Implementing Medical Algorithms for Use in Cardiology

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Abstract

A wealth of medical information exists in the form of published algorithms. These algorithms range from simple calculations to complex outcome predictions. Most clinicians use only a small subset routinely. The barriers to their use include the lack of knowledge that they exist, uncertainty about their boundaries, difficulty in converting to the units expressed in the algorithm, and lack of availability at the point of care. Algorithms would be more widely used if they were readily available in a practical format to clinicians, educators and researchers. Cardiology is knowledge-intensive and already well-computerized. Automation of medical algorithms relevant to cardiology can help to both distribute and apply medical information appropriately. This paper discusses the benefits, problems and issues in the development and clinical use of computer-based algorithms by cardiologists.

Medical Algorithms

An algorithm is defined as "a step-by-step procedure for solving a problem or accomplishing some end especially by a computer" [3]. Algorithms provide a means to achieve specific goals. They are used extensively in both computer science [4] and medical practice. To be of benefit they must be accurate, reliable, accessible and properly used.

We define a medical algorithm as any computation, formula, survey, or look-up table that is useful in healthcare. The purpose of a medical algorithm is to improve the delivery of medical care. A defining characteristic of algorithms is they are amenable to a programmatic representation. Data can be entered, processed according to formulas derived from the source material, and result in useful output.

Figure 1 shows 16 types of algorithms that were encountered during the construction of a centralized repository of such algorithms [5]. As can be seen from these descriptions, medical algorithms range from simple calculations to complicated formulas for predicting clinical outcomes.

1. Coding & look-up tables
2. Comparison with normal population standards
3. Data conversion
4. Decision rules & triaging
5. Decision trees & flow diagrams
6. Diagnostic criteria
7. Diaries & symptom tracking
8. Functional state description
9. Grading and scaling
10. Probability & statistical analysis
11. Prognostic scores
12. Questionnaires
13. Risk determination
14. Simple classification
15. Simple formulas
16. Therapeutic indications & contraindications

Figure 1: Types of Medical Algorithms

Algorithms Relevant to Cardiology
Numerous algorithms are available in Cardiology, and these may be used for diagnosis, management, monitoring or prognosis. Some typical algorithms include:

- Calculation of the body mass index (BMI)
- Calculation of anatomic areas and volumes from echocardiographic data
- Application of the Framingham data for predicting risk of cardiovascular disease
- Preoperative risk assessment prior to cardiac or noncardiac surgery.
- Identification of prognostic factors for short and long term prognosis following myocardial infarction
- Evaluation of exercise test findings
- Management of anticoagulation therapy in patients with atrial fibrillation
- Determining the severity of disease and level of disability

These algorithms may be used stand-alone, included in practice guidelines or embedded within medical devices. The fewer the barriers to use and the easier to access, the more readily these can be incorporated into actual practice. A web site **www.medal.org** (described later, and its Spanish mirror site **www.medal.org.ar**) currently makes available over 4,000 algorithms encoded as downloadable spreadsheets and includes about 200 cardiology-specific algorithms.

BENEFITS OF USING MEDICAL ALGORITHMS
Several authors have noted the value of medical algorithms in healthcare. McGinn et. al. note that validated clinical decision rules have "the potential to inform clinical judgment, to change clinical behavior, and to reduce unnecessary costs, while maintaining quality of care and patient satisfaction" [8]. Other researchers have noted that "quantitative methods to enhance clinical judgment would be of tremendous benefit to physicians caring for the critically ill" [9].

Some potential benefits of algorithm use include:

Improved Performance and Efficiency: Automation of algorithms should increase the speed of execution and reduce errors in their use. For example, an algorithm can help a physician validate his or her clinical impression and identify faulty assumptions [10]. Algorithms would have better documentation of performance, greater consistency, and reduced variability.

Expanded Scope of Practice: Cardiologists and other healthcare providers with access to algorithms can expand their scope of practice beyond the routine, especially for infrequently encountered problems. While an expert might still be consulted for a particular problem, algorithms may hasten and improve the consultation.

Quality Assurance: Clinical quality assessment (QA) and quality improvement programs can be enhanced if algorithms are used and their use is audited. This could reduce variation in care delivery [11] and allow for more meaningful comparisons between providers and institutions. The decision process can be documented through the storage of the data input and output.

Patient Self-Determination: Patients may benefit from algorithms targeted to their needs. Patients would be able to make more informed decisions.

Common Problems Encountered in the USE of algorithms
If algorithms can improve care, why are they underutilized? There are several barriers to utilization, many arising because of a lack of standard representation for algorithms.

Lack of proper documentation: on applicability, validity or level of evidence.

Errors or oversights in representation: problems in language translation or misunderstanding of terms.

Confusion about data units: Commonly involves

1. different standards between the United States and other countries,
2. different expressions for percentages (50% as 50 or 0.5), and
3. handling of large numbers (a count of 10,000 per microliter might be entered as 10000, 10 thousand, or 10*10^9).

Confusion in expression of formulas: Many users are unused to reading and understanding elements such as logarithms, exponentials, and bracketed elements.

Use of irrelevant or illogical data: An algorithm may sometimes make use of irrelevant or illogical data unrelated to clinical care, e.g. using the year of treatment to predict patient prognosis.

Uncertain transportability of data elements: The data input may involve analytical entities that have variation between institutions or countries due to different methodologies or populations, complicated by failure to specify the method or the reference range.

Difficulty in performing the requisite calculations without a calculator or reference tables: Advanced mathematical functions require calculation support.

Inability to transport interpretations: Predictive algorithms [8,12] are validated in a study population but may be poorly generalizable and transportable for use in other populations. Such predictive algorithms are possible if strict criteria are met [13].

Unresponsiveness to change: Many algorithms lack "responsiveness", that is they appear to have limited correlation between change in an algorithm's input and the patient's clinical condition [14].

Uncertain purpose: Occasionally it is apparent that the algorithm may not have been developed for any good reason (a score for the sake of a score) [15].

How problems may arise when using algorithms in clinical situations
Various types of errors can be introduced when using algorithms, such as:

Selecting the wrong algorithm for the patient, population or situation/Using an algorithm irrelevant or unresponsive to condition: Once an algorithm exists for a particular condition, the tendency may be to try to use that algorithm for ALL related conditions. Another problem is that the algorithm may be applied appropriately, but the algorithm is simply not adequate. For example,. McMurray et. al. found that the Oxford hip score raised issues related to the lack of clarity of the algorithm, the coverage, and the ultimate validity of the algorithm [16].

Making an error in remembering the algorithm (error of recall): Due to complexity.

Using a version out of date or with an error: Algorithms are constantly being revised and updated. Even a validated algorithm may be shown to be incorrect in a borderline population.

Using an algorithm that is too simple: An overly simple algorithm may be used when a more complex one is called for. This is a particular problem for people who are new or untrained in the use of the algorithm especially without supporting documentation.

Using an algorithm that is too complex: Use of an overly complex algorithm where a simpler one will do. The input data for the complex algorithm may be difficult, costly, or impossible to obtain.

Making an error during calculation or execution of the algorithm: Misreading the algorithm such as incorrectly applying brackets, or simply hitting a wrong button can cause a poor calculation.

Use on incorrect data. Most people are familiar with the saying, "Garbage in, garbage out." Ambiguous data can lead to input of the wrong information.

Failure to question the output of the algorithm: The user of an algorithm should always consider whether the result of the algorithm makes sense and if not, re-run the algorithm as well as potentially seek additional confirmation from other sources.

Inappropriate use of output. Ambiguous words or meaningless numbers are likely to be misinterpreted. Inappropriate use may occur when an algorithm is used outside of the intended population.

Benefits of an Automated Collection of Medical Algorithms
Automated medical algorithms can help to reduce errors by ensuring proper selection and application of an

algorithm. Some errors may be introduced as well, although these can be minimized through proper design and use of the system.

Reduced data entry errors: Linking the algorithm directly to the patient's data in an electronic medical record can significantly reduce errors and expedite access. In addition, the system can alert the user to nonphysiologic data, such as a body temp > 43.3C [17,18].

Elimination of calculation errors: Once the system has been shown to reliably calculate the algorithm then accurate calculations can be ensured.

Perfect recall of algorithm details.

Selection of the algorithm with appropriate complexity: The computer can suggest alternative algorithms, irrespective of complexity.

Selection of the best algorithm for population or situation: All constraints and assumptions are electronically stored and presented to the user for review. Many can be checked automatically and others can often be checked through questions at the front of the algorithm.

Appropriate use of output: Automated algorithms can provide not only the calculation capability, but also the reference to the interpretation of the output, thus ensuring that the output is used appropriately.

Use of most up-to-date version: As in many software packages, an automatic process can run whenever the program is started and a connection is available to see if there are any updates on a centralized server.

Large Scale: Although it is unlikely a "complete" repository will ever exist, large numbers of algorithms can be made available because content development can be cooperative with reduced duplication. Algorithms from other countries can be identified and translated. Under-represented areas can be identified, stimulating research.

Integration with Information Systems: To realize maximum benefit, algorithms must be integrated with clinical information. Algorithms embedded in clinical information systems can screen a patient's data, issue alerts and reminders, and monitor follow-up [19].

Evidence-Based Medicine: Evidence-based practice [20] may be facilitated. All algorithms in the repository are derived from published studies, usually peer-reviewed. Their use may therefore result in improved, evidence-based classification of patients, selection of diagnostic tests and use of therapeutics.

Global Resource: The algorithms can be translated into multiple languages, facilitating global distribution and collaboration at low cost. A global algorithm resource may benefit both developed and less developed countries [21,22] providing access to up-to-date medical knowledge. "Best practice" algorithms can help disseminate expertise. Algorithms can be modified to match the local needs of practitioners and societies with adjustments for local customs.

Education and Research: The algorithms and their associated documentation can be used as a resource for both initial and continuing education, and a library of tools useful in research.

Various Implementations of Medical Algorithms

Implementing such automated collections is an interesting problem due to the bewildering array of choices for computing platforms and networking technologies. The functionality, ease-of-use, and user acceptance of medical algorithms depends on the particular choices made during the implementation process.

There are three broad classes of delivery platforms for Medical Algorithms. These are mini or microcomputers, web/internet, and Personal Digital Assistants (PDAs). Each platform has its own benefits and issues. The implementation can be stand-alone, with the algorithm accessible on a single platform, or *networked*, with the user accessing the algorithm and data stored on a server by means of a wired or wireless network. Finally, the algorithm can be *embedded*, i.e., already built into a cardiology instrument or monitor.

Personal Digital Assistants have become increasingly popular with physicians. Their convenient form factor, easy portability, and increasing computing power make them an obvious choice as a platform for medical algorithms. These devices often boast very clear high resolution color screens. Users communicate with the

PDAs by means of a familiar device - a pen stylus - although learning the special handwriting gestures required may take some practice. There are two main operating systems for PDAs, namely the Pilot made by Palm Computing, and the Pocket PC from MicroSoft, Inc. Pilot compatible PDA hardware is manufactured mainly by Palm Computing, Sony, and Samsung, while Pocket PCs are manufactured by HP, Toshiba and others. Pocket PCs, originally based on Windows-CE, offer a limited degree of compatibility with Windows software. For example, there is a version of Excel which runs on both Windows and Pocket PCs. However, the Pocket PC version suffers from limitations such as the inability to run Excel VBA (Visual Basic for Applications) macros and fewer implemented functions.

A challenge to usability of medical algorithms on PDAs is a graphical user interface (GUI) issue, specifically the small screen size typical of most PDAs. For example, the color display of the relatively inexpensive Palm M130 model is only 2 inches by 2 inches (5 cm by 5 cm). Even though the display is clear and sharp, this small screen means that the total amount of information visible in a single screen is limited. The consequence of this limitation is a burden on developers to chop up the application into multiple pages, menu items and scrollable pages. This can lead to user frustration due to the necessity of having to scroll and/or page through numerous drop down lists and buttons. For example, an implementation of the Los Angeles Pre-Hospital Stroke Screen on a Palm Pilot has 3 separate screens and 5 drop-down lists while on a typical laptop or desktop machine the same application should require only one screen and the drop down lists could be replaced by more user-friendly radio buttons. Implementing even moderately data intensive algorithms such as Levine's Assessment of Carpal Tunnel Syndrome, a relatively trivial task for a typical 15" display, will need a non-trivial amount of GUI design ingenuity for PDA implementations.

Other issues include:
(1) The need to find and manually input all of the data. However, technologies to interface PDAs to biomedical sensors are being developed.
(2) Confidentiality of patient information if the device is lost
(3) Durability in clinical settings
(4) Backup and output into a medical record on the PDA

In spite of these issue, PDAs are definitely an important platform for dissemination and use of medical algorithms. The limitations described above should be seen as exercising the ingenuity of software designers rather than an insuperable barrier.

Medical Calculators vs. Medical Algorithms Systems
Another classification for implementations of medical algorithms is whether they are integrated in some way with a database or not. In the latter case, the algorithm implementation is that of a medical calculator with no functionality to save, update, or recall data/computations. While medical calculators can be useful, integration with the clinical information system offers far greater benefits. The ability to download data significantly reduces errors from data entry, while uploading consults can reduce clerical burdens. Integrated medical algorithm systems can be programmed to automatically select and run a suite of medical algorithms, providing alarms and other attention conditions depending on the clinical situation. The ability to graphically display sequential results in various formats over time can help the clinician understand and utilize the large amounts of data. Other benefits include validation for large patient populations and the capability to collaborate with specialists in different areas of medicine.

Stand-alone vs Networked Implementations
A stand-alone system is one that is not connected continuously by means of a wired or wireless network, to other computers, servers, or printers. Stand-alone implementations can function both as calculators and Medical Algorithm systems depending on whether they are integrated with a local database or not. Stand-alone database-enabled systems have some of the benefits of being connected with an HIS sucha s being able to save/recall computations and refer to patient histories. In principle, the databases of such systems can be synchronized with a host HIS by means of so-called "hot-sync" procedures. Depending on whether the algorithms are on a microcomputer or a PDA, the database size can range from relatively large to rather small. With advances in database storage for PDA's, such as memory sticks, database size limitations can be overcome.

Until rather recently, networking implied that the client computer had to be connected by means of wires to a local area network, and thence to the internet. However, over the last year, Wi-Fi networks have exploded in popularity. Typically, these are based on the IEEE 802.11 family of standards. The 802.11b standard yields data speeds of 10 Mbits/second, which is adequate for most purposes, including retrieval of still images and audio streams. Wi-Fi enabled PDA's include the BlackBerry (**www.blackberry.com**), Handspring TREO (**www.handspring.com**), Palm Tungsten series (**www.palm.com**). By means of a Wi-Fi flash card, most Pocket-PCs can also be wireless enabled. Some models such as the first three listed have built in thumb "keyboards". Such wireless networked PDAs have the benefits of comfortable form-factors and portability, while also being capable of being continuously networked to a database, HIS and/or LIS. With intelligent GUI design overcoming the screen size issues described above, medical algorithm systems could achieve ideal levels of usability and ubiquity. To ensure patient privacy and confidentiality the wireless network has to be made secure from nonauthorized access.

Medical Software Development Constraints

Legal Constraints: The potential for malpractice liability arising from the misuse of an algorithm is unclear. Intellectual property, copyright and patent protections issues must also be considered.

Regulatory Constraints: The US Food and Drug Administration has formulated regulations for medical software based on good manufacturing practices, similar to those used in the pharmaceutical industry [23].

Security and Privacy Concerns: HIPAA (Health Insurance Portability and Accountability Act) and other regulations to protect patient privacy rights indicate that the use, and results of algorithm use, must be kept secure and confidential.

Development Costs: The cost of programming the algorithms to be platform independent is high. However, standardization and automation can be useful to keep the cost at a reasonable level.

Validation of Algorithms: There still remains the issue of whether to believe an algorithm or not. For this issue, it is extremely important to document the source of the algorithm as well as any validation studies of the algorithm. In the area of medical algorithms called Clinical Decision Rules (CDRs), there has been some effort to describe standards for both the derivation and use of such rules [8].

ROLE OF HEALTHCARE INFORMATICS

Integration of medical algorithms into clinical practice requires solving a series of problems. Once a suitable algorithm has been identified, it needs to be transported into the local practice setting, with adjustment of laboratory values and other inputs for the population and analytical characteristics of the locale. Performance needs to be verified and the algorithm validated across the range of possible inputs. Finally, there needs to be ongoing responsibility for maintaining the algorithms and adapting them to changes in diagnostic and therapeutic modalities.

From practical and economic considerations, it is makes sense to centralize these activities in a Department of Health Informatics [24,25]. This allows for better standardization of the process and utilization of the required expertise. It also offers an environment conducive to performing the research required to develop new algorithms.

MEDAL (The Medical Algorithms Project)

The goal of the Medical Algorithms Project (**www.medal.org** and **www.medal.org.ar**) is to provide a collection of algorithms in a format that supports clinicians, programmers, and validators [5,26]. MEDAL uses a standardized representation of the algorithms that was designed to support future automation. There are four steps involved in the processing of algorithms for the MEDAL repository:

1. selection,
2. documentation,
3. implementation as a spreadsheet, and
4. implementation in a software application.

Algorithms specific to cardiology practice are contained in 2 chapters, with approximately 200 algorithms available. Other chapters contain additiontal topics that are relevant to cardiology practice. The algorithms have to be downloaded into a PC (or MacIntosh) so that they can be executed under Microsoft Excel, with documentation is available either online or in an accompanying Microsoft Word document.

Algorithms are collected from the biomedical literature, including research journals and textbooks. Algorithm selection is pragmatic. MEDAL is not intended to be a complex, vertical system nor an expert system. Documentation for the algorithms is abstracted from the medical literature. The abstract should help the user understand the algorithm implementation and determine if the algorithm is logical and medically valid. Reviewers can annotate the algorithm worksheet for clarification or commentary.

The spreadsheets are derived from the documentation and serve a number of functions:

1. A spreadsheet provides a degree of functionality that is accessible to most users.

2. It provides functionality that is easily modifiable, yet can be write-protected to safeguard against unintended changes.
3. A spreadsheet can be used by programmers for software development and in the validation of existing software applications.

The components for each spreadsheet are:

1. overview and reference to documentation,
2. unit conversion,
3. data entry,
4. intermediate calculations, if indicated,
5. interpretation, and
6. supplemental data.

To ensure the widest possible audience, the algorithms have been implemented in a Microsoft (MS) Excel workbook which can be freely downloaded from the MEDAL web site (**www.medal.org**). Each chapter is comprised of an MS Word document and MS Excel workbook compressed into one ".zip" file. The workbook contains the algorithms of the chapter, and the document has abstracts and references for the algorithms. Required software for decompression and conversion is available.

Each workbook contains a table of contents in which the listed algorithms are hyperlinked to their representation in the workbook. Within each worksheet, data entry areas are clearly identified. Other cells are write-protected. Modification of a spreadsheet requires extraction of the spreadsheet into a separate file before removing the protection.

Other implementations of algorithms as software applications have occurred to a limited extent. Selected algorithms have been implemented as Excel "add-ins" with graphic user interface (GUI) data entry methods, and as Palm OS-based applications.

MEDAL is currently in its 11th release. During the course of the project over 4,300 algorithms have been collected and processed. The algorithms have been organized empirically into 45 chapters. The chapters cover a broad range of medical information pertinent to most specialties. The MEDAL web site averages retrievals from over 1,800 unique visitors per day. The site has stimulated sufficient interest from Latin America to result in the creation of a Spanish language mirror site (**www.medal.org.ar**) based in Argentina. Development of this site has faced the challenge of also modifying content as necessary for a different practice environment.

Discussion and Conclusions

Cardiologists and other physicians are faced with an enormous amount of information to process. Many of the interventions are at risk for errors that can jeopardize patient safety. Technology that improves clinical efficiency can help reduce costs and enhance patient care.

Medical algorithms are one way for sharing medical information that can reduce errors. We have described a number of errors that can be minimized through the use of automated medical algorithms. We have also described ways in which potential introduction of errors by such automation can be minimized, primarily through rich communication of algorithm details and with validation. Since the ultimate responsibility for proper use resides with the clinician, there is a great need for such a complete representation of the algorithms that can be easily accessed.

MEDAL has been successful in collecting, categorizing and automating a large number of medical algorithms, and making them available for a worldwide audience. Our experience suggests that standardization can lead to more efficient automation, distribution and integration into useful software applications.

To improve the utility of the collection to practicing cardiologists and cardiology researchers further work must be done to improve algorithm classification, the comprehensiveness of the collection, and to deliver useful software implementations. This will require the involvement of medical informaticians, expert cardiologists, and software engineers. Interfacing to clinical information systems is needed to minimize data entry errors and to minimize user effort.

The MEDAL project currently is entirely self-funded; significant financial support would improve the chances for success. The Open Source software movement [27], (e.g. Linux [28]) provides an alternative self-supporting model for development. Web-based collaboration and communication software tools would facilitate this effort, as well as repository implementation & maintenance tools to facilitate the processes of review, classification and tagging.

Future implementations of MEDAL could support better searching and browsing through implementation in a relational database. It may be possible to identify the general attributes of algorithms, and to develop a rigorous taxonomy. Extensible markup language [29] (XML) may be useful in this restructuring effort.Each algorithm could be tagged in XML based on type, quality of supporting evidence, task applicability, clinical specialty, keywords (MeSH headings), patient population, publication of origin, authorship, etc.

Evolving standards in other areas must be incorporated where they arise. Examples include terminology standards (e.g. SNOMED, UMLS Metathesaurus), standards for decision support technologies (Arden Syntax [30]) and for clinical guidelines (GLIF [31]).

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