

# Digital tele-echocardiography: a look inside

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**Summary.** Digital tele-echocardiography (T-E) has the potentiality to allow relevant change in health care organization. The purpose of the paper is to analyze the scientific development around the digital T-E to explore the successful applications and individuate the limits which hamper the routine introduction in the National Health Care System (NHCS). A literature review was carried out by searching for studies from 1988 to 2008. The studies have been investigated according to four crucial issues: a) the employment of the digital T-E versus the traditional videotape registrations; b) the evolution of the telecommunication network and T-E; c) the quality assessment of the images after transmission; d) the economical legal and social impact of the T-E. The analysis showed a generalized increased diffusion of the digital T-E thanks to the wonderful development of the information technology. This diffusion was sometimes also accompanied by investigation studies on the diagnostic accuracy and on cost-benefit analysis with special care to the economical and social impact. The study examined some points which need to be improved to allow a better introduction of the T-E in the NHCS as a routine exam. Among these two were the most important. The first was the lacking of an easy and automatic methodology for the image quality assessment alternative to the currently used methods which are highly complex, expensive and needing a long time to be applied. The second was the lacking of a properly designed methodology for the health technology assessment in T-E, the latter, as it is well known is a very complex and heterogeneous system embedding parts from telematics, bioengineering, and medical physics.

*Key words:* tele-echocardiography, digital tele-echocardiography, telemedicine.

**Riassunto** (*Uno sguardo alla tele-ecocardiografia digitale*). La tele-ecocardiografia (T-E) digitale rappresenta attualmente una delle applicazioni telemediche con più ampie prospettive per il Servizio Sanitario Nazionale. Il presente lavoro è una revisione degli studi di T-E con particolare attenzione sia agli elementi di successo che di insuccesso focalizzando la ricerca sugli studi di interesse effettuati tra il 1988 ed il 2008. Gli studi sono stati organizzati secondo quattro raggruppamenti ritenuti rilevanti: a) la T-E digitale in confronto ai metodi tradizionali basati su videoregistratore; b) lo sviluppo delle reti di telecomunicazione e la T-E; c) la valutazione della qualità delle immagini dopo la trasmissione; d) gli aspetti legale, sociale e economico nella T-E. Da un punto di vista generale l'analisi ha mostrato un incremento generalizzato della diffusione della T-E grazie anche al rapido sviluppo della *information technology*. Questa diffusione è stata spesso inoltre accompagnata da studi di accuratezza diagnostica e di analisi costo-beneficio con particolare attenzione agli aspetti economici e sociali. L'analisi condotta inoltre ha individuato alcuni punti che devono essere migliorati per permettere una più capillare introduzione della T-E nel Sistema Sanitario Nazionale. Tra questi due sono i più rilevanti. Il primo è rappresentato dalla mancanza di una metodologia semplice ed automatica per la valutazione della qualità delle immagini alternativa ai metodi attualmente usati, i quali sono complessi, costosi e necessitano di un elevato tempo di esecuzione. Il secondo è rappresentato dalla mancanza di una metodologia strutturata di health technology assessment in T-E, quest'ultimo lo ricordiamo, è un sistema complesso ed eterogeneo che comprende anche elementi di telematica, di bioingegneria e di fisica medica.

*Parole chiave:* tele-ecocardiografia, tele-ecocardiografia digitale, telemedicina.

## INTRODUCTION

Heart failure is a very serious and common dysfunction. It is often cause of death, especially if not early diagnosed. Thus the diffusion of instrumental methodologies, through the telemedicine such as the

tele-echocardiography (T-E), to investigate heart failure is today an important challenge for the National Health Care System (NHCS). T-E could be very useful both in remote areas and in emergency care, where both the time for patients transferring and

costs are very critical. The difficulty to exchange large data through (not suitable) NETs hampered in the past its use and diffusion. Today's technology, such as the low-cost wideband communication channels, the *compression techniques* at a high bit rate, allows the implementation of low-cost and clinically accurate T-E systems. Digital tele-echocardiography has thus the potentiality to change the life of the citizens and the health care organization in the world. The general purpose of the paper was thus to analyze the scientific development around the digital T-E to explore the successful applications and individuate the limits which hamper the routine introduction in the NHCS. The principal objective of this paper was thus to review the status of the scientific development around the T-E, in order to explore the perspectives for future successful introduction in the NHCSs as a routine exam. The side objective of the paper was to critically analyze the reasons of failures of this technique and then to identify possible solutions. The selection of the works was accomplished in the electronic database MEDLINE ([www.ncbi.nlm.nih.gov/](http://www.ncbi.nlm.nih.gov/)), biomedical library databases, conferences proceedings, and Internet websites. The identified studies were published from 1988 to 2008. Studies have been investigated according to four crucial issues: a) the employment of the digital T-E versus the traditional videotape registrations; b) the evolution of the telecommunication network and T-E; c) the quality assessment of the images after transmission; d) the economical legal and social impact of the T-E.

## RESULTS AND DISCUSSION

### *Use of digital T-E versus traditional videotape registration*

Digital T-E seemed to show, since the beginning, several advantages respect to the traditional videotape recording. Feigenbaum [1] showed that the first key point of the new technology was that the digital storage avoids the strip chart recordings, allowing a rapid review of recorded echocardiograms and serial studies. He also enlightened the need of the parameter's tuning which determines the load of digital information to be stored (number of frames, the resolution, the bit rate and the gray scale). To minimize the amount of the digitized data, it was thus necessary to introduce the use of *compression techniques*. These techniques from the early uses showed a comparable quality with the standard videotapes and uncompressed images [2, 3]. In addition, a further valid support to minimize the data-storage was the *clinical compression* [4-6] for each exam. The *clinical compression* is a practice used to reduce the size of the study by recording one 1-beat loop against the 30-60s videotape recordings. In fact the cardiac activity is periodic and the 1-beat loop recording could be sufficient to obtain clinically useful information. Useful guidelines on the implementation of a digital T-E link, starting from videotape acquisitions were presented by

Trambaiolo [7]. The migration from video-tape to digital technologies has been shown feasible also in emergency care. Mohler [8], in fact, had conducted an experience of digital echocardiography in the emergency care and showed the suitability of a rapid reliable diagnosis, even if obtained by means of a minimal digital-acquisition strategy.

### *Evolution of telecommunication network and digital-T-E*

The evolution of the telecommunication network permitted wideband communication channels with a low cost. This allowed the transmission of very complex examinations, real-time diagnosis and very rapid interpretation of results.

#### *Analog lines*

The first experiences of the T-E used regular phone lines. It showed a comparable diagnosis accuracy versus traditional videotape and resulted cost saving [9-11]. An experience of emergency echocardiography telemedicine using analog lines was described by Trippi [10]. Cardiologists used laptop computers to examine the transferred echocardiograms. The method resulted comparable with traditional videotape recording but more rapid and timely. Allen [11] also confirmed the reliability of using analog lines to implement the so called *store and forward* methodology in T-E. He applied the methodology to adults in order to save the waiting time to get echocardiograms interpreted. The same author also showed a successful *store and forward* application of T-E using regular phone lines in adult echocardiography [12], critical application for the large amount of data to manage.

#### *ISDN lines*

Houston *et al.* [13] showed that one or two ISDN channels were sufficient to assure a satisfactory quality of transmission. They showed that three or more channels allowed the transmission of more complex exams. A single ISDN line (128 kb/s) for the remote diagnosis of children with suspected congenital heart disease was used by Milazzo *et al.* [14]. They showed a "value of concordance" of 95.5% with the real-time echocardiogram interpretation and subsequent videotape review.

#### *Satellite transmission and wireless technologies*

The T-E satellite transmissions were tested especially in remote and rural areas [15-19]. Experiences of satellite links were carried out and tested both for store-and-forward and real-time T-E. They proved both the technical feasibility and the clinical effectiveness of T-E with this technology [15, 16]. Real time T-E tele-screening [17] has been successfully investigated using also portable satellite transmission systems for the assessment of cardiac emergencies [18]. Preliminary investigations have also showed that emergency T-E could be implemented also using wireless communication technologies [19].

### Internet and Intranet technology

The TCP-IP protocol and the diffusion of internet technologies have also had an important role in the development of T-E applications both in the WAN and in the LAN. Intranet, Extranet and Internet applications of T-E have been widely diffused starting from the last decades and have become year after year an optimal vehicle to move echocardiography information organized in Moving Picture Experts Group (MPEG) files (described in the next section). An example of these applications is the so called ECHOCARD-NET allowing a Web based T-E:

- [ermete.ifc.cnr.it](http://ermete.ifc.cnr.it); [www.dgsan.lombardia.it/ricerca\\_progetti/europei/4prog/cardnet.pdf](http://www.dgsan.lombardia.it/ricerca_progetti/europei/4prog/cardnet.pdf);
- [www.dgsan.lombardia.it/ricerca\\_progetti/ministeriali/ermete.htm](http://www.dgsan.lombardia.it/ricerca_progetti/ministeriali/ermete.htm);
- [ermete.ifc.cnr.it/catalogo/schedaTrasf.asp?UID=13](http://ermete.ifc.cnr.it/catalogo/schedaTrasf.asp?UID=13).

This Web based application had experimented a high degree of integration and interoperability in the Intranet of the hospitals.

### Limits

The analyzed works did not plane a double connection for critical applications (cold and warm connection). For example, when a cable connection is available as regular method, a satellite connection could be provided as warm exceptional connection, available without delays when the regular connection fails *i.e.* becomes cold. This approach could be also useful for individuating and minimizing the failure-risk.

### ***Method and parameters for evaluating the quality of the compressed images and related diagnostic accuracy***

The introduction of compression algorithms has an important role in the diffusion of T-E. The assessment of the image quality (and thus the diagnostic accuracy) is strongly related to the use of these algorithms in T-E.

### Compression algorithms and T-E

Different MPEG ([www.mpeg.org](http://www.mpeg.org)) compression algorithms have been proposed in the time, performing each a different compression ratio. The first MPEG compression algorithms (MPEG-1 and MPEG-2) employ a space-temporal coding, removing the redundant information within a frame (spatial intra-frame compression) and between successive frames (temporal inter-frame compression). The MPEG-1 compression (1992) retains image quality similar to the VHS videotape. The MPEG-2 supports the DVD format and its quality is four times better than the MPEG-1 and twice than the VHS quality. The MPEG-3 has been proposed for the high-definition TV, but was merged into the MPEG-2. Finally, the last MPEG compression algorithm MPEG-4 is based on the video content and employs the content-based or model-based encoding, in contrast with the previous MPEG *compression techniques*, based on

the pixels or frames. The MPEG4 encoding extracts, from each scene of the video, different video objects, such as: a) the scene background; b) the video subjects, present in the scene in the 2D or 3D dimension; c) the audio, natural (the speech) or artificial (any other sound or music). This standard has been developed in order to realize a streaming able to be transmitted on digital data network at limited bandwidth (Internet). This standard is highly flexible: it works from few kb/s to high bit-rate, allowing the best choice between the bit-rate and the compression level. For that, it seems the most suitable for the T-E, allowing a higher quality images also with low bandwidth lines.

### Accuracy of MPEG

Greek [20] has focused to different codifiers/decoders (codecs) and showed that among the different codecs, proposed in literature, the ones based on MPEG standard resulted today the most suitable for the video compression in T-E. Different studies were addressed to evaluate the diagnostic accuracy of MPEG compressed images in T-E. Soble [21], for example, described a "by experts visual successful analysis" of the MPEG-1 compressed images carried out, by evaluating specific quantitative variables related to the cardiovascular district under investigation. Quantitative measurements of some variables were carried out on still images to compare sVHS videotapes and MPEG-1 compressed video clips by Garcia *et al.* [22]. Similar studies have been carried out on pediatric T-E applications [23] showing the feasibility of the methodology. Spencer [24, 25] showed that the digital T-E preserved its diagnostic content with MPEG-1-compression up to a ratio of 200:1. In the Harris' work [26] sVHS videotapes and the MPEG-2 digital images were simultaneously acquired and inspected by expert clinicians. They evaluated some anatomy and functionality of the heart district and found an overall concordance rate of 93.6%. The successful validation of the MPEG-4 compression was assessed by scoring the diagnostic content of T-E images generated at three decreasing compression levels versus the uncompressed images [27]. The clinical effectiveness for the MPEG-4 compression has been proved also in simply low-cost echocardiographic systems, developed for the remote diagnosis [28].

### Subjective evaluation in digital-T-E

The most effective methods for the assessment of the image quality are the subjective ones based on the eye of the experts [29]. Some methodologies used in T-E aimed to validate this affirmation. In medical imaging usually experts assign a level of the diagnostic content and quality to the transmitted and/or compressed echocardiographic images. Examples of this methodology directly applied to T-E may be found in the work proposed by Smith *et al.* [16] and by Barbier *et al.* [27] Garcia

*et al.* [22] also showed that subjective methods should be preferred in T-E. In particular they investigated the diagnostic accuracy of the compressed MPEG images versus traditional videotapes focusing on the analysis of inter-observer and intra-observer variability among analyzed parameters. Some diagnostic failures using “by experts evaluation” in T-E were reported by Widmer *et al.* [30] and Sharma *et al.* [31].

*Integration of compression algorithms into Digital Imaging and Communications in Medicine (DICOM)*

The DICOM [32] standard for medical images formatting and transmitting, is also currently investigated in digital T-E. The DICOM standard adopts the JPEG compression for still images and MPEG compression for videos. However, at the moment there is not a great agreement in literature about the opportunity of using DICOM in routine T-E application [33, 34].

*Limit*

The above shown literature analysis has enlightened that most effective methods to analyze the image quality are the ones based on subjective methods [35-38]. However these methods are complex, expensive and need time and resources (people and instruments). There is the need of an objective automatic tool with internal models of the subjective response. The use of a such tool could save time and money avoiding complex tests implying also the analysis of many operators. An example of a such tool could be the National Telecommunication and Information Administration General Video Quality Metric Model (NTIA VQM) [39], which is widely used in the field of image analysis of movies.

*Economical, legal and social impact of digital-T-E*

Core aspects for the successful use of T-E are the ones dealing with the economical, legal and social impact. Hooper compared the costs of the traveling of the cardiologists and echocardiography technicians in standard echocardiography to the T-E's ones [40]. The study showed that T-E diminished the costs and ameliorated the cardiac diseases management. Sable *et al.* [41] and Randolph *et al.* [42] showed that in neonatal pediatrics, real time T-E allowed an improvement in the patient management and provided cost and training benefits. Sable [43] showed that T-E allowed both high diagnosis accuracy and cost-effectiveness, even if presented some problems of standardization in the implementation. Some recent studies showed the successful impact of T-E diagnosis systems in terms of technical viability and the clinical validity of a T-E diagnosis system [43-46]. Sharma [31] demonstrated the practical and favorable impact in the traditional health care system, especially regarding the patient acceptance. A review [47] conducted by Bassignani illustrated and analyzed the

relevant technologies and industrial standard components available in the market, that could permit the decrease of the costs in T-E in the future.

Limits. One of the limits found is the lacking of studies facing deeply the legal and reimbursement aspects in T-E. These are core aspects for the introduction of the T-E in the NHCSs as routine exams. Another more general limits is the lack of specific methodologies for the Health Technology Assessment (HTA) [35-38] specific for this telemedicine application.

**CONCLUSIONS**

*What is lacking to digital T-E today?*

The analysis showed how researches and applications of digital T-E have spread thanks to the wide development of the information technology. In particular a great reason for the success of this technique was the introduction of specific compression algorithms and the diffusion of wide-band digital transmission mediums. However the most part of these applications are near always never accompanied by deep standardization and/or qualification actions [35-38] and thus cannot be inserted in the national health programs as routine exams. Many digital T-E applications, in fact have been developed during national or international pilot research studies (where obviously the standardization and/or the qualification were not the focusing point). Day after day the cost per bit is strongly decreasing and the data transmission is becoming faster and faster. The new challenge for T-E will be thus the facing of key points of standardization, of qualification, with special care also to the legal, reimbursements and economic aspects to become a true routine methodology. The actual problem is thus how to lead the digital T-E as a routine exam.

*How to lead the digital T-E as a routine exam?*

The conducted analysis was useful to detect the limits of digital T-E which hamper a successful introduction in the NHCS as routine exam (*Table 1*). The four points are specific of each one of the investigated issue. The first point regards the reliable connectivity in the case of the critical medical cases. In these “mission critical T-E applications” [48] (It. wikipedia.org/wiki/Mission\_Critical\_System), the authors suggest that a double connection should be introduced using the method known as cold and warm machine. To understand the second point it should be considered that the diagnostic accuracy in T-E is not only a function of quantitative parameters but also of the subjective decision of the clinician depending on his/her a priori knowledge. Thus subjective tests [36] should be preferred. However these tests ask resources (time, people and costs). An automatic tool embedding subjective models could thus save time and money. Recent experiences, investigating new metrics such as the NTIA

**Table 1** | *Issues and relevant limits in digital tele-echocardiography*

Issues	Limits	Global limit
Evolution of telecommunication network and tele-echocardiography	In the mission critical T-E applications, a double connection should be introduced using the method known cold and warm machine	
Methods and parameters for evaluating the quality of the compressed images and related diagnostic accuracy	Need of an automatic tool based on subjective models for investigating the image quality	Need of a specific health technology assessment methodology for T-E
Economical impact of tele-echocardiography	Not standardized	
Legal and social impact of tele-echocardiography	Need of studies focusing to legal aspects	

VQM have shown to be promising for the objective to provide this automatic tool [36-39, 49, 50] further useful index. The third point comprehends the complex procedures which should be set-up to guarantee the adequate reimbursement for a tele-diagnosis. The fourth point, the legal aspects is basic for the definition of the responsibilities connected to the medical decisions which could affect the patients' safety. The global limit emerged as a final global consideration. It is a basic issue for the introduction of the T-E in the NHCS. In fact today every system, before being adopted by the public administration,

must be qualified. The T-E system, such as the other telemedicine systems, is complex and heterogeneous comprehending components from bioengineering, medical physics, and information technology (software, hardware, networking). It is thus important to investigate a T-E system as a whole (considering each element) with a properly designed HTA methodology. Furthermore the design of a specific HTA could be a mean to overcome the other limits.

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