International Journal of Medical Informatics (2006) **75**, 565—576

ELSEVIER

International Journal of Medical Informatics

www.intl.elsevierhealth.com/journals/ijmi

Home telehealth—Current state and future trends

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Received 22 March 2005; received in revised form 5 September 2005; accepted 6 September 2005

KEYWORDS
Home care;
Telemedicine;
Home telehealth;
Home based eHealth

Summary
Objective: The purpose of this paper is to give an overview about the state of the art in research on home telehealth in an international perspective.
Method: The study is based on a review of the scientific literature published between 1990 and 2003 and retrieved via Medline in January/February 2004. All together, the abstracts of 578 publications have been analyzed.
Results: The majority of publications (44%) comes from the United States, followed by UK and Japan. Most publications deal with vital sign parameter (VSP) measurement and audio/video consultations (''virtual visits''). Publications about IT tools for improved information access and communication as well as decision support for staff, patients and relatives are relatively sparse. Clinical application domains are mainly chronic diseases, the elderly population and paediatrics.
Conclusions: Internationally, we observe a trend towards tools and services not only for professionals but also for patients and citizens. However, their impact on the patient—provider relationship and their design for special user groups, such as elderly and/or disabled needs to be further explored. In general, evaluation studies are rare and further research is critical to determine the impacts and benefits, and limitations, of potential solutions and to overcome a number of hinders and restrictions, such as

- the lack of standards to combine incompatible information systems;
- the lack of an evaluation framework considering legal, ethical, organisational, clinical, usability and technical aspects;
- the lack of proper guidelines for practical implementation of home telehealth solutions.

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doi:10.1016/j.ijmedinf.2005.09.002

1. Introduction

Most developed countries are facing important overall problems regarding healthcare services, such as:

- increased demand of healthcare due to an increased number of elderly and changed life styles leading to an increase in chronic diseases;
- demand for increased accessibility of care outside hospitals, moving health services into the patient's own homes;
- need for increased efficiency, individualisation and equity of quality-oriented healthcare with limited financial resources;
- difficulties of recruiting and retaining personnel in the healthcare services in general and in home and elderly care in particular.

These challenges turn home healthcare into one of the fastest growing areas of healthcare provision [1]. To decrease costs, there is on one hand a trend for centralisation of specialist care in form of fewer but more specialised clinics. On the other hand, healthcare is decentralised, leading to a shift from in-hospital care to more advanced home healthcare. Furthermore, increasing interest from individuals in self-managing their health and a preference for aging at home rather than in an institution are other driving forces [2]. The rapid development of information and communication technologies (ICT) runs parallel to these societal changes and offers the possibilities to cope with the above-mentioned challenges.

While the broader field of telemedicine and/or telehealth has been utilised in various forms for many years, telehomecare or home telehealth is a relatively recent innovation [3]. It is, therefore, the purpose of this paper to review the existing literature, to identify leading research in the field and to summarise developments, trends and future challenges of the domain.

1.1. Terminology

One of the oldest and most known terms when it comes to healthcare and IT is the term *telemedicine*, meaning ''the use of audio, video and other telecommunications and electronic information processing technologies for the transmission of information and data relevant to the diagnosis and treatment of medical conditions, or to provide health services or aid healthcare personnel at distant sites'' [4].

The term *telemedicine* has evolved into *telehealth*, often considered to have a broader scope towards health promotion and disease prevention.

A few years ago, the term *eHealth* aroused, defined by Eysenbach as ''eHealth is an emerging field in the intersection of medical informatics, public health and business, referring to health services and information delivered or enhanced through the Internet and related technologies. In a broader sense, the term characterises not only a technical development, but also a state-of-mind, a way of thinking, an attitude, and a commitment for networked, global thinking, to improve healthcare locally, regionally and worldwide by using information and communication technology'' [5].

Application of telemedicine and/or telehealth to the home environment is usually described as *telehomecare* or more recently as *home telehealth* or *home based eHealth*.

A *Telehomecare visit* is defined as ''a two-way interactive audio–visual communication between a healthcare provider and a patient in his/her place of residence. This virtual home visit involves the physical assessment of the patient's heart, lung and bowel sounds and obtaining vital signs, such as blood pressure and pulse. Telehomecare also involves a comprehensive patient/family health education program with a strong component of self-management of chronic illnesses. Other, less complex, non-interactive technology may be used for the purposes of providing patients the opportunity to report, via Internet, modem or telephone, disease specific symptoms'' [6].

The more modern term *Home TeleHealth* (HTH) is described as ''the use of telecommunications by a home care provider to link patients or customers to one or more out-of-home sources of care information, education, or service by means of telephones, computers, interactive television, or some combination of each'' [7].

Demiris [8] uses the concept of *home based eHealth* to include both telehomecare and smart homes. The first one describing how technology can enhance current home care services and the second one referring to non-obtrusive disease prevention and monitoring of residents who are not necessarily home care patients, such as, e.g. many elderly.

2. Materials and methods

The study is based on a review of existing scientific literature published during 1990–2003 and retrieved via the Medline database in January/February 2004 using the search terms presented in Table 1.

Table 1 Number of hits for each search term used, retrieved January/February 2004

Search term	No. of hits	Proportion (%)
Home monitoring	4045	72.2
Home telemedicine	613	10.9
Information systems and home care	256	4.5
Mobile and home care	151	2.7
Home telehealth	140	2.5
User interface and home care	81	1.4
Telehomecare	78	1.4
Information technology and home care	37	0.6
Decision support and home care	34	0.6
Distant home care	34	0.6
Information systems and home healthcare	32	0.6
Tele rehabilitation	28	0.5
Electronic and record and home care	23	0.4
Information systems and home healthcare	16	0.3
Home care and remote education	13	0.2
Biomedical engineering and home care	9	0.1
Decision support and home healthcare	2	0.04
Decision support and home healthcare	2	0.04
Information technology and home healthcare	2	0.04
Information technology and home healthcare	2	0.04
Home care and tele-education	2	0.04
Total (including duplicates)	5600	100

Moreover, the bibliographic search results were compared with those presented at the Telemedicine Information Exchange website[1] which contains an extensive material including non-peer-reviewed magazines, newspapers, newsletters, books (and book chapters), conference proceedings, government and other agency or general reports. For this study, however, only articles published in peer-reviewed journals and/or reviewed scientific international conference papers were considered.

The abstracts of all articles were read to decide if they belong to the scope of the research field. Finally, a total of 578 abstracts were classified as being relevant to the research field. The decision upon relevance has been made according to the following criteria.

Only research results with explicit focus on the home healthcare domain were included, comprising

- the development of hardware technology to be used explicitly for patient care and/or education at home;
- the development of computer methods and programs to be used explicitly for patient care and/or education at home;
- evaluation of hard- and software technology that is used for patient care and/or education at home.

[1] http://tie.telemed.org/homehealth.

Categories to be considered in this context (always with the focus being the home) include:

- IT tools and services for the staff;
- IT tools and services for patients and relatives;
- monitoring equipment;
- virtual visits;
- smart home technologies when applied for care or prevention;
- evaluation from different viewpoints: usability, quality of care, organisational, economic, technical, clinical, ethical and/or legal effects.

Not included is research in the following, adjacent areas:

- patient information on the web, i.e. general health related web sites about single diseases, unless they include methods/support for personalised healthcare or advice/instruction for self-care;
- research that not explicitly referred to home care as application area.

To identify future trends, even review articles and future vision papers have been included in the literature study, completed by Internet browsing of the homepages of dominant research groups and some selected interviews.

3. Results

A total of 578 publications have been classified as relevant with regard to the chosen topic. Based on the abstracts of these articles, all publications have been categorized according to a number of different criteria, such as

- publication journal;
- country of origin of the first author;
- type of publication;
- publication content;
- clinical application domain.

3.1. Results with regard to publication activity

The 578 articles were published in 244 different journals or conference proceedings. Sixty of these journals had an impact factor >1 year 2002. Thirty one percent of all articles were published in J. Telemed. Telecare, Stud. Health Technol. Inform., Telemed. J. E Health and in the Proceedings of Medinfo and AMIA Conferences (Table 2). The remaining articles were spread over a large number of different journals, mainly journals of specific medical application fields. No attempt was made to evaluate the scientific quality of the publications. Well-known evaluation methods, such as the journal impact factor (JIF) were considered to be inadequate as the JIF of the major medical informatics journals is relatively low compared to the JIF of medical journals and the scientific quality of the single publications would not be reflected properly.

The majority of publications comes from the United States (44%), followed by the UK (9%) and Japan (7%) (Table 3). Apart from the UK, the European countries with most peer-reviewed publications are Germany and Greece. Australia and Canada build the middle of the scale; Sweden is topping the Nordic countries, at the bottom of the list.

Not unexpectedly, the number of publications on home telehealth in general increased remarkably since the year 2000 and comprised about 100 publications per year in 2002 and 2003 (Table 4).

USA has since 1990 been the country that produced most scientific publications in the field. Nevertheless, the percentage of North American publications dropped from 73% in 1991 down to 30% in 2002 and 43% in 2003. Comparing the number of publications of the most frequently

Table 3 Number of publications per country

Country	No. of publications
USA	238
UK	52
Japan	39
Germany	31
Greece	22
Australia	20
Canada	18
France	17
Spain	17
China	14
Italy	14
Sweden	13
Finland	6
Other	77

Table 2 Journals with 10 publications or more

Journal	No. of publications	JIF (2002)
J. Telemed. Telecare	88	1.366
Stud. Health Technol. Inform.	30	n.a.
Telemed. J. E. Health	23	0.8
Medinfo Proceedings	20	n.a.
Proceedings AMIA	18	n.a.
Biomed. Tech. (Berl.)	12	n.a.
Int. J. Med. Inf.	10	1

Table 4 Total number of scientific publications on home telehealth (1990—2003)

Year	No. of publications
1990	1
1991	11
1992	13
1993	5
1994	10
1995	20
1996	28
1997	34
1998	49
1999	47
2000	79
2001	77
2002	103
2003	101

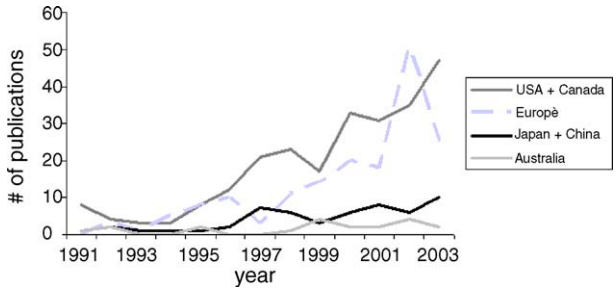

Fig. 1 Comparison of publication frequency per continent.

publishing North American[2], European[3] and Asian[4] research groups, European research indicates a trend towards more frequent publishing activities (Fig. 1). Some European countries, such as Greece, Sweden and Finland did not even publish any papers on home telehealth before 1998 and most other European countries increased their publication frequency since 1998. This might be an effect of specific support activities such as the European 5th Framework Programme that continued until 1998 and supported a number of research projects with focus on home telehealth [9].

The selected abstracts were further analyzed according to the type of publication. For this analysis, the following publication types have been defined:

(a) *System description*: Mainly papers on the own development and implementation of technical solutions for home healthcare.
(b) *Case studies*: Description of the implementation and test of off-the-shelf products in specific clinical settings.
(c) *Evaluation*: Methodological and result papers with focus on user acceptance, economic effects and/or clinical outcome.
(d) *Review articles*.
(e) *Future perspective papers*.

Table 5 shows that most papers deal either with the description of own developed solutions, mainly for data acquisition and transfer from the home to a specialist clinic, or with case studies describing implementation and test of off-the-shelf products for teleconsultation using video—audio communication. Even if there does exist a number of evaluation papers, they merely reflect usability tests on minor populations. A deeper evaluation of home telehealth in form of randomized controlled clinical trials and large scale, long-term empirical studies is still lacking. This has been observed by other authors, too [3,8]. Furthermore, a number of papers that were classified as either review (e.g. [1,10—35]) or future vision papers (e.g. [36—50]) in Medline were included in the literature study in order to describe future trends in the field. However, these papers very often either did not consist of scientific reviews or only covered partly the field of home telehealth.

Table 5 Number of publications per type of article

Type of article	No. of publications
System description	162
Case study	121
Evaluation	116
Of user acceptance	62
Of clinical outcome	32
Of economic effects	11
In general	11
Review article	103
Future perspectives	31
Not classified	45

3.2. Results with regard to publication content

An obvious result of the literature study is the fact that most of the research done on home telehealth is performed with a strong technical viewpoint supporting two dominant services: vital sign parameter (VSP) measurement and audio—video teleconsultation. Publications about IT tools for improved information access and communication as well as decision support for staff, patients and relatives are relatively sparse (Table 6).

Not surprisingly, the majority of publications deals with vital sign parameter measurement (e.g. [42,43,46,51—62]) as these were the first applications of technology in the home healthcare sector.

Table 6 Number of publications per category of home healthcare application

Main category	No. of publications
VSP	238
Audio/video teleconsultation	141
Information access, decision support	36
Education	18
Not classified	145

[2] USA and Canada.
[3] Germany, Greece, France, Spain, Italy, Sweden and Finland.
[4] Japan and China.

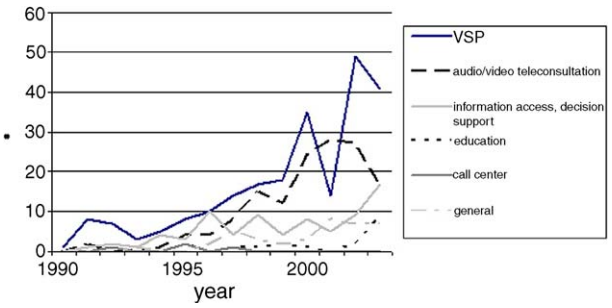

Fig. 2 Research focus (1990—2003).

The second, large application category deals with audio and/or video consultations (e.g. [63—75]). Research in that area in the early 1990s lead to the development of working products for ''virtual home care visits'' using audio- and videoconferencing techniques in the late 1990s. The technique for this type of *electronic housecall* or *virtual visit* is available today and virtual visits are in focus of many North American and Canadian publications (e.g. [72,74,76—78]). European publications focus more on support tools for the staff performing an actual visit at the patient's home or for the patients themselves (e.g. [79—88]). This might be due to differences in the proportion of country size and population as well as due to different health care delivery and reimbursement systems. Nevertheless, virtual visits and VSP measurements have seldom been combined with information from other systems, such as electronic patient records or different types of decision support systems. Research on information systems, however, has often been done in parallel and not in an integrated way. As a consequence, there are obvious difficulties in inter-professional document sharing due to the lack of communication standards and the lack of work process-oriented and patient-centred information systems.

Since 2001, there is an increase of publications concerning information access and education (e.g. [89—97]). This may reflect the increased use of the Internet for disease and lifestyle management including an increased involvement of patients and relatives into the health care process. An overview over information and communication technology to support elderly people and their relatives can, e.g. be found in Ref. [98].

At the beginning of the 1990s, the research focus was on VSP measurement in a wired environment (Fig. 2). Successively, VSP measurement was combined with data transfer between the home and the care provider (mainly hospitals). In recent years, research has been directed towards smart homes (e.g. [99,100]), wearable sensors (e.g. [31,101—105]) and mobile techniques for data transfer (e.g. [106]) (Table 7).

Home telehealth is mainly applied to patients with chronic diseases, such as cardiac and/or pulmonary diseases (Table 8). Due to demographic changes, elderly patients are a special group in focus. The use of wearable sensor devices for rehabilitation and home care of the elderly in combination with smart home technology (e.g. to prevent fall injuries [107—110]) is one main area of research. However, research on how to design usable support systems and information services that can intuitively be handled by specific patient groups, such as elderly, disabled or visually impaired and their relatives is just at the beginning (e.g. [111]).

3.3. Trends

Recent advances in information and communication technology have made home telehealth both feasible and affordable. The results of this literature review clearly show that research from the early 1990s could be transformed into working products by now. Consequently, ICT has been recognized as a potential tool to provide high quality healthcare in the home. Driving forces exist for implementing new solutions and main trends within the field can be characterised by migration from pure technical to integrated, user-centred solutions and their evaluation. Societal and organisational changes lead to a shift from provider-driven to patient-centred healthcare thus forcing the development of tools for new user groups, such as patients, relatives and citizens and the development of tools for computer supported cooperative work (CSCW) as professionals work increasingly team-oriented. The most relevant trends affecting the field of home telehealth are summarised in Table 9.

In conclusion, a lot of research has been performed on home telehealth, but we meet a number of hinders and restrictions when it comes to practical and sustainable use of it. Mainly

- the lack of standards to combine incompatible information systems;
- the lack of an evaluation framework considering legal, ethical, organisational, economical, clinical, usability and technical aspects;
- the lack of proper guidelines for practical implementation of potential home telehealth solutions.

Therefore, research is critical in order to determine the impacts and benefits, and limitations,

Table 7 Most frequent techniques over time

Time period	Publication content	No. of publications
1990—1994		*40*
Whereof	ECG, blood pressure, temperature monitoring and spirometry (case studies, system descriptions)	11
	Fetal heart monitoring	5
	Evaluation (usability, quality of life)	4
	Information systems	3
	Blood glucose monitoring	3
	Video- and teleconsultation	3
	Decision support	2
	Other	9
1995—1998		*131*
Whereof	Video- and teleconsultation, nursing	36
	ECG, blood pressure, temperature monitoring and spirometry (case studies, system descriptions)	28
	Evaluation (cost-effectiveness, usability, feasibility, clinical outcome)	16
	Information systems	9
	Education (patients, relatives)	4
	Decision support (mainly diabetes)	3
	Smart home, elderly	3
	Other	32
1999—2000		*126*
Whereof	Video- and teleconsultation, nursing	32
	ECG, blood pressure, temperature monitoring and spirometry (case studies, system descriptions)	18
	Evaluation (effectiveness, usability, clinical outcome)	18
	Smart home and fall detectors (elderly)	5
	Information systems	5
	Decision support	1
	Education (patients, relatives)	3
	Other	44
2001—2002		*180*
Whereof	Video- and teleconsultation, nursing	55
	Evaluation (usability, clinical outcome, cost-effectiveness, quality of life)	34
	ECG, blood pressure, temperature monitoring and spirometry (case studies, system descriptions)	30
	Rehabilitation	6
	Information systems	4
	Education (patients, relatives)	3
	Other	48
2003		*101*
Whereof	Evaluation (usability, clinical outcome, cost-effectiveness)	27
	ECG, blood pressure, temperature monitoring and spirometry (case studies, system descriptions)	19
	Video- and teleconsultation, nursing	15
	Education (patients, relatives)	8
	Information systems	7
	Wearable biosensors	3
	Decision support	2
	Other	20

Table 8 Number of publications per medical category

Application area	Medical category	No. of publications
Chronic diseases		*157*
Whereof	Cardiovascular disease	35
	Diabetes	23
	Pulmonary disease	19
	Hypertension	16
	Hemodialysis	10
	Asthma	9
	Motoric disability	7
	Cancer	6
	Aids	4
	Other	28
Elderly		*87*
Whereof	Fall injuries, alarm, smart home environment	19
	Alzheimer, dementia	8
	Cardiorespiratory	4
	Diabetes	1
	Other	55
Obstetrics/pediatrics		*49*
Whereof	Fetal monitoring	15
	Sleep apnoea	12
	Asthma	5
	Neonatal	2
	Cardiorespiratory	2
	Diabetes	2
	Cancer	2
	COPD	1
	Other	8
Home care (general)		*285*

Table 9 Relevant trends for the development of home telehealth

Domain	From	To
Software development	Technical development focus	User centred design
Sensor development	Wired devices	Small, wireless, embedded devices
Research focus	Technical implementation	Evaluation
Degree of standardisation	Stand-alone systems	Integration
Application area	Disease management	Life-style management and prevention
User focus	Tools for professionals	Tools for patients, relatives and citizens
Health care process	Provider driven	Patient centred
Environment	Static	Mobile

of potential solutions. In an international research perspective, there is a need for

- new cross-disciplinary evaluation methods for home telehealth tools and services;
- better design solutions considering usability aspects for future users (such as, e.g. elderly);
- better tools for self-managed care (patient empowerment), tools for family caregivers and relatives and individual services to support a healthier lifestyle;
- better methods for introduction of home telehealth tools and services into clinical practice;
- better integration of new knowledge about diagnosis and treatment into evidence-based decision support tools at the point of care;
- further development of wireless tools and devices (e.g. smart clothing);
- more research on privacy and confidentiality issues, payment and reimbursement issues as well as legal and ethical issues.

4. Discussion

The aim of this review was to give an overview of current state and future trends in research about home telehealth. For this purpose, it was necessary to define the field of home telehealth and to decide what could be classified as research.

Chapter 2 discusses the development of different terms for the field whereof *home telehealth* is probably the most common one today, so it was decided to use this term in the title of the paper. Home telehealth may comprise anything from e-mail consultations and educational programs for patients, relatives and/or staff to advanced sensor surveillance, decision support at the point of care and clinical robots that are placed into patients' homes.

The broadness of the term and the interdisciplinarity of the field make it difficult to give an exact definition. Due to its interdisciplinarity, research is performed in a number of different research fields, the two main ones being medical informatics and biomedical engineering. Other

connecting research fields consist of the respective research fields of the application domain, i.e. health sciences (medicine, caring sciences). In addition, valuable knowledge and methods can be taken from the fields of psychology, social sciences, economics, ethics and law. In fact, the integration between those disciplines has gained increased interest (e.g. [37—39]). Neither home telehealth, telehomecare nor home based eHealth are part of the *Index Medicus* keywords making it difficult to identify all relevant literature. The search terms used in this study tried to consider the different aspects of home telehealth but might have missed the research in adjacent areas without specific focus on home healthcare as application domain that may, nevertheless, easily be applied to it.

Home telehealth is clearly an applied and interdisciplinary research field, based on basic research performed in a number of different research fields. In the context of this study, applied research and research and development results published in refereed scientific journals and/or in refereed international conference proceedings were included as research in home telehealth. The transition between basic and applied research and research and development is, of course, fluent. Basic research, that may have an impact on home telehealth in the future, has, however, not been included in this study.

In contrast to other review articles, not only original articles but also review articles and future vision papers have been included into the study to identify future trends. The predominant findings of this study consist in the high amount of technical papers on vital sign monitoring and virtual visits, the small amount of papers on information systems and decision support and the lack of scientific evaluation studies. This is probably no coincidence. Techniques for, e.g. fetal monitoring, telecardiography and blood glucose monitoring have been available in the early 1990s, applications are well defined and they can be used stand alone. The impact of these techniques has been tested in several case studies and smaller clinical trials. The same is true for teleconsultation systems of type ''virtual visit'' where there exist a number of evaluation studies as well (e.g. [112]). However, scientific evidence of the effects of home telehealth solutions is still rare. Reasons are the long period for transforming innovations into clinical practice, which is especially difficult when they require organisational changes, as telemedicine usually does. Apart from few exceptions (e.g. [113—116]), the advent of information and decision support systems in home health care did not take place before 1998. Whereas there has been extensive research in the field regarding primary and hospital care, in the home healthcare domain it has just started. Organisational and societal changes, such as increasingly demands for shared care and patient empowerment and an aging population are the main driving forces for this change. However, practical implementation of the related research results is even more complex as those systems will have a high impact on organisation, society and legislation. Consequently, there are few systems available for thorough evaluation and we are lacking scientific evaluation of these types of system. In addition, we are lacking a holistic model for scientific evaluation from different perspectives (clinical, technical, economic, social, legal, etc.) requiring a multidisciplinary approach. When such a model is available, it will be interesting to see how the measured effects can be related to an interacting network of technical solutions, knowledge transfer and organisational and societal changes.

Acknowledgments

The author would like to thank Oskar Grenholm for performing parts of the literature search and VINNOVA Swedish Agency for Innovation Systems (P23037-1 A) for financial support. A more detailed report about this work has been published as VINNOVA report VR 2005:11 and can be downloaded from http://www.vinnova.se/.

Summary table

''What was already known before our study''
- home telehealth is an expanding field of interest;
- evaluation studies are rare in the domain of home telehealth.

''What has our study added to our knowledge''
- the majority of publications in the field deal with vital sign parameter monitoring;
- cultural differences between North America and Europe regarding virtual visits;
- European publications increased remarkably after 1998;
- lack of a holistic model for scientific evaluation based on a multidisciplinary approach.

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