A Taxonomy of Telemedicine Efforts with respect to Applications, Infrastructure, Delivery Tools, Type of Setting and Purpose

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Abstract

In the history of telemedicine, various definitions have been published and numerous terminologies have been coined. The introduction of new technologies played an important role in the changing definitions. After three decades of experience in telemedicine and its variations, the need for a single taxonomy that is detailed enough to define all the terms introduced until today is evident. Taxonomy we propose takes into account purpose, application area, delivery tools, communication infrastructure, and delivery setting dimensions. The purpose is to create a taxonomy that can explain how these dimensions fit together. Our taxonomy helps to categorize and compare current/future telemedicine efforts and plan several emerging telemedicine scenarios using new technology. The paper concludes with an explanation of how the proposed taxonomy can be used by parties involved in telemedicine as a diagnostic tool, and can help them to understand their needs and capabilities for participating in next generation healthcare environments.

1. Introduction

Telemedicine and related healthcare technologies aim to provide efficient healthcare to improve the well-being of patients and bring medical expertise at a lower cost to the right people at the right time. The health expenditures as a share of Gross Domestic Product (GDP) have been rising in the United States and other member countries in the Organization of Economic Cooperation and Development (OECD) since 1960s. A study, conducted to justify the reasons of this increase, concluded that Information technology (IT) is playing an important role to reduce increasing costs [1]. However, experts around the world believe that new demands in providing healthcare will require fundamental changes in the structure of the industry. Besides the failure to disseminate medical knowledge fast enough or use it in a methodical manner, there is another shortfall: medical practitioners with scarce, specialized knowledge cannot bring it to bear beyond their geographical confines [2-4]. Telemedicine's effort to bridge this gap has been reported repeatedly [2, 3].

Telemedicine and associated technologies are touted as critical to solve the above mentioned problems. As a result of growing interest in telemedicine during the last decade [5], many telemedicine applications have been developed and deployed during recent years [6]. Telemedicine has various potential uses such as clinical, educational and administrative. The promising potential of bringing high quality service to under-served areas via telemedicine is an example of how IT can reduce the quality-adjusted cost. Bashshur [7] notes that telemedicine provides a solution to the problems such as access to care for large segments in the population, continuing healthcare cost inflation, and uneven geographic distribution of quality (1) by enhancing accessibility to care for underserved populations, (2) by containing cost inflation as a result of providing appropriate care to remote patients in their home communities, and (3) by improving quality as a result of providing coordinated and continuous care for patients, targeted and highly effective continuous education for providers, and highly effective tools for decision support.

Besides all the promises outlined here, telemedicine is still a black box for public. The authorities have not yet reached a consensus on a clear and precise definition of telemedicine content and boundaries [7]. What is telemedicine and how does it differ from traditional medicine? What are the new laws and regulations needed to bring this technology across the globe? In this study, we will try to provide a broad definition of telemedicine and make a first attempt to introduce a taxonomy that will help all stakeholders of telemedicine applications to understand the five dimensions that it introduces. This taxonomy can also be used to understand the differences between traditional medicine and telemedicine.

We will classify telemedicine applications based on

their potential use by taking the medical domains they serve into consideration. The goal is to identify the IT infrastructure needs and requirements for each of these applications in order to provide a satisfactory telemedicine experience to end users. There is a variety of applications, devices, and communication technologies that are used in telemedicine. The reasons for this variety are (1) the diversity of telemedicine locations and physical limitations of each location; (2) the application areas that utilize the telemedicine applications; (3) the purpose of the use of telemedicine. Communication technologies, such as telephone lines, internet, or leased lines, also have a critical impact on the applications utilized in telemedicine and hence on the outcome. A telediagnosis case in psychiatry domain and a teleconsultation case in telecardiology domain are expected to have different requirements since the information that is necessary to make a clinical decision differs based on the application domain. Therefore, it is not fair to expect similar results from the same technology when it is used in different domains and/or for different purposes.

The rest of the paper is organized as follows. In Section 2, we provide a brief background and evolution of telemedicine. Section 3 introduces our taxonomy based on five dimensions that we propose. Each of these dimensions is explained in the same section. In Section 4, we present classification of various papers in literature based on the new taxonomy as an example of how this taxonomy can be used for classification and comparison purposes. We finally conclude the paper in Section 5 with a discussion on implication of this study and future research possibilities.

2. Background and Evolution

The evolution and growth of telemedicine is highly correlated with the developments in communication technology and IT software development. This dependency is evident if we quickly browse through the history of telemedicine technologies, which was categorized into three eras [8]. All the definitions during the *first era* of telemedicine focused in medical care as the only function of telemedicine. The first era can be named as telecommunications era of the 1970s [8]. Telemedicine programs during the first era ended as the government terminated the funding before these programs got mature. It is important to note that "telemedicine is a product of the information age, just as the assembly line was the product of the industrial age." [8]. The application in this era was dependent on broadcast and television technologies where telemedicine application was not integrated with any other clinical data.

The *second era* of telemedicine, dedicated era, started during the late 1980s as a result of digitalization in telecommunications and it grew during 1990s [8]. The transmission of data was supported by various communication mediums ranging from telephone lines to Integrated Service Digital Network (ISDN) lines. The high costs attached to the communication mediums that can provide higher bandwidth became an important bottleneck for telemedicine.

Dedicated era has turned into an Internet era where more complex and ubiquitous networks are supporting the telemedicine. The *third era* of telemedicine is supported by the technology that is cheaper and accessible to an increasing user population [8]. The enhanced speed and quality offered by Internet2 is providing new opportunities in telemedicine. In this new era of telemedicine, the research strategies should include "…an understanding of the functional relationships between telemedicine technology and the outcomes of cost, quality, and access." beyond the assessment of technical sufficiency [8].

During the evolution of telemedicine, new terminologies were developed as the applications and delivery options increased in variety and the application areas expanded to almost all the fields medicine can cover. This resulted in confusion and identification of what falls under telemedicine and what falls under telehealth or e-health became more complicated as the field advanced. Cybermedicine was another term introduced lately to the literature.

Since the first formal definition of telemedicine by Bird in 1971, many researchers tried to define this term in order to clarify the boundaries of telemedicine and its use. Even though the core of these definitions is the same, telemedicine, and hence its definition, evolved dramatically as a result of the tremendous changes experience in the telecommunication and information technologies. These changes were so significant that new terminologies like telehealth, e-health, and others were introduced, and explaining the difference between telemedicine and these new terms became important. Studies defined telehealth as a big umbrella that encompasses more applications than the definition of telemedicine can cover [9, 10]. Table 1 presents a selected list of definitions proposed in the literature for telemedicine, telehealth, and e-health.

Table 1. Definition of terms

Definition	Ref.
Telemedicine is the practice of medicine without the usual physician-patient confrontation …via an interactive audio-video communications system.	1971 Bird [8]
Telemedicine is a system of care composed of six elements: (1) geographic separation between provider and recipient of information, (2) use of information technology as a substitute for personal or face-to-face interaction, (3) staffing to perform necessary functions (including physicians, assistants, and technicians), (4) an organizational structure suitable for system or network development and implementation, (5) clinical protocols for treating and triaging patients, and (6) normative standards of behavior in terms of physician and administrator regard for quality of care, confidentiality, and the like.	1975 Bashshur [8]
Telemedicine is the use of electronic information and communications technologies to provide and support healthcare when distance separates the participants.	1996 Committee on Evaluating Clinical Applications of Telemedicine [11]
Telemedicine is the delivery of health services when there is geographical separation between healthcare provider and patient, or between healthcare professionals.	2001 Miller [12]
Telemedicine is the provision of healthcare services, clinical information, and education over a distance using telecommunication technology.	2001 Maheu [9]
Telehealth is the removal of time and distance barriers for the delivery of healthcare services or related healthcare activities. (In this study, telemedicine is a subset of telehealth)	2001 American Nurses' Association [10]
E-health refers to all forms of electronic healthcare delivered over the Internet, ranging from informational, educational, and commercial "products" to direct services offered by professionals, non-professionals, businesses or consumer themselves.	2001 Maheu [9]

This list of definitions gives an idea about the competing terminologies and more terminologies may be introduced in the future as the technological advances are achieved. Therefore, it is important to understand that the purpose of research in this field is to support the "ultimate quest" which is to cure disease, prevent it if possible, reduce infirmity, and enhance quality of life, as stated by Bashshur [7].

"Some may question whether this is telemedicine, telehealth, e-health, health informatics, or biohealth informatics. It does not really matter what we call it or where we draw boundaries. …collective and collaborative efforts from various fields of science, including what we call now telemedicine is necessary. [7]"

It is important to note that the ultimate goal of any telemedicine effort is to improve the well-being of the patients. The taxonomy proposed in this paper can be extended to cover all possible dimensions that are necessary to define all of these terminologies. However, this study will only focus on the clinical applications of telemedicine and leave the details of the other sections to future research.

3. Taxonomy of Telemedicine

Previous attempts [11] to classify telemedicine were motivated by the demand for evidence of its effectiveness and therefore were focused on coming up with a strategy to evaluate the telemedicine applications and their effects on quality, accessibility or cost of healthcare. A broad classification, which is more focused on identifying different dimensions of telemedicine and telehealth, and which can then be used to identify user requirements for different categories in an organized manner, will have an impact on the use and development of applications. We propose five dimensions that will help us categorize different telemedicine efforts. These dimensions were driven from our literature review and they reflect a combination of various classification schemes proposed in the early studies. First subsection will provide description of these five dimensions, Application Purpose, Application Area (Domain), Environmental Setting, Communication Infrastructure, and Delivery Options. Next subsection will explain how these dimensions interact in our taxonomy.

3.1. Definition of Taxonomy Dimensions

Application Purpose refers to the purpose of communication and is categorized under two main groups: Clinical and Non-clinical [13]. In 1996 Committee on Evaluating Clinical Applications of Telemedicine published their report [11] and classified

clinical application of telemedicine under six categories (p.30): (1) initial urgent evaluation, (2) supervision of primary care, (3) provision of specialty care, (4) consultation, (5) monitoring, and (6) use of remote information and decision analysis resources to support or guide care for specific patients. We believe that in addition to these six categories, clinical purpose covers diagnostic and treatment (surgical and non-surgical) components of patient care as well. Telemedicine is not only providing a tool that can be utilized by professionals, it is slowly moving in the direction where a patient can be treated through electronic channels without intervention of a local supervisor. Hence, Table 2 extends the previous classification and presents a list of clinical telemedicine application purposes.

Non-clinical purpose includes medical education, administrative meetings and does not involve decisions about care for particular patients. Table 3 shows non-clinical purposes that will be utilized in this taxonomy. This paper will not focus on the non-clinical applications of telemedicine. However, we are aware of other groups working on various classifications of applications for non-clinical purposes one of which is a study on developing ontology of IT-based medical education.

Table 2. Clinical application purpose

Clinical	Triage
	Diagnostic
	Non-Surgical Treatment
	Surgical Treatment
	Consultation
	Monitoring
	Provision of specialty care
	Supervision of primary care

Table 3. Non-Clinical application purpose

Non-Clinical	Professional Medical Education
	Patient Education
	Research
	Public Health
	Administrative

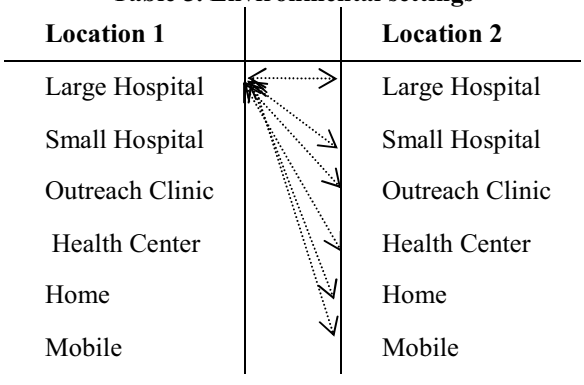
Application Area refers to the domains in the medical field. The domains listed in Table 4 represent a high-level example list of medical domains and can be expanded as necessary. The reason for including medical domains as a dimension in this taxonomy is to point out the domain specific differences that affect the information required and gathered through communication channels. For example, the information required to make a diagnostic decision may differ significantly in cardiology domain compared to psychiatry domain. Information can be in various formats, such as text, audio, video, and the application purpose and application area defines the amount and type of information required to make a clinical decision. Based on our current knowledge of the literature, we have not come across any studies that identified the application domain as a classification criterion for telemedicine efforts.

Table 4. An example list of application areas

Neurology	Home Care	Microbiology and Immunology
Cardiology	Ophthalmology	Mental Health
Pathology	Dermatology	Otolaryngology
Radiology	Rheumatology	Emergency Room
Pediatrics	Surgery	Obstetrics and Gynecology

Environmental Setting refers to the type of physical environment that the physician or the patient will be using during the telemedicine event. These settings can be dramatically different and can range from a patient at a primary care hospital to a mobile patient, or a professional at a fully equipped hospital to a professional being reached at home. Considering the physical environment attributes of medical videoconferencing identified in [14], a difference in the quality of the information transferred between two ends is inevitable regardless of the communication channel, as long as the two sites involved are not identical in terms of environmental setting. These physical attributes are usually related to the characteristics of the physical location. Therefore, environmental setting was included in this taxonomy as the third dimension. Table 5 illustrates some possible telemedicine settings that can be encountered during a telemedicine event.

Table 5. Environmental settings



LeRouge et al. [14] provided a list of physical environment attributes for videoconferencing. These

attributes were facilitating décor, quite/soundproof environment, privacy of the exam room, space and room size, and room lighting. Some of these attributes are very specific to videoconferencing. However, some of them can be generalized to various delivery options. The main idea is to be able to provide a meaningful description of the physical setting and environmental values with regards to the telemedicine event. Personal preferences as well as patients' skills and physicians' skills should also be taken into consideration while assessing the feasibility of a telemedicine system use by the parties involved. Some patients may be capable of performing related tasks only through the help of others as noted by Kaufman et al.[15]. Therefore, environmental setting attributes should include an indicator for the presence of assisting personnel and their relevant skills.

Communication Infrastructure refers to the channels that are available for the transmission, emission, or reception of data or information in any format. Communication infrastructure can be based on wired networks, radio waves, fiber optic lines, and many other forms of telecommunication technologies. Each of these technologies has their own limitations and advantages that need to be considered carefully before a telemedicine event occurs. Understanding the possible limitations, available resources, and how these various factors can affect the telemedicine event is critical for achieving satisfactory experiences. Table 6 illustrates some of the available communication infrastructure options as a function of telecommunication technologies that can be used in a telemedicine event and bandwidth they could provide.

Table 6. Telecommunication technologies and their bandwidth capabilities

	Technology	**Bandwidth**
Wired	Dial-up	33.6kbps
	DSL	64kbps – 1.544Mbps up 128kbps-1.544Mbps down
	Cable Modem	200kbps – 2Mbps
	High Speed	10/100Mbps to 1Gbps
Wireless	802.11b	11Mbps
	802.11g	54Mbps
	802.16a	70Mbps
	3G	144kbps-1Mbps
	2G	>128kbps

Delivery Options is the final dimension of our taxonomy and it refers to the applications provided to conduct a telemedicine event by fully complying with the requirements generated based on the other dimensions explained above as well as the requirements posed by the professionals and patients. Even though various delivery options are available in today's innovative technology environment, delivery options in telemedicine can be categorized under two main groups [9, 16]: (1) synchronous and (2) asynchronous. Information transactions that occur among two or more number of participants simultaneously are called synchronous communications. In asynchronous communications these transactions occur at different points in time [17]. Table 7 presents some examples of these delivery options based on these two main categories. The chosen delivery options can have an important effect on the final quality of the telemedicine event and the outcome.

Table 7. Delivery options

	Synchronous	Asynchronous
Audio	Telephone, Audioconferencing	Voicemail
Video	Videoconferencing	Video/Audiostreaming
Data	Instant Messaging, Shared Electronic white boards	Paging, Fax, Email, Web Pages, Store and Forward, Web Forums

3.2. Interaction of Proposed Dimensions

These five dimensions can be grouped under two main themes. First two are dimensions strictly related to the medical field and hence, they are grouped as medical dimensions. The next theme is formed of three dimensions (environmental setting, infrastructure, delivery options) that are related to the way healthcare is delivered. All three dimensions have one common goal, that is, to support the medical dimensions' needs while delivering health services. Therefore, they are grouped under delivery dimensions. A simple picture of our taxonomy is presented in Figure 1.

As Figure 1 illustrates, there is an additional group called organizational dimension in our taxonomy that is pervasive to all healthcare organizations and their activities. This group consists of important aspects of any organization such as human resources and IT management. Two other important dimensions that were excluded from this study but have significant importance for future telemedicine efforts are cost and legal issues, which we also grouped under organizational dimensions. These issues were not studied in this paper since the main focus was the higher levels of the taxonomy. However, future studies should be conducted to understand the effects of organizational dimension on the final outcome of telemedicine applications.

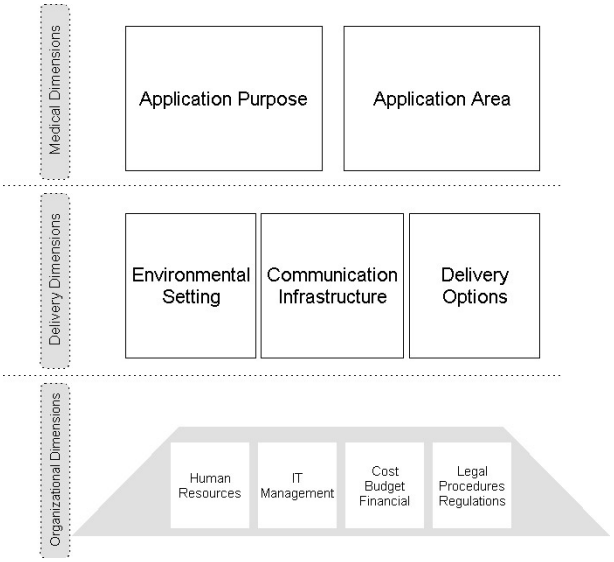


Figure 1. Telemedicine taxonomy

In this study, we concentrated on the five core dimensions of telemedicine to provide a simple way of identifying different efforts. These core dimensions will eventually affect the cost and legality of the telemedicine applications. Legal issues and cost have been discussed before and have been very important for the healthcare industry. One study [18] reported how the laws regarding telemedicine are being enacted by different states and how the cost of these applications are affecting the decision making process. Further studies are necessary to understand how the core dimensions can make a difference on the decision-making processes of lawmakers and payers.

4. Classification of Literature Based on the New Taxonomy

We selected 13 articles from the recent literature that are representative and diverse examples of telemedicine applications. We applied our taxonomy to classify this broad range of telemedicine efforts and presented it in Table 8 as an example of how this taxonomy can be used as a classification and comparison method.

Table 8. A classification of literature based on the proposed taxonomy

Paper	Application Area	Purpose	Delivery Option	Communication Infrastructure	Environmental Setting	Outcome and Results
Clarke et al. 2000 [19]	Tele cardiology (Cronary Artery Disease)	Consultation (Initial Cardiological Investigation)	Desktop Videoconferencing and Electronic Data Exchange	Satellite Link (512kbps>BW BW>128kbs) to ISDN	Clinics in Remote Areas and a mainland hospital	Early diagnosis of a disease that can kill quickly.
Eich et al., 2004 [20]	Tele radiotherapy	Diagnostic Consultation Prescription	Teleconference and Electronic Data Exchange	Mobile carries, ISDN, analog phone lines	Radiotheraphy reference centers and study centers	Improved information flow and reduced delays in treatment.
Glykas and Chytas, 2004 [21]	Chronic Diseases – Asthma Homecare	Consultation Monitoring Education	Web-based data gathering and information delivery	Internet using mobile, wireless or wired connections	Anywhere to Surveillance Center in the hospital	Increased the efficiency of doctors work and enhanced the well being of the patients
Gonzales, 2002 [22]	Cardiology Pediatric Psychiatry Neurosurgery	Consultation Monitoring Second Opinion Emergency	High Quality Videoconferencing and electronic data exchange	ISDN	Between health centers, accident and emergency coordinating centers, district and leading referral hospitals	Both patients and doctors are satisfied and patients prefer telemedicine to transferring to a referral hospital

Table 8 (continued). A classification of literature based on the proposed taxonomy

Paper	Application Area	Purpose	Delivery Option	Communication Infrastructure	Environmental Setting	Outcome and Results
Kerner et al., 2004 [23]	High Risk Pregnancy surveillance Obstetrics and Gynecology	Monitoring Homecare	Portable Monitors, Electronic Data Transmission, Audioconferencing	Analog Phone lines	Patient's home and clinic	It is safe and feasible for high-risk pregnancies. Patient satisfaction was high.
Kaufman et al., 2003 [15]	Chronic diseases – Diabetes	Monitoring Elderly Homecare	Web-based, PC-based	Not mentioned	Elderly patients at home	Usability is critical for success. Interfacing with a computer is problematic for some patients.
Oberleitner and Laxminarayan, 2004 [31]	Autism	Diagnosis Treatment Therapy	Store and Forward, Videoconferencing	Internet	Patient's home and hospital	Provided quick and efficient medical consultation, behavioral interventions, and other services and support.
Kim et al., 2001 [24]	Surgery	Collaborative Diagnosis Treatment Planning Second Opinion	PC-based Simulation	Internet	Multiple locations mainly clinics and hospitals.	Network latency and rendering performance was quite tolerable. Latency depends on the amount of network traffic.
Bouchard et al., 2004 [25]	Psychology Psychotherapy	Treatment	Videoconferencing (Tandberg), Fax, Document Camera	ISDN (384kbps)	Hospital to local clinics	They compared telepsychotherapy with face-to-face therapy. Videoconferencing is found to be an effective tool for the delivery of empirically validated treatment.

Table 8 (continued). A classification of literature based on the proposed taxonomy

Paper	Application Area	Purpose	Delivery Option	Communication Infrastructure	Environmental Setting	Outcome and Results
Olsen et al., [26]	Radiotherapy	Treatment Planning and Evaluation Consultation	Videoconferencing, Remote image display and sharing	1.5MB T1 lines	Main clinic center and satellite clinic units	Improved regional integration of specialized radiotherapeutic treatments and participation of many centers in clinical trials that require complex treatment planning and verification.
Yoo et al., 2001[27]	Brain function monitoring during a brain surgery	Teleconsultation	Videoconferencing, Electronic data exchange, Scanner, Surgical microscope	Internet Highspeed (ATM, FDDI) backbone with 10 Mbps Ethernet end-networks	Intra-hospital and inter-hospital	Improved patient care in a timely fashion. For this teleconsultation system to succeed, various types of multimedia must be transmitted simultaneously for proper interpretation.
Kuntalp and Akar, 2004 [28]	Cardiology Internal Medicine Neurology Pediatrics Orthopedics Radiology	Remote monitoring Teleconsultation	Web Browser-based Electronic Data Exchange, Email, Phone, Fax, Chat	Internet	Main hospital and rural clinics	Designed to operate asynchronously; hence the delay is not critical. Physicians found the system easy-to-use and reported the positive impacts of the system on the treatment of their patients.
Sezeur et al., 2001 [29]	Chemotherapy	Teleconsultation (with the local surgeon and remote chemotherapist)	Videoconferencing	ISDN (128kbps)	Hospital to hospital	Did not change the doctor-patient relationship. Preferred by most of the patients instead of transportation. Supported multidisciplinary collaboration.

It is evident that a simple classification of all telemedicine applications is not easy. The taxonomy we provided in this paper, however, will help the parties involved in planning, assessing, and providing telemedicine services to structure their decision making process and justify their results. It may also help them to make meaningful comparison between various studies.

5. Conclusion

The state of the art in clinical telemedicine and telehealth applications was discussed [30] based on the level of maturity. Their study created three categories (mature, maturing, and emerging) and here we provided examples from each category in our literature review. As Table 8 suggests, based on the domain and the purpose of the application, we can see different delivery options and telecommunication infrastructures are utilized. All the five dimensions included in our taxonomy have an effect on the outcomes and the results of telemedicine events.

Medical providers are one of the stakeholders of the telemedicine applications and they are usually the ones carrying the burden of providing high quality medical decisions using these applications. However, usually these systems are no more then a black box for the providers. Using our taxonomy can help them to understand the building blocks of their telemedicine systems and give them an idea about why their telemedicine system is a success or a failure. Moreover, providers can layout their current status under each dimension, learn where they fit in the taxonomy, and utilize this positioning to initiate new services that they are capable of providing.

Patients are always the most important stakeholders of the healthcare related systems. This taxonomy helps them to grasp the unknown world of telemedicine and guides them in setting their expectations and evaluating their own telemedicine capabilities at home or in their local communities. This can eventually improve the acceptance and adoption of telemedicine applications among patients. This taxonomy can also be utilized as a guideline while building community centers for healthcare services.

Organizations, such as HMOs and hospitals, can make use of this taxonomy while identifying which dimensions are most critical for the services they provide currently or in the future. This taxonomy can help them understand the relationship between cost and other dimensions involved in a telemedicine environment. It can be used as a guideline for planning or evaluating existing or new services by hospital management. Studying the dimensions and their position compared to others, organizations can plan their future investments in IT infrastructure and plan for adopting new delivery options that can improve the quality of care they provide.

Finally for the researchers, this taxonomy presents an original effort to put all important telemedicine dimensions and their interactions together in order to develop a comprehensive taxonomy. It provides a method to compare and contrast different efforts and studies in the field. Emerging research groups will be able to position their work utilizing this taxonomy. In the future, clustering techniques can help classify more initiatives in a certain area, which can then be properly funded by agencies such as NIH.

In summary, our study suggests that there are multiple dimensions in telemedicine environments that need to be considered while planning such systems or operating them. Domain specific requirements and purpose should be taken into account while making decisions about the support dimensions provided in our taxonomy. However, there is no single way of capturing these requirements that are generated by the medical dimensions. It is important to keep in mind that the channel used to deliver telemedicine services is always limited. It should be used wisely to allocate enough capacity based on the priority of data required on each end. Unfortunately, every channel and setting can support only a limited variety of medical dimensions. Before starting a telemedicine event, it is useful to understand the capabilities of the support dimensions in hand and what types of scenarios under medical dimensions can utilize that capability.

Our future research will focus on this specific measurement problem while utilizing the proposed taxonomy as its basis. A capability measure for each of these dimensions will be developed and these measures will be utilized for identifying the telemedicine capability of a specific setting in a short period of time.

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