Standards on Digital Echocardiography: An Israel Heart Society Position Paper Presented by the Israel Working Group on Echocardiography

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ABSTRACT: The output settings of echocardiographic systems should be set to the full (original) frame rate and lossless compression (e.g., run-length encoding) in order to transmit echocardiographic videos so that they retain their original quality. In addition, monitors and display cards of echocardiography systems and workstations should be able to support an adaptive refresh rate for displaying video at an arbitrary frame rate, including a high frame rate (90+ fps) without dropping frames and preserving the original frame duration. Currently, the only available option for echocardiography monitors is 144–165 Hz (or higher) based on adaptive frame rate G-Sync or FreeSync technology monitors. These monitors should be accompanied by compatible display cards. Echocardiography systems and workstation video playback software should support G-Sync or FreeSync adaptive frame rate technology to display echocardiography videos at their original frame rates without the effects of jitter and frame drops. Echocardiography systems should support an online display of the videos on the workstations during acquisition with the original quality. The requirements for web-based workstations are exactly the same as for desktops workstations. Hospital digital networks should provide transmission and long-term archiving of the echocardiographic videos in their original acquisition quality.

IMAJ 2019; 21: 524–527

KEY WORDS: digital echocardiography, echocardiography workstations, echocardiography monitors, echocardiography video

The latest comprehensive recommendations on digital echocardiography were published in 2005. At the time, echocardiography systems were able to acquire video with a frame rate of up to 30 frames per second (fps) and a resolution of 480 × 640 pixels. Hospital networks were limited to approximately 100 megabytes per second (Mbps) and echocardiography videos underwent significant compression in a lossy format when stored for long periods of time [1]. Since then, echocardiography systems have improved significantly. Today, the typical echocardiographic video frame rate is 50–90 up to 120 fps, network speed has increased to at least 1000 Mbps, and 4D echocardiography datasets and speckle tracking imaging measurements have become a part of routine echocardiography study. New standards are needed to reflect the new technological advances and updated clinical and research needs. The proposed recommendations are based on a recent investigation conducted at 10 Israeli hospitals regarding the transfer, storage, and reproduction of echocardiography studies [2], and was endorsed by Thomas [3].

REQUIREMENTS FOR THE STORAGE AND TRANSFER OF ECHOCARDIOGRAPHIC VIDEOS

Echocardiographic videos are reviewed by physicians using workstations, where they are transferred from echocardiography systems via the hospital network. In a modern echocardiography laboratory, a workstation is the only place where physicians observe echocardiographic examinations. During the transmission, the echocardiographic videos undergo significant changes and degradation. Paradoxically, the echocardiography system is the only place where echocardiographic

examinations can be observed at the original quality; however, the only person who observes original quality video is the technician. The quality of the transferred image depends on the exported frame rate and compression settings. A loss of image quality can lead to a wrong diagnosis. Therefore, workstations should reflect and maintain the original image quality of echocardiography systems including compression settings and frame rate.

Echocardiographic workstations are classified as workstations for either research or clinical use. Research workstations retain the original frame rate and the raw Digital Imaging and Communications in Medicine (DICOM) format; however, clinical workstations typically endure a reduced frame rate (usually 30 fps) and video with lossy compression. These parameters are defined in the output settings of echocardiography systems and cannot be changed on workstations [Figure 1].

Frame rate

High frame rate videos are more informative than low frame rate videos. Today, in many echocardiography laboratories echocardiography examinations are acquired with high frame rate, but frame rate is reduced before transmission in the output settings of echocardiography systems. Echocardiography examinations that are more sensitive to the reduction of frame rate are videos with fast heart rates; for example, stress echocardiography, and atrial fibrillation. In a typical case, the frame rate of the stress echocardiographic study is 60 fps, and the patient's peak heart rate is 150 beats per minute. One cardiac cycle will contain 24 recorded frames. Typical 30 fps export settings of an echocardiography system significantly reduces the number of frames per cardiac cycle to only 12 frames; therefore, a physician who reviews this stress echocardiographic study on a workstation would observe only half of the echocardiographic information. The same applies to storage. This sample study can be obtained later from a hospital digital archive, but with a reduced frame rate.

Figure 1. Output settings of the echocardiography system
[A] Settings that are not recommended
[B] Recommended settings

Compression

Lossily compressed videos cannot be restored to their original quality and are useless for post-processing techniques such as 4D echocardiography, speckle tracking imaging, or big data analysis. Lossy compression does not guarantee the preservation of all of the important diagnostic information and the absence of artifacts after compression (even 100% JPEG quality is lossy).

Summary of storage and transfer of echocardiographic video recommendations

With regard to the storage and transfer of echocardiographic videos, original frame rate and lossless compression, such as run-length encoding (RLE), should be set in output settings of echocardiography systems [Figure 1].

REQUIREMENTS FOR THE ECHOCARDIOGRAPHY WORKSTATIONS

In the field of medical imaging, radiology is typically the first imaging specialty that comes to mind [4]. Radiological workstations have firm and clear requirements. Recently, pathology workstations [5], dermatology digital imaging [6], and teleophthalmology workstations [4] have been introduced.

Although an integral part of the clinical diagnosis, echocardiography has been mistakenly considered an important, but secondary, method of examination that often can be performed using a portable device. Such a simplified approach may be suitable for the point-of-care medicine often provided by non-cardiologists, but it cannot be extrapolated to an echocardiography laboratory. In part, cardiologists are to blame for the depreciation of the diagnostic value of echocardiographic studies, having previously agreed to observe them on regular computer screens. For example, a radiologist would not be able to effectively and accurately interpret an X-ray without access to a proper workstation.

Combined workstations

In the era of multimodality imaging, the use of radiological workstations for both radiology and echocardiography has increased, despite the completely different requirements for radiological and echocardiographic imaging. Radiological workstation monitors have extremely high resolution, but the unintended effects of that quality include low refresh rate and slow response time. In contrast, echocardiographic videos have low resolution but a high frame rate; therefore, radiological workstation monitors are not suitable for echocardiography. The investment in expensive radiological monitors (e.g., medical diagnostic monitors)

to improve the quality of echocardiographic videos results in a paradoxical significantly reduced video quality.

Web-based workstations

In many cases, echocardiography workstations are replaced by web-based software running on any accessible computer. Currently, web browsers support natively only lossy video codecs and limited maximum video frame rate that is not suitable for echocardiographic videos. At the present time, no suitable web-based video streaming software is available. This situation is due to the absence of any standards for display of echocardiographic videos.

Summary of echocardiography workstation recommendations

With regard to echocardiography workstations, video playback software should support G-Sync or FreeSync adaptive frame rate technology to display echocardiography video at their original frame rate without the effects of jitter and frame drops. Displaying echocardiography examinations on a radiology workstation is not recommended. Requirements for web-based workstations are the same as for desktop workstations. The web-based and desktop workstations should use full frame rate and lossless compression.

REQUIREMENTS FOR ECHOCARDIOGRAPHY MONITORS

Radiology monitors

The American Association of Physicists in Medicine and the American College of Radiology classify radiology monitors into two main categories: primary and secondary. Primary monitors are used by radiologists to interpret images for official reports. Secondary non-diagnostic monitors are intended for multiple uses [7,8]. In radiology, the most important features of the primary diagnostic monitor are the screen size and spatial resolution [7].

Problems with echocardiography monitors

Unlike in radiology, there are no standards for echocardiography monitors, and in most hospitals, conventional monitors are used in echocardiography. Sometimes, to improve the quality of the video, expensive radiological monitors are also used. Both types of monitors have a limited non-adaptive refresh rate of up to 60–75Hz. This misuse causes two significant problems. The first problem is known as jitter, in which the monitor refresh rate is unevenly divided by the video frame rate, for example when a video with a frame rate of 45 fps is played on a monitor with a fixed refresh rate of 60 Hz. In such a case, video playback cannot maintain a constant frame rate 45 fps and two consecutive frames are played at a speed of 60 fps and the third is played at a speed of 30 fps, and so forth. This speed is the only way to synchronize the fixed monitor refresh rate with the mean video frame rates. Thus, monitors with a fixed refresh rate of 60 Hz can only display properly video with frame rates of 30 and 60 fps; monitors with a fixed refresh rate of 75 Hz can only display video with frame rates of 25 and 75 fps. An acquisition frame rate depends on many factors, including zooming, depth, and sector width. Therefore, it cannot be aligned with a fixed monitor refresh rate.

If a video frame rate is higher than a monitor refresh rate, a second problem develops: frame drops or tearing. In this case, every second frame will be dropped and the remaining frames will be displayed twice as long when displaying videos with a frame rate of 120 fps on a monitor with a fixed refresh rate of 60 Hz. A typical example of video playback with a frequency of 99 fps on a monitor with a refresh rate of 60 Hz is shown in Figure 2. Of the 483 frames, only 290 frames were drawn, and 193 frames were dropped: $290 \times 1/60 \sim (290 + 193) \times 1/99$. During playback, each cardiac cycle appears randomly with different frames due to the loss of random frames. Another example shows that the 198th frame, which has little diagnostic value was played, but the best diagnostic 199th frame was dropped during video playback of 97 fps on a 60 Hz monitor [Figure 3]. In rare cases, when VSync synchronization between the monitor and the display card is disabled, video frames are torn.

The only monitors that can correctly display an echocardiographic video with an arbitrary frame rate (including high frame rates) are 144–165 Hz (or higher) monitors based on Nvidia G-Sync or AMD FreeSync technology. Such monitors with an adaptive refresh rate should be accompanied by compatible display cards.

Echocardiography monitors: eyes strain

It is known that the human eye cannot distinguish between frame rates of less than 70 or more than 80 fps. New research in this area has reported that much higher frame rates up to 500 Hz can be observed [9].

The concern of monitors with a low refresh rate is important not only in light of possible diagnostic problems but also because of the potential eye stress that has not been reported in the literature with regard to the use of echocardiography monitors. The American College of Radiology technical standard recommends checking the quality of diagnostic displays

Figure 2. Dropped frames while displaying 99 fps echo video on 60 Hz monitor. Of the 483 frames, only 290 frames were reproduced and 193 frames were dropped [arrow]: 33% of frames cannot be seen

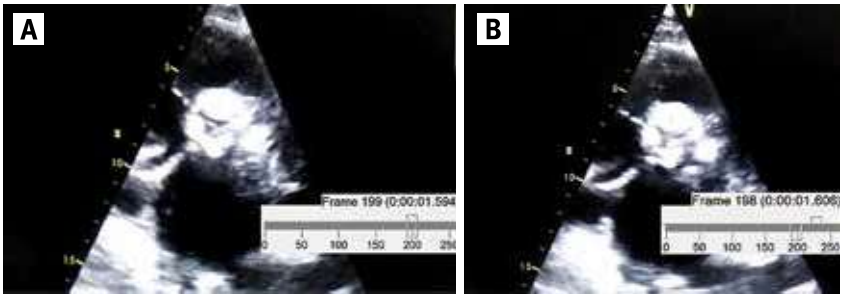

Figure 3. Images of a 97 fps echocardiograph video displayed on monitors with adaptive and non-adaptive refresh rate

[A] A 97 fps video is played on the monitor with adaptive refresh rate 144 Hz. Internal edges of the calcified aortic valve are seen clearly at frame 199

[B] A 97 fps video is played in the monitor with a non-adaptive refresh rate of 59 Hz. Frame 199 cannot be reproduced, while the nearest frame, 198, is reproduced. Calcified stenotic aortic valve is seen less clearly than in frame 199

at least once a month [7]. Vertinsky and Forster [10] showed that 36% of radiologists reported eye strain depending on the length of working time, the number of breaks, and flickering of the screen. Even environmental factors, such as indoor light, can cause visual fatigue and should be considered when planning radiological workstations [11].

Cardiologists spend a great deal of time reviewing echocardiographic studies on monitors, and therefore eye strain is an important consideration, especially with regard to moving images. An additional stress factor includes motion blur. To minimize the negative impact of motion blur on the eyes, echocardiographic monitors should have an adaptive refresh rate to properly display the video at an arbitrary frame rate.

Summary of the use of echocardiography monitors

Monitors and display cards of echocardiography systems and workstation cards should be able to support an adaptive refresh rate for displaying video at an arbitrary frame rate, including a high frame rate (90+ fps) without dropping frames and preserving the original frame duration. Echocardiography monitors should have an adaptive refresh rate of at least 144–165 Hz, based on G-Sync or FreeSync technology. They should be accompanied by compatible display cards.

CONCLUSIONS

In recent years, computerized technologies have developed significantly and opened wider opportunities for the transmission, storage, and playback of echocardiography data. The old simplified approach to echocardiography examinations using a reduced frame rate and the lossy format is deceptive and can lead to a degradation of video quality and loss of useful information. This reduction in the quality of the echocardiography data is associated with a risk of misdiagnosis. In our recommendations, we defined new standards for the transmission, storage, and reproduction of echocardiographic studies in their original quality.

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"The smart way to keep people passive and obedient is to strictly limit the spectrum of acceptable opinion, but allow very lively debate within that spectrum - even encourage the more critical and dissident views. That gives people the sense that there's free thinking going on, while all the time the presuppositions of the system are being reinforced by the limits put on the range of the debate"

Noam Chomsky (born 1928), linguistics professor and political activist