ needs.

Fourth, the range of traditional laboratory and radiologic studies that are performed routinely by different ophthalmologists can vary widely. Subspecialists in uveitis or neuro-ophthalmology may perform or order these studies frequently. However, most other ophthalmologists perform typical systemic disease diagnostics only infrequently, and instead rely on ophthalmology-specific evaluation and testing. Therefore, ophthalmology EHRs should support general ancillary testing, should have the ability to generate orders for and collect data from laboratory systems and Picture Archiving and Communication Systems (PACS), and also should meet specific ophthalmology evaluation and testing needs.

Fifth, ophthalmologists frequently perform studies using ancillary ophthalmic measurement and imaging devices. These studies are performed by technicians or photographers, often during the course of clinical evaluation by an ophthalmologist. Outputs from these devices include graphical displays of measurement data (e.g., visual field testing, electroretinography), numerical data (e.g., autorefraction, keratometry, biometry), and ophthalmic image data that are reviewed and interpreted directly by ophthalmologists (e.g., fundus photography, optical coherence tomography). Efficient access to the measurements, images, and findings from these ancillary studies is essential to support clinical diagnosis, to track disease progression, and to plan surgery. Because of specialized patient care workflow and device interface requirements, these data and images often are stored on the acquisition devices in proprietary databases, and sometimes even in proprietary file formats. Some EHRs are able to store graphical reports using their own image
management system, whereas other EHRs build interfaces with other ophthalmology-specific PACS. However, many ophthalmology-specific PACS allow only limited interoperability with institution-wide PACS developed by radiology vendors, in part because of incomplete implementation of the Digital Imaging and Communication in Medicine (DICOM) standard. To support these requirements, ophthalmology EHRs must facilitate the rapid, accurate storage and retrieval of structured data from these ancillary measurement and imaging devices.

Finally, ophthalmology is a high-volume ambulatory specialty in which patients are seen and evaluated at a rapid pace. Although many practices include physician extenders such as technicians and orthoptists, the key portions of the examination, assessment, and plan are performed and documented directly by ophthalmologists. This means that EHRs must support all of the above special requirements in a practice environment that demands ease of use by ancillary staff and fast-paced, accurate clinical documentation by ophthalmologists.

**Essential Ophthalmology-Specific Electronic Health Records Functions**

Based on the factors above, a number of EHR features are important enough to be considered essential for ophthalmic care (Table 1). Absence of these features could adversely affect the ability of ophthalmologists to provide safe and efficient patient care.

### Clinical Documentation

Virtually all EHR systems include traditional data fields for clinical documentation (e.g., history of present illness, family history). In addition to these traditional data fields, EHRs should organize ophthalmology-specific data fields separately (e.g., past ocular history, ocular medications). Electronic health records should enable entry and storage of discrete clinical information specified in the Preferred Practice Patterns of the Academy that are relevant to patients. These Preferred Practice Patterns also may provide a basis for developing computer-based clinical decision support tools. Systems should provide links to relevant Preferred Practice Patterns, other clinical decision support resources, and patient education materials.

Systems should conform or map to vendor-neutral standard terminologies for clinical data representation (e.g., Systematized Nomenclature of Medicine—Clinical Terms [SNOMED CT], International Classification of Diseases Ninth Revision and International Classification of Diseases Tenth Revision when mandated, RxNorm, Current Procedural Terminology [CPT]-4). This should be carried out for all cases where standard terminologies have been developed and should include problem lists, medications, diagnoses, and procedures. In particular, SNOMED CT has been shown to have better ophthalmic content coverage than other controlled terminologies and has been adopted by the Academy as an official clinical ophthalmology terminology. The authors believe ophthalmology EHRs should

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<tr>
<th>Function</th>
<th>Essential</th>
<th>Desirable</th>
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<tbody>
<tr>
<td>Clinical documentation</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Exchange full set of ophthalmic clinical data with EHRs from other vendors</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Link clinical documentation to billing and charge capture and integrate with practice management</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Allow physician to review patient information easily before entering room</td>
<td>X</td>
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**Ophthalmic vital signs and laboratory studies**

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<tr>
<td>Record visual acuity and refractive discrete elements in accordance with DICOM Supplement 130</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Record intraocular pressure as a discrete data element</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Display and graph visual acuity and intraocular pressure over time</td>
<td>X</td>
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</table>

**Medical and surgical management**

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<tr>
<td>Electronically associate all preoperative, operative, and postoperative documents</td>
<td>X</td>
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</tbody>
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(Continued)
Table 1. (Continued.)

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<tr>
<th>Function</th>
<th>Essential</th>
<th>Desirable</th>
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<tbody>
<tr>
<td>Support documentation of office-based and operating room procedures</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Allow physician to generate operative report at time of surgery</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Ophthalmic measurement and imaging devices</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Conform to vendor-neutral standards (e.g., DICOM) for receipt and representation of data from all ophthalmic instruments and devices</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Conform to vendor-neutral standards and profiles for ordering ophthalmic imaging and measurement studies (e.g., DICOM Modality Worklist and IHE Eye Care Workflow)</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Document completion and interpretation of ophthalmic imaging and measurement studies</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Request, retrieve, display, and communicate all imaging and measurement data generated by ophthalmic instruments in a standard vendor-neutral format (e.g., DICOM)</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Manage all ophthalmic imaging data in vendor-neutral format (e.g., DICOM) or provide tight integration with external PACS in vendor-neutral format</td>
<td>X</td>
<td></td>
</tr>
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</table>

DICOM = Digital Imaging and Communications in Medicine; EHR = electronic health record; ICD = International Classification of Diseases; IHE = Integrating the Healthcare Enterprise; PACS = Picture Archiving and Communication System; SNOMED CT = Systematized Nomenclature of Medicine-Clinical Terms.

There is no consensus about the most efficient computer–user interface for entry of clinical data by ophthalmologists and staff. However, because ophthalmology is a heavily visually oriented specialty, EHRs should allow physicians to incorporate color drawings. This may or may not involve computerized drawing tools, but should include annotation of standard graphical templates for representing clinical findings (e.g., extraocular motility, gonioscopy, strabismus measurements, slit-lamp biomicroscopic examination, retinal examination).

Electronic health records vendors should be expected to perform workflow analysis before system implementation and to plan with individual ophthalmology groups for how workflow will be changed and optimized after implementation.

**Ophthalmic Vital Signs and Laboratory Studies**

Ophthalmology EHRs should record visual acuity, including partial-line notation (e.g., +2, –1), optotype (e.g., Snellen, Early Treatment of Diabetic Retinopathy Study visual acuity, HOTV), testing conditions (e.g., distance, without correction, with contact lenses, pinhole), and the ability to record nonnumeric acuities (e.g., hand movements, no light perception). There should be a comment field to record supplementary information (e.g., “best in right gaze”).

Electronic health records should record IOP and should document testing method (e.g., applanation) and testing time. There should be a comment field for supplementary information (e.g., “squeezing”) and the ability to record a target pressure.

Systems should store and display visual acuity and IOP as discrete data elements and should provide the ability to chart these values over time. It also should be ideal to chart the differences between target IOP and actual IOP over time. There should be tools for visualizing these data in relation to relevant clinical findings such as surgical procedures, ocular medications, and cup-to-disc ratio.

Ophthalmology EHRs should provide a mechanism to document refraction, including method (e.g., subjective, retinoscopy), conditions (e.g., after cycloplegia), testing distance, prism, individual performing refraction, and additional relevant factors (e.g., reading add, contact lens parameters). This should allow generation of a prescription. There should be a comment field for supplementary information (e.g., “not reliable”).

Systems should conform to accepted, vendor-neutral standards and profiles (e.g., DICOM) that are available for representation of ophthalmic vital signs, refraction, and ancillary testing and laboratory studies.

**Medical and Surgical Management**

Systems should associate electronically all relevant preoperative, operative, and postoperative documentation. This includes clinical notes, preoperative medical clearance, anesthesiology notes, informed consent forms, informed consent discussion support tools for risk management, clinical data required for surgical procedures (e.g., axial length measurements, intraocular lens selection), and operative reports. This should be done both for surgery performed in...
the operating room as well as the office (e.g., intraocular injections, laser surgery procedures).

Ophthamic Measurement and Imaging Devices

Ophthalmology EHRs should conform to accepted, vendor-neutral standards and profiles for representation and transfer of data from ophthalmic instruments and devices (e.g., Health Level Seven International, DICOM, Integrating the Healthcare Enterprise [IHE] Eye Care).\textsuperscript{13–16} If appropriate standards have been defined for ophthalmic devices (e.g., numerical autorefraction, axial length measurement, fundus photography, optical coherence tomography, ultrasound, visual fields), then these standards and profiles should be implemented. Accessibility to original measurement data will allow ophthalmologists to review and use clinically relevant findings within the EHR, without the risk of error associated with manual data transcription. In the future, accessibility to image parameters may provide important opportunities for computer-based clinical decision support and clinical research.

Systems should allow ophthalmologists to create orders for ophthalmic imaging studies and procedures within the EHR, such that these orders can be processed by ancillary personnel (e.g., technicians, photographers). Among other benefits, this would obviate manual re-entry of demographic and clinical information on the devices, thus preventing errors in matching patients with studies. Implementation of the DICOM Modality Worklist in the IHE Eye Care Workflow profile provides this function.

Systems should provide a mechanism to document completion and interpretation of ancillary studies (e.g., fundus photography, visual field testing). This should be linked to the ancillary study when possible and should be linked to the office visit when relevant. These should conform to accepted, vendor-neutral reporting standards and profiles (e.g., DICOM) when available.

Other Ophthalmology-Specific Electronic Health Records Functions

Based on the factors above, there are other features that often are believed by ophthalmologists to be lacking in many EHR systems that are now commercially available (Table 1). Many of these are functionalities that physicians have become accustomed to while using traditional paper-based records. Although EHRs provide many important advantages over traditional paper-based records,\textsuperscript{17,18} the authors believe that absence of the following features will limit the ability of EHRs to achieve their full potential. Many of these features may require additional research, as well as additional testing and development from vendors.\textsuperscript{19,20}

Clinical Documentation

Entry of textual and numerical data into EHRs often is more cumbersome than paper-based documentation, particularly in fast-paced clinical environments. There are important unanswered questions with regard to identifying the computer–user interface strategies that provide the highest levels of accuracy and efficiency for entry of ophthalmic examination data. Collaborative investigation and testing by researchers, vendors, and ophthalmologists will provide important solutions in these areas.

Standards for exchange of basic clinical data (e.g., medications, allergies) among different EHR systems have been implemented by many vendors. However, there is no existing standard format for exchange of clinical ophthalmic assessment data (i.e., documentation of examination findings, assessment, and plan) among different EHR systems. Lack of such a standard seems to represent a barrier for many ophthalmologists to adopting any EHR for fear of difficulty in switching between products (i.e., being “locked in” with a vendor).\textsuperscript{1} Some ophthalmologists have additional concerns about committing to small vendors with uncertain long-term financial viability. Thus, the development of a vendor-neutral standard for representation and exchange of clinical ophthalmic assessment data will be extremely important. One aspect of this effort will require representation of clinical findings and allergies using a reference terminology such as SNOMED-CT.

Electronic health records should link clinical documentation (e.g., diagnoses, problem lists) to billing and charge capture tasks. However, some EHR systems seem to have been designed largely to support documentation for billing and compliance, often resulting in extensive computer-generated lists with limited clinical value. Vendors are encouraged to design systems that are more clearly directed toward supporting clinical reasoning and decision making.

In high-volume practices, many ophthalmologists are accustomed to reviewing the chart before entering the examination room. This can enhance efficiency, while creating benefits for the physician–patient relationship. Paper charts, which often are stored outside the examination room, allow this practice to occur seamlessly. However, this ability to review charts outside the examination room often is lost after transitioning to EHR systems. Vendors should find ways to accommodate comparable workflow.

Most current EHR drawing tools use mouse-based interfaces. While attempting to sketch with a mouse, it is far more difficult to document details than with paper-based notes. It has been the authors’ observation that many early adopters of ophthalmology EHRs do not use existing drawing tools because they are cumbersome and provide insufficient detail. Improved methods of data entry for representing picture-based findings (e.g., drawings, photographs, other methods) will be useful to ophthalmologists.

Medical and Surgical Management

Operative procedures often are performed in hospitals or surgical centers, which may use electronic systems that are different from the EHR that the ophthalmologist uses in the office. This often creates difficulty for information exchange among multiple electronic systems. In the long term, standard reporting and communication formats for surgical documentation will facilitate the ability to generate opera-
Ophthalmic Measurement and Imaging Devices

Ophthalmologists frequently perform studies using ancillary ophthalmic measurement and imaging devices. As described above, these include autorefractors, lensometers, axial length determination (biometry) devices, visual field testing devices, optical coherence tomographers, fundus cameras, and others. Currently, very few vendors allow for seamless integration of data from these devices. Electronic health records vendors should work toward either storing image data directly using standards such as DICOM when available, or toward providing better integration with PACS vendors by encapsulating image reports as DICOM objects.

Standards for Data Representation and Exchange

Interoperability is an important concept, representing the ability to exchange data freely among information systems and devices, regardless of the vendor or brand. This will create opportunities for important advances in medical care, data accessibility, clinical research, disease registries, and public health. Even for ophthalmologists who never exchange patient data for referral or consultation outside their practices, interoperability within their practices is required for communication between the EHR system and various ophthalmic imaging devices.

An essential component of infrastructure for supporting interoperable computer-based systems is the creation of standards for electronic representation and transmission of ophthalmic data. These include SNOMED CT for findings and concepts, DICOM for images and machine-derived measurement data, Health Level Seven International for documentation and transfer of textual and other clinical data, and IHE Eye Care for profiles to support implementation of these various standards in real-world settings for interoperability of devices and software.\(^{11-16}\) For example, the IHE Eye Care Workflow Technical Framework allows for vendor-neutral integration of EHRs with practice management software to ensure accurate sharing of patient identification and demographics. Recognizing the importance of controlled terminologies and data transmission standards for supporting EHRs, the Academy has participated in longstanding efforts to model ophthalmic concepts comprehensively in the SNOMED CT, to encode ophthalmic measurement and imaging studies using the DICOM standard (e.g., fundus photographs, visual fields, biometry, optical coherence tomography), and to demonstrate interoperability through IHE Eye Care.\(^ {15,16,21}\)

However, many ophthalmology devices and EHR systems continue to use proprietary formats defined by individual vendors. The authors believe that this locks ophthalmologists into particular vendors and into added fees for new devices, and that this ultimately limits the ability of EHRs to transform the practice of medicine efficiently. In the field of radiology, universal adoption of DICOM-based image storage and communication has facilitated rapid PACS implementation and improved quality of patient care,\(^ {22}\) while still allowing vendors to compete on features and price. Ophthalmology EHR systems that adopt an open standard approach for data storage and transfer will provide similar advantages for health information exchange, incorporation of clinical data into large-scale public health and research registries, and integration with clinical decision support systems to improve patient safety and compliance with evidence-based practice guidelines.

Future Directions for Electronic Health Records Systems in Ophthalmology

Technological advances and information management challenges are creating stronger incentives for ophthalmologists to adopt EHRs. Meanwhile, federal initiatives are creating rules for the meaningful use and formal certification of EHRs, along with both the incentive payments for physicians starting in 2011 and reduced payments for lack of adoption starting in 2015.\(^ {7}\) The authors hope that this summary will help ophthalmologists to identify important features when searching for systems and will stimulate vendors to recognize and incorporate these functions. In addition, we believe that the principles in this article provide a strategic framework for the large-scale deployment of ophthalmology EHRs to provide infrastructure for improved patient care and public health. To the extent that EHRs provide opportunities for ophthalmologists to maximize collaboration with primary care providers or other specialists, the Academy believes that they will improve the ability of ophthalmologists to contribute to the overall coordination of care, management of chronic disease, and quality of patient care.

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Footnotes and Financial Disclosures

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