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Impact of various compression rates on interpretation of digital coronary angiograms[1]

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Abstract

According to the ACC/ACR/NEMA/ESC-guidelines, digital techniques should be replaced by cinefilm for coronary angiography. The ad hoc group of experts recently chose CD-R (CD recordable) as transport media and the JPEG standard for image compression. To avoid a possible loss of image quality, the guidelines allow a maximal data compression of only 2:1. This, however, leads to a considerable limitation: coronary angiograms cannot be viewed in real-time directly from CD. Since the possible influence of higher compression rates on image quality of coronary angiograms had not been investigated in a controlled study, we evaluated 8 various compression rates (ranging from 5:1 to 43:1) according to a prospective, randomized and blinded protocol. Four independent observers assessed 1440 angiograms using a semiquantitative score. We found that angiograms with a compression rate of 5:1 and 6:1 did not lead to a clinically relevant deterioration of image quality, whereas 11:1 was still acceptable, but 43:1 becomes unacceptable. Since no clinically relevant loss of information at a compression rate of 6:1 was experienced in our study, a modification of the ACC/ACJ/NEMA/ESC-guidelines allowing higher compression rates should be considered. © 1997 Elsevier Science Ireland Ltd.

Keywords: cardiac catheterization; coronary artery disease; computer application; CD-ROM; ACC standard

1. Introduction

The advantages of the filmless cathlab are obvious: No use of chemistry and subsequent environmental protection, reduction of radiation exposure, simpler handling and finally, reduction of costs [1]. Therefore, replacing cinefilm by digital techniques is generally desired.

The ad hoc group of experts achieved a major task by establishing a general technical standard for digital archiving and interinstitutional exchange of coronary angiograms: the guidelines of the ACC (American College of Cardiology), ACR (American College of Radiology) and NEMA (National Electrical Manufacturers Association) [2]. The logical format is the in medicine well established DICOM 3.0-standard (Digital Imaging and Communications in Medicine). The physical format is the CD-R (compact disc-recordable). Its write-once-technique warrants a high degree of data security, using the industry standard of 'orange book' [3]. CD-R is faster and more robust than digital tapes like DAT, Exabyte or DLT. The capacity of a single CD-R with its 680 MB is sufficient to store 99% of cardiac catheterizations [2].

The technique chosen for data compression is JPEG (Joint Photographic Experts Group). However, the expert group recommended a maximal data compression of 2:1 (lossless compression), directly

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leading to a considerable limitation of its practicability: even with the up-to-date CD-technology, coronary angiograms cannot be replayed in real-time directly from the CD-R. But exactly this option of immediately viewing coronary angiograms in real-time (like cinefilm) will ascertain the worldwide acceptance and distribution of CD-R for archiving and exchanging coronary angiograms. Since higher compression rates would allow real-time viewing of coronary angiograms directly from CD-R, but the possible deterioration of image quality using various higher compression rates had not yet been established in a controlled study with coronary angiograms, we performed the following prospective randomized and blinded investigation.

2. Methods

Diagnostic cardiac catheterization was performed in standard technique after puncture of the right femoral artery; coronary angiograms were obtained with 5F-Judkins-catheters (Baxter). The contrast agent was identical in all patients (Solutrast™, Byk-Gulden). Twenty four consecutive patients were enrolled (15 with coronary artery disease, 2 with valvular disease, 2 with dilative cardiomyopathy and 5 without abnormal findings). The mean age was 58.7±9.3 years, the mean height 170.4±8.9 cm and the mean weight was 80±11.7 kg. LV−EF was 68±11%. The lossless compressed angiograms (General Electric Advantx-Hiline-System, 512×512 pixels, 256 grey levels, Huffman encoding and differential pulse-code modulation, DPCM [4]) served as reference.

Angiograms were digitized at 25 frames per second using various JPEG-compression rates with the Media 100™-system (Data Translation, USA) installed in a Power-PC (Macintosh™ (8100/110; 80 MB RAM) and stored on Seagate-Barracuda™ hard disks (SCSI-2 fast disk array, 9 GB) using Remus™ Software from Trillium-Research. The Media 100™-system performs a single frame by frame JPEG data compression of 786×576 pixels. We chose 8 various compression rates: 5:1, 6:1, 7:1, 9:1, 11:1, 14:1, 22:1 and 43:1. In blinded and randomized sequences, four experienced observers (A, B, C and D, three invasive cardiologists, one experienced technician) evaluated the angiograms. These real-time movies were continuously displayed and compared with the reference angiogram as better (1 point), equal (2 points), good but somewhat worse (3 points), acceptable (4 points) or unacceptable (5 points). The overall assessment included general image quality, image contrast, delineation of stenoses, visibility of small vessels and collaterals as well as disturbing signals, blurring effects and block artifacts possibly introduced by higher JPEG compression. A total of 1440 assessments had to be made by the observers (45 coronary angiograms, 23 left coronary artery, 22 right coronary artery with 8 different compression rates). To exclude the possible influence of different views, all angiograms were evaluated in the 30° RAO projection. The statistical analysis was performed using Scheffé's test. $p<0.05$ was regarded as significant*.

3. Results

Fig. 1 depicts the overall results: most angiograms

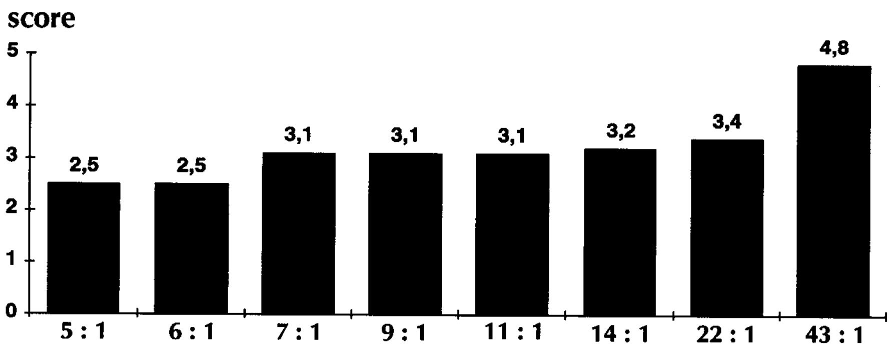

Fig. 1. Mean values for image quality acccording to the semiquantitative score: overall results (for p-values and significances please see Table 1).

Table 1
Significance of differences between the various compression rates

	5:1	6:1	7:1	9:1	11:1	14:1	22:1
6:1	0.9997						
7:1	0.2349	0.5663					
9:1	0.3871	0.7399	1				
11:1	0.1748	0.4751	1	1			
14:1	0.0040*	0.0308*	0.9371	0.8408	0.9654		
22:1	0.0001*	0.0001*	0.0072*	0.0023*	0.0122*	0.3158	
43:1	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*

were classified as equal or good up to a compression rate of 6:1, followed by a mean classification as good to acceptable. The rate of 43:1 was unacceptable. Analyzing the semi-quantitative score, compression rates from 5:1 to 11:1 did not show statistically significant differences among each other (Table 1). The higher compression rates of 14:1, 22:1 and especially 43:1 were significantly worse. The first and closest pair of compression rates showing a statistically significant difference was 6:1 vs. 14:1 (p=0.03, Table 1). There was no difference between the assessment of the left or right coronary artery (3.3±0.7 vs. 3.4±0.6, p=0.27).

Interobserver variability: the mean values of the four observers were 3.3±0.9, 2.9±1.1, 3.3±0.7 and 3.4±0.8. Although these mean values were close, the individual analysis revealed significant differences between individual observers (Fig. 2, Table 2): Observer B classified the quality of the angiograms constantly significantly better than A and D, whereas observer C scored significantly better than A, but worse than B. Therefore, viewing the data in analogy to Fig. 1, the overall trend shows a similar tendency with the individual curves, however, vertically shifted (Fig. 2).

Table 2
Significance of differences between the four observers A, B, C, and D.

	A	B	C	D
A		0.0001*	0.0001*	0.7143
B	0.0001*		0.0007*	0.0001*
C	0.0001*	0.0007*		0.2298

4. Discussion

Coronary angiography remains the gold standard for the diagnosis of coronary artery disease. Most coronary angiograms are still stored on 35 mm cinefilm. With the increasing number of centers performing coronary interventions and the availability of faster and cheaper computer systems, digitizing coronary angiograms has become increasingly accepted since the mid-80s [5]. Today, approximately 75% of the cathlabs use digital techniques for the immediate assessment of coronary angiograms for

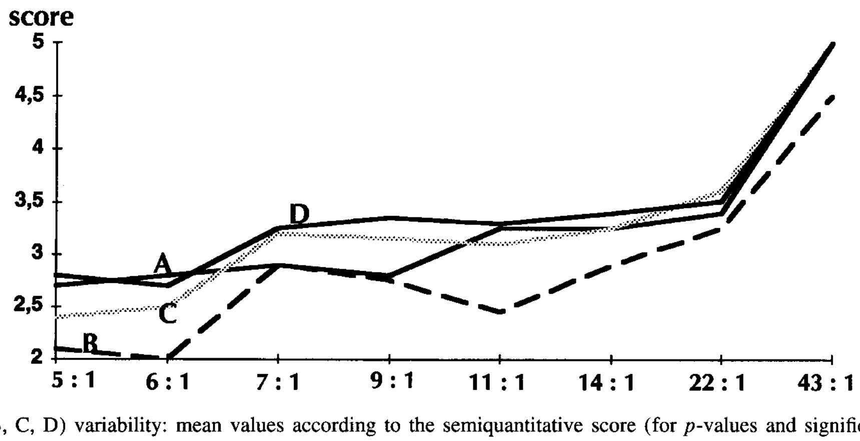

Fig. 2. Inter-observer (A, B, C, D) variability: mean values according to the semiquantitative score (for p-values and significances please see Table 2).

diagnostic and interventional procedures [2]. These digital angiograms are usually then erased from the hard disk.

For archiving digital angiograms, the prerequisites for replacing cinefilm are clearly defined: Firstly, image quality should not be inferior to cinefilm [1,6]. Since the ACC/ACR/NEMA-standard was not yet established until recently, many cathlabs decided on a filmless-digital, but not standardized archiving. Others opted for a filmless-analog archive using video techniques: videotapes offer several advantages: they are in widespread use (and therefore simplify inter-institutional exchange), offer easy handling, instant replay capability and are inexpensive [7–9]. The ACC/ACR/NEMA-expert group, which was recently joined by the ESC (European Society of Cardiology), however, is very much concerned about the increasing use of video techniques for archiving and for inter-institutional exchange. The expert group says that S-VHS angiograms are — at their best — only half as good as digital angiograms [1,2,10]. Even the use of analog laser disks (e.g. LDA) may be only an interim solution [6]. In contrast, however, others showed that analog laser disks may be sufficient for clinical purposes [11,12]. Even S-VHS, particularly with edge-enhancement, offers an acceptable quality comparable to cinefilm [13]. Disadvantages of videotapes are the loss of image quality after copying as well as their sensitivity to external influences.

Digital techniques offer several advantages over video techniques: no loss of quality of copies, the possibility of zooming and the 'aura' of modern technology. Digital coronary angiography is similar to cinefilm, even for the quantification of lesions [14], with its tendency to overestimate stenoses in small vessels [15].

The minimum requirement for digitizing coronary angiograms is a pixel resolution of 512×512 at 256 grey levels (8 bit), resulting in 256 KB per frame (512×512×8). Using a data compression of 2:1 according to the ACC/ACR/NEMA/ESC-guidelines, a data flow of approximately 3.9 MB/s for NTSC (30 frames/s, USA) or 3.1 MB/s for PAL/SECAM (25 frames/s, Europe) can be calculated. These challenging data streams, however, cannot be accomplished by CD-players: even the fastest commercially available CD-players with their '12×-speed' (i.e. 12 times as fast as audio CD-players), achieve only up to 1.8 MB/s. Therefore, CD-players cannot provide real-time viewing of digital angiograms directly from CD. This leaves only two choices: Viewing coronary angiograms in slow motion (appr. 8 frames/s) or accepting longer waiting times until the angiograms are copied from CD-R to a hard disk, which may take up to 15 min per study.

To reduce the data streams, the following possibilities exist: The field of view may be cut, choosing the most important, representative part of the image (reduction of data per frame). The acquisition speed may also be reduced to, for instance, 12.5 frames/s in Europe or to 15 frames/s in the USA. This, however, is not recommended by the expert group [2,6]. Recently, the creation of new quantization tables was proposed in order to reduce the amount of redundancy as well as some irrelevant information and noise [16]. One might on the other hand wait until newer and faster CD-players are developed. This is, however, highly unlikely, because a 24×-speed player would be necessary to replay approximately up to 3.5 MB/s. The new DVD-standard (Digital Versatile Disc) will not only increase the storage capacity per disc (up to 19 GB), but also allow a higher replay speed [17].

Therefore, the only realistic possibility available today is to increase the compression rates: in contrast to lossless compression algorithms (including variable-length bit codes (Huffman codes and variants), dictionary-based compression (Lempel-Ziv variants) and arithmetic coding [18], higher compression rates carry the inherent risk of deteriorating image quality due to compression artifacts with their uncertain clinical impact [1]. These techniques were traditionally classified as 'lossy' (destructive, irreversible).

The ACC/ACR/NEMA/ESC-group has chosen the JPEG standard, because JPEG is already established in medicine, especially in many angiography systems. The JPEG compression algorithm with its inherent risk of blocky artifacts (8×8 pixel-DCT-blocks) is generally accepted to be lossless only for a compression rate of 2:1. This historical classification into lossless and lossy compression is based on physical-mathematical considerations and not on physiologic-clinical criteria. Recently, the 'lossy' compression rates of 3:1 and 4:1 were classified as 'not entirely loss free' [19].

As our study has shown, a JPEG data compression of 5:1 and 6:1 yielded the best results for 'lossy compression' and did not lead to a clinically visible loss of image quality. In particular, blocking artifacts were not clinically relevant. Furthermore, there is enough safety margin from the limit of clinically acceptable image quality.

Other studies comparable to ours with coronary angiograms using various compression rates were not conducted or not published. Koning et al. mentioned that a compression rate of 4:1 does not lead to a significant deterioration of visual interpretation of 19 coronary angiograms [19]. Several groups have worked on the problem of data compression under clinical circumstances with static pictures: JPEG compression with 10:1 of conventional X-ray images, computer tomograms and ultrasound images showed no visible differences compared with the originals [20]. Using the FFBA-technique and a compression rate of 20:1 for X-ray images of the chest, acceptable results were obtained [21]. For the JPEG algorithm, however, 15:1 already delineated a loss of image quality [17,22]. On the other side, JPEG compression rates of 40:1 in dermatology did not influence diagnostic performance, although resulting in a significantly lower rating [22]. Since image quality was significantly more deteriorated in images of skeletal muscle compared with images of the abdomen [23], one can assume that the results for one type of image cannot necessarily be extrapolated to images of other organs. Movies are possibly more sensitive to compression rates than static images. In a recently published study, lossy JPEG (15:1) compression of coronary angiograms did not alter the diagnostic assessment of lesion severity [24]. However, no conclusions could be drawn regarding the accuracy of other compression rates [24].

The results of our study are only applicable for JPEG-compression, as required by the ACC/ACR/NEMA/ESC-standard. Other compression algorithms, like MPEG-1 (CD-I) with 352×288 pixels and 'interframe interpolations', should not be used for digital coronary angiography as well as other restricted formats like AVI, low level Quick Time, Cinepack, Indeo or Xing. The influence of adaptive ('dynamic') compression algorithms, i.e. different compression rates depending on image contents, is not known. Newer compression algorithms like MPEG-2 or MPEG-4 with lower compression rates as compared to MPEG-1 may be promising. However, they are not accepted as a cardiology standard.

Another advantage of reducing data streams offers easier real-time transmission of coronary angiograms through networks (ATM, FDDI) to other locations, for example to heart surgeons or referring physicians.

4.1. Study limitations

It was our purpose to investigate the influence of various compression rates on image quality of coronary angiograms in consecutive patients referred for invasive diagnostic procedures. Further studies are necessary to analyze the influence of the severity of stenoses, of the lesion types (plaque, thrombus, dissection) and the assessment of the results of interventions. In particular, a similar study using various compression rates with quantitative lesion analysis [25] depending on image contrast and the use of different contrast agent osmolality is necessary. Digital systems may need higher requirements for scientific work than for clinical practice [13,26].

5. Conclusions

Following the new international standard using CD-R as archiving and exchange media for digital coronary angiography results in a dilemma between complying with official guidelines (2:1 compression) and practicability (no real-time viewing from CD-R). Since no clinically relevant loss of information at a compression rate of 6:1 was experienced in our study, a modification of the ACC/ACJ/NEMA/ESC-guidelines allowing higher compression rates should be considered.

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