Determination of the acceptable MPEG-4 quality for clinical real-time tele-echocardiography services

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Summary. The characteristics of Moving Picture Experts Group (MPEG-4) video compression, in particular its adaptability to narrowband channels and the elevated degree of compression obtainable, make it of interest for services of telemedicine that require instantaneous video transmission and interpretation. In this study we faced the problem of the minimum quality of service (QoS) in specific applications of tele-echocardiography (T-E). In the specifics we evaluated the clinical adequacy of MPEG-4 compression in the real time transmission of echocardiographic studies. Forty echocardiographic examinations consisting of standard projections of patients affected by ischemic heart disease were submitted to two observers expert in echocardiography, who made 4 separate evaluations as follows: 2 on the same equipment on which the original studies were performed; 1 after online MPEG-4 codification of the studies at 256 kb/s; 1 after online MPEG-4 codification of the studies at 128 kb/s. For each evaluation, the following data were collected: subjective opinion on the overall visual quality of the images; estimate of ejection fraction and level of impairment; wall Motion Score Index and percentage of asynergy; mitral failure. The results: 1) the subjective quality of the echocardiographic images was the same as that perceived in the video at Mpeg4/256 kb/s compression level while it was lower, as expected, in the video Mpeg4/128 kb/s; 2) the quality degradation did not produce a statistically significant difference in the evaluation of left ventricular function and regional wall motion impairments. These results confirm the feasibility of MPEG-4 compression for the transmission of echocardiographic studies for use in telemedicine and suggest that it is not necessary to seek transmission speeds higher than 256 kb/s for the semiquantitative reading of left venticular kinetics.

Key words: echocardiography, telemedicine, data compression.

Riassunto *(Soglia minima di accettabilità di un servizio di tele-ecocardiografia digitale in real-time basata su MPEG-4 per alcune indagini cliniche cardiache)*. Le caratteristiche della compressione video MPEG-4, in particolare la sua adattabilità a canali a banda limitata e gli elevati fattori di compressione ottenibili, la rendono interessante per servizi di telemedicina che richiedano trasmissione ed interpretazione di video in tempo reale. In questo studio si è valutata l'adeguatezza clinica della compressione MPEG-4 nella trasmissione in tempo reale di studi ecocardiografici. Quaranta esami ecocardiografici composti dalle proiezioni standard di pazienti affetti da cardiopatia ischemica sono stati valutati da due operatori ecocardiografici esperti per 4 volte di cui: 2 sullo stesso apparecchio dove erano stati realizzati gli studi originali; 1 dopo codifica MPEG-4 online degli studi a 256 kb/s; 1 dopo codifica MPEG-4 online degli studi a 128 kb/s. Sono state raccolte, per ogni valutazione: un giudizio soggettivo sulla qualità visiva globale delle immagini, la frazione d'eiezione stimata ed il grado di compromissione, lo Wall Motion Score Index e la percentuale di asinergia, l'insufficienza mitralica. Per quanto riguarda i risultati: 1) la qualità soggettiva delle immagini rilevata sull'ecocardiografo è la stessa che viene percepita nel video Mpeg4/256 kb/s, con un prevedibile peggioramento nel video Mpeg4/128 kb/s; 2) il degrado in qualità non ha prodotto differenze statisticamente significative sul giudizio circa la funzionalità e le alterazioni regionali della cinetica del ventricolo sinistro.

Parole chiave: ecocardiografia, telemedicina, compressione dati.

INTRODUCTION

Studies exist on the application of various Moving Picture Experts Group (MPEG) compressors/decompressors (codec) in the echocardiography (EC) setting, especially with the prospect of its substitution for classic video-tape for storage purposes [1-4]; for MPEG-1 and -2, published studies exist documenting the codec's reliability to transfer the information content necessary for a correct diagnosis [2, 5]. Regarding MPEG-4, a promising codec for its

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flexibility in that it can operate with highly different bit-rates [6], two studies alone have investigated its use in echocardiography, but these were restricted to evaluating the space savings obtainable in the memorization of ED sequences [4], and to synthetic qualitative evaluations based on compressed images coming from just 11 cardiac cycles [7], this perhaps due to the variety of possible combinations between the parameters of the codec that regulate image quality and compression factors.

Aims

This study aimed to determine the minimum quality of service required for the use of MPEG-4 in EC, in particular in relation to visualization of the endocardium and of left ventricular wall motion segments [8], with the prospect of its possible use in the provision of services of telemedicine such as telepresence during the examination, tele-consultation or tele-medical reports.

The study's priority was to focus on the quality of the video signal in movement; thus it did not investigate the effect of MPEG compression on the precision of eventual quantitative measurements that would be performed on static images.

MATERIALS AND METHODS

From the files of the Laboratory of Echocardiography we selected 40 complete echocardiographic studies (Echo 2D, Color Doppler with standard apical 4-, 3- and 2-chamber views) featuring a diagnosis of ischemic heart disease based on medical records. The choice of ischemic disease was based on the fact that it induces regional wall motion alterations of the left ventricle; the studies and corresponding video sequences are hence more fitting for the scope of this study, *i.e.* to evaluate the effect of compression on the quality of the signal in movement. Moreover, the semiquantitative standardized procedures for calculating wall motion that are normally used for the medical records provided a useful basis for the statistical comparison.

The video sequences were obtained from the optical files and streamed from ultrasound unit (Agilent Sonos 5500) via MPEG-4 video encoder (Vbrick 9140, VBrick Systems Inc. USA) using the RTSP protocol through the local PC network; the streams were received by a personal computer using appropriate software (StreamPlayer, VBrick Systems Inc. USA) and saved as separate MPEG-4 files *(Figure 1)*.

The transmissions were conducted at 128 and 256 kb/s (compression = approx. 70:1, 40:1) in order to have the same images with different "bit rates" so as to evaluate the effect of compression on the quality of the reconstructed video signal.

The reading protocol was as follows: 2 expert operators viewed the echocardiographic studies twice, at a distance of two weeks, and then independently viewed, in randomized mode, the files saved after MPEG-4 conversion. For the viewing of these latter we used a specific program designed to provide the basic functions (play, stop, etc.) necessary for viewing the images anonymously, *i.e.* with patients' anagraphic data masked *(Figure 2)*.

No information was given *a priori* to the observers, who were blinded both as regards the study patients and the compression conditions (128 or 256 kb/s) of the files they evaluated.

For each reading we collected:

- a subjective judgment about the global visual quality of the images (excellent, good, adequate, poor);
- estimate of ejection fraction and level of impairment (from absent to severe);
- wall motion score index, percentage of asynergy and wall motion assessed according to the 16-segment model of the American Society of Echocardiography (ASE);
- mitral failure (from absent to severe), from the color doppler images recorded in apical 4-channel view according to Helmcke 1987 [9];

making a total of 7040 recorded assessments sub divided into 22 parameters.

A schematic of the data collection and analysis protocol is presented in *Figure 3*.

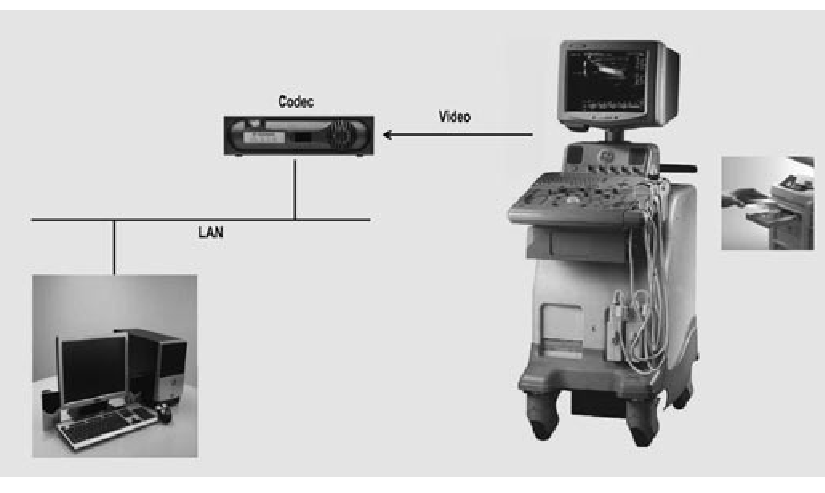

Fig. 1 | *Experimental setup and data flow: video signals coming from the playback of selected echocardiographic examinations on an ultrasound unit are encoded using the MPEG-4 algorithm and streamed to a reviewing station at different bit rates (128, 256 kb/s).*

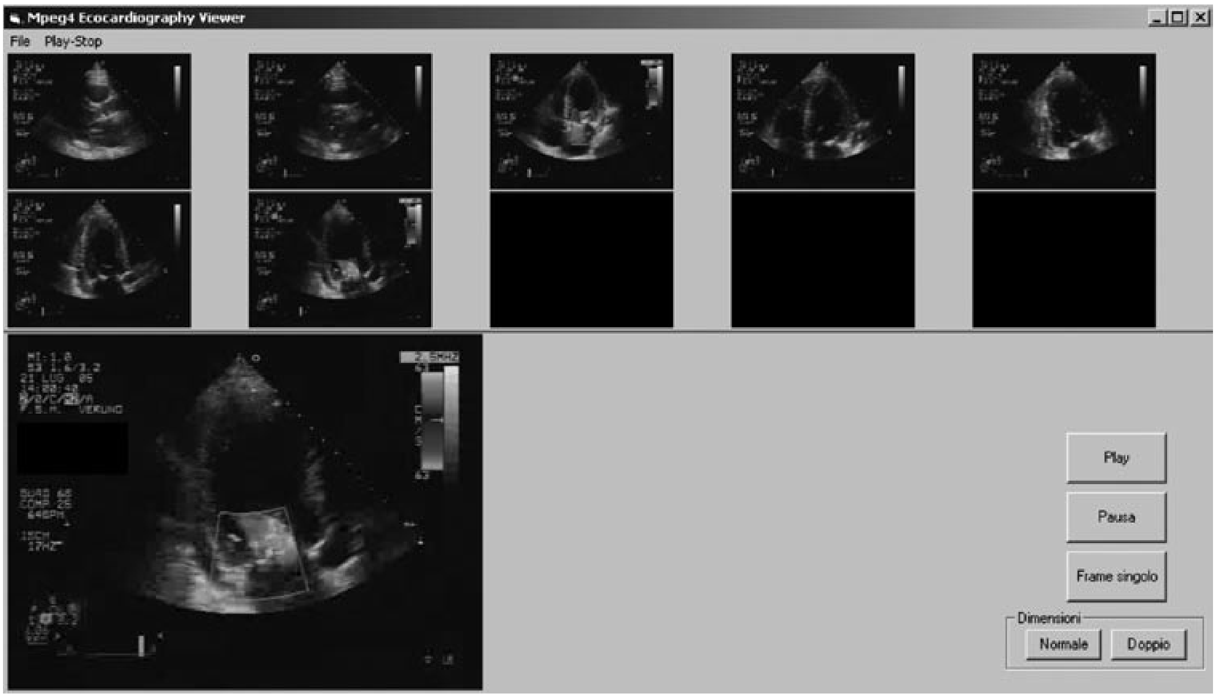

Fig. 2 | *User interface of the review program.*

STATISTICAL ANALYSIS

Results were compared to determine the agreement between the two echocardiography readings, considered as reference, and the agreement between the first echocardiography reading and the two MPEG-4 readings.

Student's t test for paired data was performed on the quantitative assessments and McNemar's tests on the qualitative evaluations. A p value < 0.05 was considered as significant.

RESULTS

Table 1 shows the means and standard deviations of the quantitative parameters obtained over the 4 readings from the two readers. The results are not subdivided by reader, since it was not required for the purposes of the project to evaluate interoperator variability, but rather to estimate how the characteristics of image compression-transmission influenced individual performance.

The probability p refers to the hypothesis that there is a difference between the assessments made at the second reading, after compression for transmission at 128 kb/s and 256 kb/s, respectively, and those obtained during the first reading.

Table 2 shows the findings related to the perceived quality of the recording and of the level of mitral failure and ventricular impairment for each reading condition (1st and 2nd echocardiography reading, and reading after compression for transmission at 128 kb/s and 256 kb/s).

For the analysis of concordance, we calculated the differences between the single judgments for each subject between the two readings on echocardiography, then calculated the differences between the first echocardiographic reading and those after

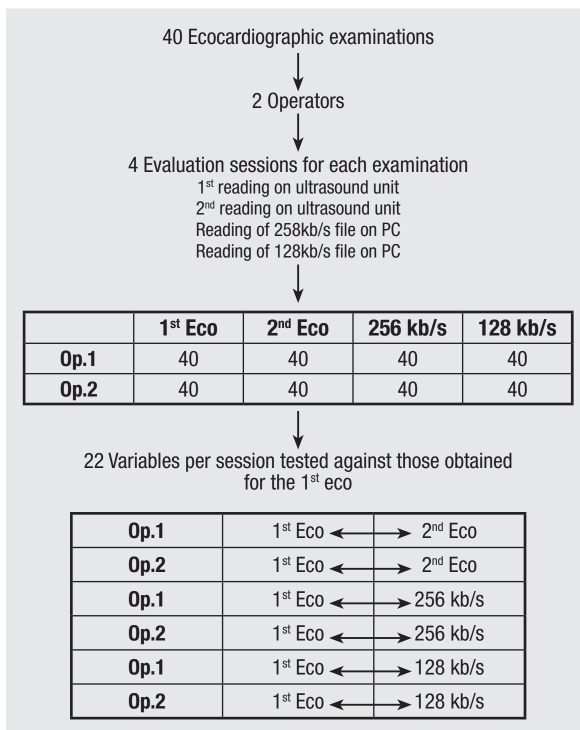

Fig. 3 | *Protocol description.*

Table 1 | *Overall findings and comparison with the 1st reading for the quantitative assessments (mean ±SD, n = 80)*

	% EF	P	% Asynergy	p	WMSI	p
1st Reading	36.2 ± 13.91	-	36.6 ± 19.46	-	1.92 ± 0.44	-
2nd Reading	36.2 ± 13.53	N.S.	36.5 ± 19.80	N.S.	1.91 ± 0.44	N.S.
128 kb/s	36.7 ± 14.28	N.S.	37.3 ± 19.59	N.S.	1.93 ± 0.44	N.S.
256 kb/s	36.2 ± 14.14	N.S.	36.3 ± 20.37	N.S.	1.93 ± 0.46	N.S.

Table 2 | *Judgments (events, n. tot = 80)*

	1st Reading	2nd Reading	128 kb/s	256 kb/s
Quality				
Mediocre	5	5	10	5
Adequate	33	34	26	32
Good	42	41	44	43
Mitral failure				
Absent	4	5	7	5
Slight	41	41	40	41
Slight-moderate	15	17	11	14
Moderate	13	11	13	14
Moderate-severe	6	5	6	4
Severe	1	1	3	2
Ventricular impairment				
Absent	20	19	20	20
Slight	8	8	11	8
Moderate	19	21	17	18
Severe	33	32	32	34

Table 3 | *Analysis of agreement for quality, mitral failure and ventricular impairment*

		1st Reading *vs* 2nd Reading		
Quality		**=**	**<>**	
1st Reading *vs* 128 kb/s	=	67	0	p = .0015
	<>	12	1	
1st Reading *vs* 256 kb/s	=	75	0	p = N.S.
	<>	4	1	
		1st Reading *vs* 2nd Reading		
Mitral failure		**=**	**<>**	
1st Reading *vs* 128 Kb/s	=	65	4	p = N.S.
	<>	9	2	
1st Reading *vs* 256 Kb/s	=	73	3	p = N.S.
	<>	1	3	
		1st Reading *vs* 2nd Reading		
Left ventricle impairment		**=**	**<>**	
1st Reading *vs* 128 kb/s	=	74	1	p = N.S.
	<>	3	2	
1st Reading *vs* 256 kb/s	=	75	3	p = N.S.
	<>	2	0	

MPEG-4 compression; the results of the comparison are presented in *Table 3*.

Table 4 presents the results of the evaluation of regional wall motions for each reading condition.

Table 5 summarizes the agreement between single judgments for the readings following the first based on echocardiography for the judgments of regional wall motion; major and minor errors are evaluated according to clinical significance.

Table 6 shows the concordance between first and second reading compared to the one between the first reading and each condition of compression, segment by segment.

DISCUSSION

The conversion of video into digital format, whether or not accompanied by sound, produces enormous quantities of data particularly if no form of compression is used (the common format PAL would require approximately 220 Mb for each second of film) – that cannot be conveniently transported or memorized on a support unit [10]. To overcome this problem, mechanisms of compression-decompression (CoDec) have been devised to reduce the dimensions of large data flows in such a way that the data can be transmitted on narrowband communication lines or "sent" and memorized in a convenient way as files. Numerous types of codec have been developed, both in hardware and software form, in order to obtain the greatest possible

Table 4 | *Regional wall motion, clinical score for each reading condition (segments)*

	1st Reading	2nd Reading	128 kb/s	256 kb/s
Normal	613	616	620	613
Hypokinetic	199	197	187	203
Akinetic	436	439	453	429
Dyskinetic	23	18	13	26
Aneurismatic	9	10	7	9

Table 5 | *Regional wall motion – score concordance with first reading (percentage segments = 1280)*

	Comparison with 1st reading		
	2nd Reading	**128 kb/s**	**256 kb/s**
=	1179 (92.1)	1054 (82.3)	1137 (88.8)
Minor errors	52 (4.1)	113 (8.8)	66 (5.2)
Major errors	49 (3.8)	113 (8.8)	77 (6.0)
Total errors	101 (7.9)	226 (17.6)	143 (11.2)

Table 6 | *Regional wall motion – concordance between readings* versus *each compression condition, segment by segment*

		1st Reading *vs* 2nd Reading			
		=	**Minor**	**Major**	
1st Reading *vs* 128 kb/s	=	78.91 (1010)	1.64 (21)	1.80 (23)	p = N.S.
	Minor	6.56 (84)	1.80 (23)	0.47 (6)	
	Major	6.64 (85)	0.63 (8)	1.56 (20)	
		1st Reading *vs* 2nd Reading			
		=	**Minor**	**Major**	
1st Reading *vs* 256 kb/s	=	86.80 (1111)	1.02 (13)	1.02 (13)	p = N.S.
	Minor	2.97 (38)	2.97 (38)	0.08 (1)	
	Major	2.34 (30)	0.08 (1)	2.73 (35)	

compression of the video signal and its restitution so it can be re-utilized without excessive loss of quality. The compression operates by eliminating from the original signal as much superfluous information as possible, leaving only what has the highest information content and implementing a set of compromises (*e.g.* between speed of compression, reproduction, transmission, and the size and quality of the signal transmitted) according to complex mathematical procedures developed by specific working groups and formulated in universally accepted standards.

The MPEG was set up in 1988 and is the group responsible for the development of standard procedures for the codified representation of audio and video signals. The work of MPEG is a work "in progress", as demonstrated by the series of codecs so far developed.

The codec MPEG-1 was released in 1993 and operates at 1.5 Mb/s at a resolution of 352x240 pixels for 30 frames per second, with a quality equivalent to a VHS videotape. This format is interpolated (adjacent pixels are mixed and then the result is given a colour resembling it as close as possible by the codec) and scaled to be brought back to full video resolution (768x576): 1 pixel in reproduction is up to 4 pixels larger, resulting in a slightly "blocky" image.

MPEG-2 was designed for audio and video of high quality, suited for commercial transmission, and is the format of Digital Versatile Disc (DVD) and of satellite television. This codec transports more information at speeds that can require up to 15 Mb/s, at a resolution of 704x480 pixels at 30 frames per second, four times greater than MPEG-1 and with double the quality of a good VHS tape.

MPEG-4 is the most recent codec, developed in order to have a high quality streaming (continuous video transmission on digital networks) in narrowband channels such as Internet, starting from a few kb/s.

Soble [3], Harris [2] and Umeda [4] respectively demonstrated the equivalence, for diagnostic purposes, between echocardiographic studies memorized on SuperVHS tape and those memorized digitally, after digital compression of the signal, in accordance with MPEG-1, MPEG-2 and MPEG-4 standards.

Barbier [7] also investigated the application of MPEG-4 in echocardiography, again with the aim to produce practical systems for memorizing the studies, but this time the effect of compression was compared with the original video in digital format.

Main [11] investigated the use of video compression for the real time digital transmission on high speed lines of EC studies, with the scope of establishing the requisite conditions for applications of tele-consultation, establishing a lower limit of 2 Mb/s for transmission after MPEG-2 compression, while Yoo [12] established a limit of 600 kb/s for transmission after MPEG-4 compression for echographic studies of radiological interest.

Our findings show that an MPEG-4 compressed echocardiographic study transmitted at 256 kb/s is clinically equivalent, in terms of intra-observer variability, to the same study presented directly on echocardiography. Assessments for the single quantitative and qualitative parameters do not disclose any particular sensitivity to the fact of compression and even at 128 kb/s, despite the significant perception of a reduced image quality, the observers were still able to give reliable readings.

A few word on the choice of the specific appliance we used for the encoding.

The selected codec was chosen to provide a basic framework for tele-echocardiograpy solutions, suitable for high quality stand-alone operation, without an encoding PC. Any ultrasound device can be used as a source of video sequences, either directly via its video outputs or using a RGB to video converter. Its streaming protocol (RTSP) is suitable for Internet transmission of compressed video, both in a point to point or multicast applications and its low transmission delay (less than 250 ms) allow for tele-presence during remote examinations.

A number of limitations must be taken into account when considering the results of this study.

The image format was restricted to 384x288 pixels/frame, in order to compare results to studies in the literature that presented comparisons with sVHS video format (popular recording media in the echocardiographic laboratory). The number of operators is limited, but since their intra-operator variability was comparable by that obtained in previous studies in the same laboratory we believe that the results can be viewed with confidence nevertheless.

Further studies are necessary to investigate the capability of MPEG-4 compressed video to show other clinically significant echocardiographic findings (as wall thickness, for instance).

CONCLUSIONS

These results confirm the feasibility of MPEG-4 compression for the transmission of echocardiographic studies for use in telemedicine and suggest that it is not necessary to seek transmission speeds higher than 256 kb/s for the semiquantitative reading of left ventricular kinetics. Moreover the compression MPEG-4 at 128 kb/s, though featuring a reduced video image quality, preserves the information content necessary for an evaluation of the left ventricular wall motion with a variability comparable to that between different readings of the same operator.

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