White Paper ■

Military Research Needs in Biomedical Informatics

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Abstract The 2001 U.S. Army Medical Research and Materiel Command (USAMRMC) Biomedical Informatics Roadmap Meeting was devoted to developing a strategic plan in four focus areas: Hospital and Clinical Informatics, E-Health, Combat Health Informatics, and Bioinformatics and Biomedical Computation. The driving force of this Roadmap Meeting was the recent accelerated pace of change in biomedical informatics in which emerging technologies have the potential to affect significantly the Army research portfolio and investment strategy in these focus areas. The meeting was structured so that the first two days were devoted to presentations from experts in the field, including representatives from the three services, other government agencies, academia, and the private sector, and the morning of the last day was devoted to capturing specific biomedical informatics research needs in the four focus areas. This white paper summarizes the key findings and recommendations and should be a powerful tool for the crafting of future requests for proposals to help align USAMRMC new strategic research investments with new developments and emerging technologies.

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Recognizing the recent advances in biology, medicine, information systems and computer technologies and their potential synergism and relevance to the U.S. Army Medical Research and Materiel Command (USAMRMC) mission,[1] the USAMRMC Telemedicine and Advanced Technology Research Center[a] (TATRC) convened a $2\,^1/_2$-day Biomedical Informatics Roadmap Meeting in spring 2001.[2] The goal of the meeting was to produce a roadmap or strategic plan to help align the Army biomedical informatics science and technology (S&T) portfolio and investment strategy with new developments and emerging technologies in this rapidly growing field. This review paper identifies research priorities that can form the basis for making new strategic research investments in biomedical informatics by the military in general and by the USAMRMC in particular. Availability of these military research initiatives to the civilian healthcare community can provide input for public policy, foster collaboration, and avoid duplicity of research efforts.

The Roadmap Meeting brought together approximately 90 attendees, including military materiel and combat developers, end users, members of the research community, and representatives of other government agencies who are engaged in biomedical informatics research. Speakers and participants were selected to provide a multidisciplinary group of attendees, with as broad a representation as possible from the government, industry, and academia, so that end users could lead technology developers to the

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[a]The USAMRMC is the lead U.S. Army Command for medical R&D and TATRC is the Command's advanced research branch, responsible for leading-edge research in a number of fields.

unique military needs. Reference 2 provides details about the meeting, including the agenda, copies of the presentations, biographies of the presenters, and transcribed records.

The first day of the meeting was devoted to presentations from members of the three services and representatives from other government agencies who described ongoing projects and identified informatics needs. The second day consisted of presentations on current and future research directions by representatives from the scientific, academic, and private sector communities. The morning of the third day was devoted to capturing specific biomedical informatics S&T research needs from four breakout sessions:

- Hospital and Clinical Informatics
- E-Health
- Combat Health Informatics
- Bioinformatics and Biomedical Computation

Within these four focus areas, participants identified several important areas of research needs, assigned them to three timelines—near-term (<2 years), mid-term (2–5 years), and long-term (>5 years)—and ranked them into top-, high- and medium-priority levels. Priority rankings reflect the potential impact of the research need and the degree to which a specific research is a prerequisite to other key research needs. Consequently, top-priority research ideas should offer the highest payoff. The priorities were set by the authors based on their knowledge of current Army programs and interests and from an initial list generated by the work group members at the meeting. An attempt was also made to recognize research needs for which related projects are currently sponsored through core USAMRMC funds, special interest Congressional appropriations managed by TATRC, and other Department of Defense (DOD) sponsored programs.

It is recognized that many of the biomedical informatics goals, barriers, and research needs identified here—in particular, the ones at the higher echelons of military care[3] corresponding to health care at general hospitals—are germane to the civilian setting and have already been reported elsewhere. In fact, during the past few years, several U.S. national level committees have attempted to define the barriers to the widespread use of computers and networking technology to improve health care delivery. Of particular note is a set of documents from the President's Information Technology Advisory Committee (PITAC). The PITAC Panel on Transforming Health Care presented a set of findings and recommendations to foster the impact of computational methods on biomedicine,[4] and the Panel on Digital Libraries discussed issues involved in the development of digital repositories of information.[5] Although the PITAC recommendations are designed primarily for the typical medical care setting in the U.S., they are even more critical in the military setting, where medics, with limited medical training, may be helping patients using a limited set of treatment modalities in an unfamiliar environment.[6] Additional notable reports describing social and technical issues—including topics ranging from the use of the internet as a technology for integrating information across the healthcare environment to the widespread access to medical data while maintaining privacy and security of the data and strategies for building the national health information infrastructure—were produced by the National Research Council[7,8] and the U.S. Department of Health and Human Services.[9]

The military needs and requirements in biomedical informatics exceed the ones in the civilian setting. The military health system supports a continuum of care starting at the point of injury in the battlefield (echelon I)—where resources are scarce and the "working" environment is dynamic and unknown in advance—all the way to Continental United States (CONUS)-based military and civilian hospitals (echelon V), resulting in additional requirements and system functionalities unequaled in the civilian environment. For example, the capability to perform remote life-sign detection of trauma casualties through nearly undetectable wireless networks,[10] which would help reduce morbidity and mortality of wounded soldiers in the battlefield, may have no parallel in the civilian setting. Furthermore, the combat medic (who is the "doctor" in the battlefield) has limited medical training, carries limited resources, and works in an unknown, often hostile, environment. Hence, additional medical informatics technologies addressing specific requirements and possessing unique functionalities are clearly needed for the military field environment and for linkage to upper echelons of care. Throughout the manuscript we highlight the similarities and differences between civilian and military biomedical informatics challenges and distinguish the unique military requirements from those already identified in the civilian literature.

This white paper summarizes the findings of the four breakout sessions, which were subsequently supplemented with contributions from key participants of

each of the four focus areas, analyses of the meeting presentation materials and transcribed records, and literature review performed by the first author. Each of the following four Sections, Hospital and Clinical Informatics, E-Health, Combat Health Informatics, and Bioinformatics and Biomedical Computation, consists of a summary statement and lists of identified qualitative performance goals, technology barriers, and research needs. These are followed by a Summary Section.

Hospital and Clinical Informatics

The Hospital and Clinical Informatics Group examined opportunities that enhance the design, facilitate the use, and expedite the deployment of computer systems to optimize inpatient and ambulatory medical care. In addition, the group also addressed technologies that could potentially improve the access to clinical data and medical knowledge by both patients and providers. Technologies spanning the range of issues from data capture to data integration and representation to decision support tools and to patient and provider access to data and knowledge were covered.

Goals

The Hospital and Clinical Informatics Work Group identified five key areas for improvement in the design and implementation of computer systems to support medical care. The areas identified are a common infrastructure for both the peacetime mission (which is identical to the customary civilian healthcare) and the war-fighting mission:

- Improved speed and completeness of data capture
- Improved integration of data sources and computing services
- Improved coverage and utility of decision-support systems
- Improved access by patients and providers to medical data (patient records) and knowledge (medical literature)
- Facilitation of interaction between patients, providers, and information resources to optimize patient care outcomes

Technology Barriers

Many of these key goals share common technological barriers. (Because of the technological nature of this report, we chose not to address other types of barriers, such as organizational and behavioral, in this section as well as the sections that follow). In particular, the mapping of medical terminologies and standards offer significant barriers that cut across many application areas and inhibit the faster development and deployment of medical computer-based tools. Overall, the technological barriers span the whole range of health care delivery from difficulties in acquiring data to the ability to summarize the data stored in longitudinal health records. Some of the major technical barriers to overcome include:

- Data capture techniques are too slow, awkward, or error-prone
- Need improved data integration technologies
- Need improved medical terminology mapping[11]
  1. From system to system to allow for data exchange
  2. From information system to decision-support systems
  3. From clinical terminology to lay terminology
- Data capture are not always integrated into patient care process
- Medical guideline description standards are not sufficient to encode all guidelines
- Better tools and methods are needed to expedite the guideline-encoding process and integrate encoded guidelines within institutional environments[12]
- Decision-support systems are not easily adjustable for different medical contexts
- Information retrieval systems do not support the precise retrieval of answers to biomedical questions[13]
- For patient data to be useful, it often needs to be summarized and put in the appropriate context
- Need improved mechanisms for sharing information between patients and providers
- Need to model and understand the medical care process and provider needs in support of successful installation of computer-based tools

Research Needs

Significant improvements in hospital and clinical informatics for inpatient and ambulatory medical care require near-, mid- and long-term research

Table 1 ■

Major Research Needs for Hospital and Clinical Informatics

Data Capture	Data Integration & Representation	Decision Support Tools	Data/Knowledge Access	
Analysis of current voice-activated transcription tools and pen-based note-taking tools +	Standardization of existing clinical terminologies to support data integration tasks ‡	Develop and standardize medical guideline description language ‡	Develop tools for the summarization and interpretation of clinical data *	NEAR-TERM < 2 years
Investigate how the clinical environment affects note-capture techniques +	Provide integrated approach to visualize complex clinical data to facilitate physician analysis * $	Develop and deploy tools for encoding medical guidelines into software ‡	Explore methods to facilitate online provider/patient communication +	
Investigate multi-modality user input (pen + speech + keyboard) ‡	Develop methods for translating between different database schemata ‡	Investigate how to adjust guidelines for use in diverse clinical environment *	Develop mechanisms to translate terminology from clinical to lay concepts *	MID-TERM 2–5 years
Investigate recovering structured information from transcribed clinical notes ‡		Improve precision of information retrieval techniques from the Web +	Develop easy-to-use technology for patient review of medical records +	
Design of high reliability multi-modal input device for clinical notes +	Integrate clinical guidelines with patient electronic medical records to allow automated use of decision-support systems ‡	Customize decision-support tools for patient use +	Design computer systems that support patient/provider review of the medical literature, including metanalysis of evidenced-based studies, as an aide to joint decision-making +	LONG-TERM >5 years
Advanced natural language processing to extract structured information from clinical notes +				

‡ = Top Priority * = High Priority + = Medium Priority $ = Currently Funded Project

strategies that address the identified technology barriers. The identified research needs can be structured into the following four technology areas: data capture, data integration and representation, improved decision support tools, and patient/provider access to data/knowledge. These four areas represent the natural progression of patient information flow in hospital and clinical settings—starting with the capture of a patient's records and ending with the access to structured data, clinical analysis, and medical knowledge by patients and providers.

Table 1 identifies the near-term (<2 years), mid-term (2-5 years), and long-term (>5 years) research needs under each one of the four technology areas. Each proposed research is also ranked according to top-, high- and medium-priority levels based on their potential impact in improving medical and clinical informatics and the degree to which a specific research is a stepping-stone to other key research needs. The priorities were set by the authors based on their knowledge of current Army programs and interests and on an initial list generated by the work group members. Related projects currently being funded through core MRMC research dollars, special interest Congressional appropriations managed by TATRC, and other DOD-sponsored programs are also identified.

E-Health

The facts that 55% of adult Americans with Internet access (52 million people as of November 2000) will go online in search of health-related information and that about 50% of those have said that such information has influenced a decision about treatment,[14] provides considerable challenges and opportunities for E-Health technologies to improve health care. Among others, the challenges stem from the vast amount of available information whose quality has not been assessed.[15] This is a mammoth challenge. To date, there are over 60,000 websites on breast cancer alone and over 40,000 sites on diabetes. On the other hand,

the rapid adoption of Internet-enabled and other information technologies provides significant opportunities to improve the quality of care delivered, drive economic efficiencies and reduce costs, facilitate the linkage of fragmented systems, and give consumers better access to information that can help them better understand and address their own health care needs.

The E-Health Group addressed a wide range of issues spanning from the lack of standards to technology gaps and from increased availability of online information to improved education opportunities for both patients and providers. These issues are relevant to both military and civilian requirements.

Goals

The broad goals of E-Health are to make information systems, both hardware and software, more supportive of provider and patient information needs to enhance satisfaction, quality, affordability, and portability of health care delivered while reducing errors, delivery time, and inconvenience. To achieve these goals the following needs have been identified:

- Development and adoption of standards
- Improved man-machine (device) interfaces
- Identification of technology gaps to bridge various health services support systems
- Improved interface among various applications and databases
- Improved information access by patients and providers to enhance decision-making
- Improved education of patients and providers about existing information technologies

Technology Barriers

Technology barriers that inhibit wider acceptance and faster deployment of E-Health from both the patient and the provider perspective have been identified. These include interoperability barriers among different applications and between new and legacy systems, such as the lack of mechanisms to lay new applications over legacy databases; man-machine interface barriers characterized by the lack of suitable user interfaces that provide expeditious and comprehensive view of the complete patient health condition; and performance indicator barriers reflected in the lack of quantitative measures to assess the quality of health care delivered by new information technologies. More specifically, the technology barriers include:

- Need to interface and/or integrate new applications with legacy systems
- Lack of standards for a core set of quality care measures
- Need to migrate from proprietary applications to standards-based, open source, generalizable, published applications and architectures to ensure interoperability
- Need user-friendlier interfaces that provide customizable, quicker, and easier access to desired information
- Lack of uniform evaluation criteria and automated methods to assess the quality of the ever increasing amount of online health care information[15]

Research Needs

Research that is needed to overcome the identified technical barriers falls into two categories: infrastructure and applications. Infrastructure research is needed to provide enabling technologies to overcome interoperability issues, reliability concerns, and technology gaps and to provide the foundation for the next-generation of E-Health systems. Applications research will support the development and deployment of new systems that will improve the safety (e.g., reduce errors), effectiveness, timeliness, and efficiency of health care delivered and that will relieve patients and providers from the painstaking tasks of fusing, sorting, searching, and extracting information from exponentially increasing health-related data sources. Table 2 identifies the near-term, mid-term, and long-term research needs in E-Health in these two categories. The research needs are supportive of both the military specific health care systems (known as the TRICARE system[16]) as well as public systems at large.

Combat Health Informatics

The Combat Health Informatics Group examined opportunities to improve the quality of combat medical care through the use of information and computer-based technologies. In particular, the focus was on technologies that address environmental stressors—a leading cause of non-battle illness[17]—and battlefield trauma—as the overwhelming majority of American combat deaths since World War II have occurred on the battlefield.[18,19] Technology barriers

Table 2 ■

Major Research Needs for E-Health

Infrastructure		Applications		
Develop technical and social approaches to data security/confidentiality	Investigate existing technology gaps *	Establish performance indicators of health care quality *	Develop evaluation criteria for qualification of medical Web sites * $	NEAR-TERM < 2 years
Investigate user-interface design issues on mobile platforms +	Develop modular, scalable and extensible software and hardware architectures +	Identify applications and tools that make individuals better users of health care systems +	Develop information repository/database to facilitate exchange of DOD R&D capabilities ‡	MID-TERM 2–5 years
	Define interoperability standards for next-generation systems ‡	Establish goals for improvement in care processes and outcomes +	Develop tools to empower individuals to manage their own health care +	
Analysis of wireless communication standards and reliability issues +	Develop evaluation processes for quality assurance of hardware and software systems +	Identify health metrics that could be passively and unobtrusively monitored by sensors +	Develop personal Web Page supporting individual health integrated with distributed, multi-site electronic medical records +	LONG-TERM >5 years
			Develop health sensors integrated into the home environment +	

‡ = Top Priority * = High Priority + = Medium Priority $ = Currently Funded Project

were identified that involve the entire process starting at the collection of physiologic data at the sensors to the transmission of information to the medic and hospitals behind the front line of the battlefield (upper echelons), including a central data repository system, and to the development of mathematical models for decision support. Accordingly, the work group recommendations include technologies ranging from sensing devices to communication systems and from data warehousing to system modeling.

Goals

The goal of Combat Health Informatics for the next five years and beyond is to improve the quality of medical care of the soldier in the battlefield through the use of information and computer-based tools. This near-term focus is critical, since time is of the essence in combat casualties, and systems to improve far-forward medical care will improve both battlefield and civilian healthcare.[20,21] More specifically, the goals include:

- Reducing the size and improving the reliability of physiologic sensor data and biosensor networks to effectively manage vast amounts of information in a timely fashion
- Identifying life-savings medical interventions and key physiologic parameters predictive of clinical outcome of trauma casualties
- Constructing trauma databases for knowledge extraction
- Developing decision-support systems to aid combat medics in emergency triage, including patient monitoring, diagnostics, treatment, and prognostics
- Developing computational tools to expedite and improve clinical training for medics, nurses, and doctors[22,23]

Technology Barriers

Opportunities to improve the combat medical health care are inhibited by several key research-related barriers. The most significant barriers fall within the areas of physiologic information and communication systems. The lack of understanding of which physiologic parameters are most useful in predicting trauma casualty outcome precludes the development of downstream decision-support tools, while the lack of compatible communications systems that move data seamlessly from the combat field through the various echelons inhibits information exchange and

precludes effective delivery of a continuum of care. The identification of these parameters and their implementation will improve the entire spectrum of healthcare, from far-forward battlefield to rear echelons to CONUS-based military and civilian hospitals. These research areas are applicable for battlefield (prehospital care), triage (emergency department evaluation), intensive care units, and operating theaters. Of interest, the technologies developed for the battlefield are exactly the ones that are lacking in supporting civilian disaster response and homeland defense. The technical barriers to overcome include:

- Lack of sensor information redundancy results in missing or corrupted data
- Lack of understanding of the salient informative physiologic data needed to develop decision-support systems and more effective training tools
- Need for database architecture that accommodates disparate data types from diverse sources
- Divergent information needs and difficulty of moving data through various echelons or from one civilian hospital to another
- Inadequate hardware and software compatibility for logistics and communications at all levels
- Need universal yet secure communication systems

Research Needs

Significant improvements in battlefield medical care and disaster response require near-, mid-, and long-term research strategies that address the technology barriers. The identified research needs can be structured into the following four fundamental technology areas: sensing devices, communications and control (such as a central "command center" to coordinate disaster response), data warehousing, and modeling and simulation (to predict ongoing consequences of disaster response). These technologies represent a natural progression of information that starts at the sensor level and moves through the echelons through various communications systems until it reaches a data repository or command center where analyses are performed and medical emergency decision-support systems and training tools are deployed.

Table 3 identifies the needed research under each one of these four technology areas. The identified research needs have elements that support legacy systems as well as new Army initiatives of the Objective Force strategy,[24] such as the Land Warrior system[25] and the Objective Force Warrior system,[26] that can reach a field-testing maturity level within the next five years. These future combat systems include medical informatics technology components, such as an array of biosensors embedded in the soldier's uniform and integrated with database management systems and decision support systems to provide assistance in casualty prevention and casualty management,[10,21] in an effort to improve force survivability and sustainability across the entire spectrum of military operations. Developments in these future battlefield healthcare systems could concomitantly be applied to civilian disaster response.

Bioinformataics and Biomedical Computation

The recent developments in the Human Genome Project[27] create both challenges and opportunities for the Army to extract knowledge from large amounts of gene and protein data that lead to the discovery of new drugs, diagnostics, and detection of chemical toxic and biological threats and diseases. The challenges stem from the need to ensure that researchers from bioscience and computer science, who generally "speak different languages" and have limited cross-disciplinary skills, work together in an effective manner. On the other hand, the mapping of new gene sequences and the discovery of protein 3D structures offer significant opportunities for the development of novel bioinformatics tools and algorithms that could expedite and reduce the cost of detecting and diagnosing biological threats, toxic exposure, and diseases. The Bioinformatics and Biomedical Computation Group focused primarily on software technologies that address challenges in bioscience and biomedical research and that provide infrastructure that supports the other three domains—Hospital and Clinical Informatics, E-health, and Combat Health Informatics.

Goals

The goal of Bioinformatics and Biomedical Computation is to speed the progress of bioscience and biomedical research through the power of computing to manage and analyze data that will support rapid scientific progress. It has been recognized,[28] however, that this goal cannot be achieved without cross-disciplinary collaboration involving researchers from both information science and technology and bioscience and biomedical research areas. In particular, the goals include:

Table 3 ■

Major Research Needs for Combat Health Informatics

Sensing Devices	Communication	Data Warehousing	Modeling	
Develop sensor validation algorithms *	Investigate field use of digital photography for assessing temporal changes of battlefield casualties +	Consolidate all post Vietnam combat casualty data in a single database *	Develop flexible (not "hardwired"), portable and realistic simulators and training tools ‡	NEAR-TERM < 2 years
	Develop interactive combat medic/medical support unit communications systems for reach back _	Construct civilian pre-hospital (emergency transport) physiological trauma database ‡ $		
Develop a wearable biosensor network to monitor physiologic state and injuries of soldiers ‡ $	Develop portable "dash-board" communications architecture to facilitate overall information exchange _	Develop computer systems capable of integrating, storing and retrieving complete patient's records coming from sources ranging from the battlefield to the hospital +	Identify physiologic parameters predictive of clinical outcome of trauma casualties to develop predictive models and decision support systems ‡	MID-TERM 2–5 years
Conduct research on sensors and systems for psychological assessment and interventions to reduce stress * $	Develop data communication systems to transmit continuous and intermittent soldier physiologic status data through various echelons _			
Develop non-invasive scanning hand-held sensor device and portable "plug-and-play" monitor for injury assessment * $		Develop database management systems that support ad-hoc query of streaming and historical time-series data * $	Develop computer-based medic aids for triage of unforeseen injury conditions *	LONG-TERM > 5 years

‡ = Top Priority * = High Priority + = Medium Priority $ = Currently Funded Project

- Fostering interdisciplinary research involving the collaboration of bioscentists and computer scientists
- Creating better algorithms and tools to analyze genomic and proteomic data
- Investigating the use of distributed databases consisting of heterogeneous types of data to identify, prepare for, and respond to emerging biological threats or diseases
- Identifying specific applications of high-performing computing and communications (HPCC) that would enhance Army medical research[29]
- Encouraging the development of applications that would benefit from the large bandwidth of the Next-Generation Internet

Technology Barriers

A number of technology barriers inhibit the faster development of bioinformatics and biomedical computation, precluding the invention of more insightful tools that would improve understanding and extraction of knowledge from the immense and fast growing genomic and structural genomic databases. Some barriers are related to the lack of basic understanding of how genes—and the proteins they instruct the body to make—work. A better understanding of these phenomena would lead to a more expedient development of analytical tools and would help improve the accuracy of simulation models and knowledge extraction algorithms. Other barriers relate to the lack of standards and methods associated with data acquisition, representation, archival, and retrieval. The noted technology barriers include:

- Lack of standards for data characterization and storage in databases
- Need to store massive amounts of data, which are being generated at exponentially increasing rates
- Lack of flexible methods for indexing information and for purging/adding obsolete/new information

- Need for new data acquisition, registration and storage methods to accommodate disparate data types from diverse sources collected at different times
- Inadequate data mining tools and algorithms for information visualization, knowledge extraction, and intelligent ad-hoc query in an ever-increasing data-rich environment
- Inadequate security systems to protect networked computers and linked databases
- Need to understand how genes and protein work and identify functional markers
- Need for multiple data representation schemes to accommodate different user needs

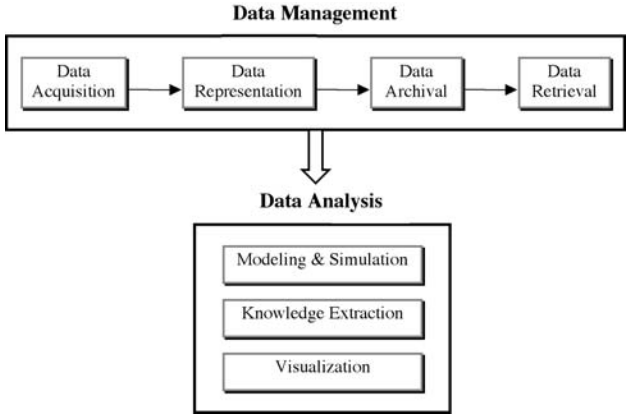

Figure 1 Research needs in Bioinformatics and Biomedical Computation.

Research Needs

Research that is needed to overcome technical barriers falls into two broad areas: data management and data analysis (Figure 1). Research in data management addresses the four logical sequential elements (data acquisition, data representation, data archival, and data retrieval) of data processing from the point data are acquired to the point they can be retrieved for mining and analysis. By and large, the identified research needs in these four elements are not necessarily unique to the Army environment as they represent basic needs that encompass applications in any environment involving significant data collection. Research needs in data analysis, on the other hand, consisting of modeling and simulation, knowledge extraction, and visualization algorithms, potentially have more components that are unique to the Army Bioinformatics and Biomedical Computation environment and should, therefore, be the primary focus of the USAMRMC strategic investments in this area.

In bioinformatics, data analysis tools are not being invented at the same rate that gene and protein data are being generated, continuously increasing the gap between available information and acquired knowledge. To make effective use of the large amounts of data being generated, new, more insightful data mining and analysis tools need to be developed.[30] These and other research needs in data analysis as well as in data management are identified in Table 4.

Summary

This review paper summarizes the key findings and research recommendations in each of the four focus areas, Hospital and Clinical Informatics, E-Health, Combat Health Informatics, and Bioinformatics and Biomedical Computation, covered at the USAMRMC Biomedical Informatics Roadmap Meeting. In general, each area had distinct aims and recommendations, although there was some overlap between Hospital and Clinical Informatics and E-Health, because the character of the problems in these areas are quite similar. An attempt was also made to identify similarities and differences between civilian and military biomedical information challenges. Of interest, because of the recent terrorist attacks to the U.S., many of the challenges once considered unique to the military may now be associated with homeland defense and, hence, related to public health care.

Analysis of the results identified several fields of research as being important across all four areas. Most notable of these "cross-cutting" issues are the needs for: (a) developing natural language processing software with semantic capabilities to enhance and expedite information retrieval and facilitate the man-machine interface; (b) investigating technologies that allow for seamless integration and interoperability of promising new systems and applications with legacy systems and databases; (c) establishing standards for guideline description languages, interoperability of next-generation systems, and data exchange formats, including data representation, characterization, and storage; and (d) developing methods to integrate multimodality data from distributed databases.

Although these common research needs are important in and of themselves, in general, they are not unique to the Army. They are symptomatic of the

Table 4 ■

Major Research Needs for Bioinformatics and Biomedical Computation

Data Management		Data Analysis		
Develop improved systems for data/information search and retrieval *	Develop Web-based tools locating and integrating information from distributed and diverse database sources *	Develop algorithms for automated image synthesis +	Develop algorithms for analysis of gene and protein array expression patterns for diagnosis of exposure to toxic and biological threats ‡	NEAR-TERM < 2 years
Develop intelligent natural language processing capabilities for database querying ‡	Develop new networking algorithms to harness the power of thousands of dormant computers +	Develop HPCC systems for medical simulation, visualization, and training *	Develop HPCC systems for modeling molecules and simulating protein structures to improve basic understanding * $	MID-TERM 2–5 years
Establish standard data exchange formats that allows for seamless system interoperability +	Develop innovative database technologies and standard query that accommodate multiple data representations +	Conduct research on predictive algorithms that can handle high-dimensional data in sparse data sets +	Develop algorithms for extracting knowledge from protein primary and tertiary structure information and identify functional markers * $	
Develop a comprehensive biological threat database that transforms dispersed biological threat resources into integrated and interconnected information resources ‡		Investigate evolutionary programming algorithms capable of automatically writing and debugging software _		LONG-TERM >5 years

‡ = Top Priority * = High Priority + = Medium Priority $ = Currently Funded Project

"curse of the information age," in which many different technologies are being developed at an accelerated pace without a firm foundation and oftentimes lacking adequate interoperability. While the USAMRMC should closely monitor progress in these areas, it should focus its resources in niche research areas that address unique military needs, such as the development of:

- Information repository/database to facilitate exchange of DOD R&D capabilities
- Wearable biosensor network to monitor physiologic state and injuries/illnesses
- Data communication systems to transmit continuous and intermittent soldier physiologic status data through various echelons
- Military casualty database to warehouse detailed documentation of all military engagement casualties in the post-Vietnam era
- Civilian pre-hospital physiologic trauma database to allow the identification of life-savings interventions and key physiologic parameters predictive of clinical outcome
- Flexible computer-based medic aid for triage of unanticipated injury conditions
- Comprehensive biological threat database that transforms dispersed biological threat resources into integrated and interconnected information resources
- Analysis algorithms of gene expression and protein folding patterns for diagnosis of exposure to biological agents and chemical toxics

Although the USAMRMC has recently started sponsoring research in some of these areas, such as the collection and analysis of prehospital trauma data for the identification of salient physiologic parameters predictive of clinical outcome, research efforts in emerging, less mature areas are yet to be formalized. For instance, bioinformatics, linking data-driven machine-learning computational algorithms capable of analyzing huge quantities of gene and protein data in an expeditious manner to gain insight into therapy, drug targeting, and diagnosis of biological threats, provides one such example that would be of particular benefit as it cuts across all four major research focus areas of the Command.[1]

The USAMRMC and the research community at large should benefit from the findings summarized here as this paper provides increased awareness of both the challenges and opportunities that lie within the realm of Biomedical Informatics and the particular Army needs in this field. Furthermore, it provides sufficient information to craft a science and technology pathway for guiding funding priorities and future solicitations.

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