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# Analysis of Temporal Requirements for Myocardial Tissue Velocity Imaging

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***Aims:*** Movements of myocardial walls include components of high velocity and short duration calling for a high sampling rate in the acquisition of tissue velocity imaging data. This study aims at establishing the optimal sampling requirements for tissue velocity imaging measurements.

***Methods and Results:*** In 16 healthy individuals, tissue velocity imaging data were acquired at a frame rate of 141–203 frames/s for a subsequent off-line analysis using software enabling a reduction of the sampling rate to 50%, 25% and 12.5% of the initial frame rate. Different components of the myocardial velocity profile were measured at each of these frame rates. The deviation of the results from the initial values increased markedly at decreasing frame rates, producing an underestimation of peak systolic and diastolic velocities, most other measured parameters being overestimated. A cut-off point for an acceptable $\leq 10\%$ deviation of the results corresponded to at least 70 frames/s for peak systolic and early diastolic velocity, and to at least 100 frames/s for other systolic and diastolic parameters.

***Conclusion:*** A high sampling rate is essential for a proper rendering of tissue velocity imaging signals, too low frame rates resulting in inferior accuracy of the results. This should be kept in mind while viewing reported tissue velocity imaging data.
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***Key Words:*** tissue velocity imaging; sampling frequency; frame rate; myocardial velocity.

## Introduction

It is now fairly well established that the echocardiographic analysis of myocardial wall movements using tissue Doppler imaging adds significantly to the proper evaluation of different forms of myocardial dysfunction. The method is based on the detection of Doppler shift caused by the motion of the myocardial tissue during cardiac cycle and was originally performed applying a pulsed Doppler signal adopted to measure low movement velocities[1]. The introduction of 2-dimensional images of cardiac velocities in the form of colour-coded maps[2], and the development of the echocardiographic equipment with high temporal resolution and extended degree of digitization, laid down the foundations of current tissue velocity imaging from which extensive velocity information can be achieved at practically any discrete point within the myocardial wall. The recently introduced multiple line acquisition technique provides, for example, a considerably increased temporal and velocity range resolution without compromising spatial information. This has opened possibilities for the detection of rapid movements of the myocardial walls causing reshaping of left ventricle during short systolic and diastolic events, such as isovolumetric contraction and relaxation phase. Both isovolumetric phases containing these rapid left ventricular reshaping movements are very short and the corresponding myocardial velocity curves form steep slopes, a fact which makes the employment of high frame rate in the measurement of these parameters imperative, otherwise a considerable amount of temporal and velocity information would be lost.

Whereas the echocardiographic equipment at the time of the first tissue colour Doppler imaging[2] provided a sampling rate of 11 frames/s, most other diagnostic imaging techniques, such as computed tomography, angiography or magnetic resonance operate routinely with sampling rates between 30 and 40 frames/s. The

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latest developments in the echocardiographic acquisition technique have created a basis for data sampling at a considerably higher frequency and a sampling rate of 60–70 frames/s is usually considered to be adequate for studying fast cardiac movements with a sufficient temporal resolution. However, the optimal temporal requirements for tissue velocity imaging have not yet been reported. Therefore, the aim of this study was to establish optimal sampling rates for measurements of various systolic and diastolic events with tissue velocity imaging technique.

## Methods

The study involved 16 healthy volunteers, three men aged 18–37 years and 13 women aged 16–59 years without any symptoms of cardiovascular disease. The study was approved by the Ethics Committee at Huddinge University Hospital, Stockholm, Sweden, and all subjects gave their informed consent to participate.

### *Tissue Doppler Imaging Echocardiography*

All study participants were subjected to tissue Doppler imaging echocardiography, using a GE Vingmed System Five equipment with tissue velocity imaging facility. A standard phased array 2·5 MHz multifrequency transducer was used. All recordings were performed from an apical four chamber position with the subjects in left lateral position. The formatted raw data containing both grey scale and tissue velocity imaging information was stored as IQ-data in the scanner. Ventricular septum and the left ventricular lateral wall were recorded separately and the data from cineloops of two consecutive heartbeats were stored. The 2D-sector angle was minimized to attain a high frame rate.

After completion of the echocardiographic examination the IQ-data was transferred to a standard PC for analysis of the tissue velocity imaging profiles. The PC-software employed allows for a real-time digital acquisition of tissue velocity imaging data with a subsequent off-line quantification of the tissue velocity imaging profiles at any point in the myocardial location from the stored cineloops. A total of 45 cineloops were recorded with an initial frame rate of 141–203 frames /s (eight cineloops with 203, eight with 174–179, 10 with 162–164 and 19 with 141–143 frames/s).

### *Data Analysis*

The echocardiographic tissue velocity imaging signal analysis was performed by an experienced operator on data acquired from an optimal measuring point, set at the basal septum or at the basal lateral wall of the left ventricle, depending on image characteristics. The initial frame rates (141–203 frames /s) for the respective

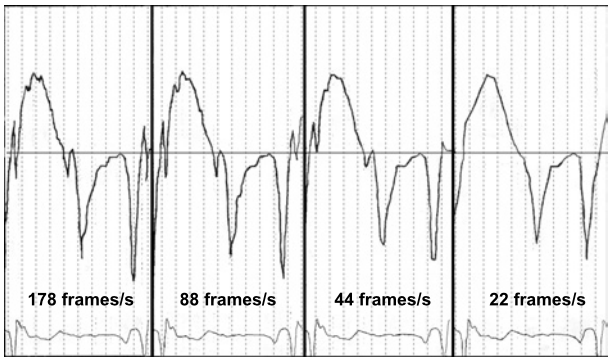


**Figure 1.** Typical myocardial tissue velocity curves from the basal septum obtained at different acquisition frame rate. Note the change in the curve shape between 178 and 22 frames/s.

acquisitions were set at a level of 100%. Only one of the two consecutive heart cycles stored in the initial cineloops was selected and analysed throughout, i.e. the cycle which provided the best probability to measure a given waveform by its conformity to an expected shape (see Fig. 1, 178 frames). The frame rates for the respective initial cineloops were then decreased to 50, 25 and 12·5% of the initial frame rates for each particular acquisition set, keeping the fixation of the measuring points intact. The analysis of the tissue velocity imaging data was performed at each frame rate level. The initial values for the measured variables obtained in each individual at the highest frame rate were considered to represent a value of 100% and the values obtained at decreasing frame rates were expressed as a percentage of these respective initial values. The measured variables in the tissue velocity curve were defined as follows (cf. Fig. 1).

***Isovolumetric contraction time***. A period of time between the onset of Q wave in the ECG signal and the starting point for the ascending limb of the tissue velocity curve at the beginning of the electromechanical systole (directly after R wave in ECG).

***Systole (a positive wave)***. A period of time from the end of isovolumetric contraction time as above to the zero crossing point for the descending limb of the systolic tissue velocity curve at the end of electromechanical systole.

***Peak systolic velocity***. Maximal velocity on the tissue velocity curve during systole.

***Time from Q wave to peak systolic velocity***. A period of time between the onset of Q wave in the ECG signal and the peak systolic velocity.

***Isovolumetric relaxation time***. A period of time between the end of systole as above and the zero crossing point for the ascending, descending or two-phase tissue velocity curve at the start of the diastolic E wave.

***E wave (a negative wave)***. Starting at the end point for isovolumetric relaxation time as above and ending at the top point of the ascending limb of the early diastolic tissue velocity curve.

***E wave peak velocity***. Maximal velocity on the tissue velocity curve during E wave.

***A wave (a negative wave)***. Starting at the onset of the descending limb of the late diastolic tissue velocity curve (directly after the beginning of P wave in the ECG signal) and ending at the zero crossing point for the ascending limb of the tissue velocity curve at the onset of isovolumetric contraction time as above.

***A wave peak velocity***. Maximal velocity on the tissue velocity curve during A wave.

The intra-observer variability for different systolic and diastolic parameters has been found earlier to vary between 5 and 10%[3].

## Results

An increase in the employed frame rate always resulted in an increase of the time/velocity information obtained, the rapid myocardial movements being especially frame rate sensitive. As can be seen from Fig. 1, at a low frame rate, the velocity information describing rapid motion during isovolumetric contraction and relaxation phase is totally lost.

The results of the measurements of the systolic parameters are presented in Figs 2 and 3. As can be seen from the figures, a decrease in the frame rate for the acquisition of tissue velocity imaging data was followed by a markedly increased deviation of the obtained results from the initial values. In addition, a clear tendency to overestimate the values for the duration of systole and the period of time from electrocardiographic Q wave to peak systolic velocity obtained at the highest employed frame rates was observed (Figs 2(b) and 3(a)). On the other side, the deviation of isovolumetric contraction time at decreasing sampling frequency did not reveal any evident tendency to over- or underestimation as compared with the values at the highest frame rates (Fig 2(a)), whereas a tendency to underestimate the peak systolic velocity appeared at the low frame rates tested (Fig. 3(b)).

Figures 4 and 5 summarize the results of the measurements of the diastolic parameters. Similar to what was observed with the systolic parameters, the deviation of the diastolic results, too, increased along with a decreasing acquisition frame rate. A clear tendency to overestimate the values obtained at the highest employed frame rates was seen for isovolumetric relaxation time, and the duration of diastolic E and A wave (Fig. 4). In contrast, the peak myocardial tissue velocity during E and A wave were underestimated when the frame rate was decreased (Fig. 5).

As can be seen from Figs 2–5, a cut-off point between still acceptable, and a considerably increased deviation of the tissue velocity imaging measurements from the initial values with the tendency to over- or underestimation of the values obtained at high frame rates appears to correspond to a sampling rate of at least 100 frames/s for all the parameters except peak systolic and early diastolic (E wave) velocity for which parameters a sampling rate of at least 70 frames/s should be used.

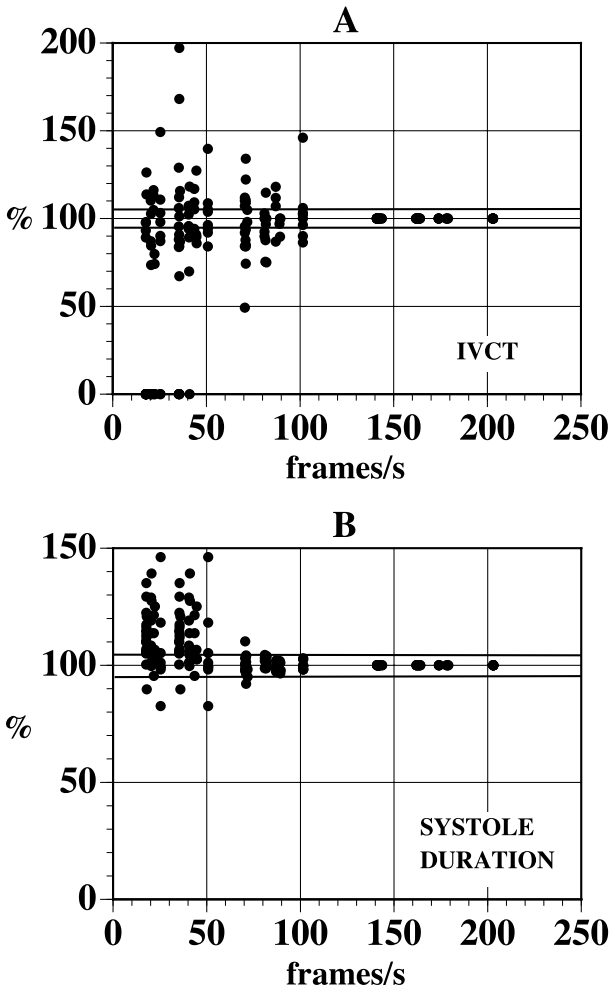


**Figure 2.** The distribution of the values of the measured systolic tissue velocity imaging parameters at different acquisition frame rates. All values are expressed as a percentage of the values obtained at the highest frame rates employed and the ± 5% threshold levels are indicated. (a) Isovolumetric contraction time; (b) duration of systole.

## DISCUSSION

Despite the fact that myocardial tissue velocity imaging has been performed for more than 10 years and, from being mostly a subject of continuous technical refinement and a tool in various research activities, is now becoming a valuable complement to a routine echocardiographic evaluation, the sampling requirements for an optimal temporal resolution have not yet been explicitly studied, even if the absolute limit of sampling rate of at least twice the bandwidth of the measured analogue signal is given by Shanon's sampling theorem[4]. The theorem assumes, however, an ideal repetitive, noise-free, band-limited signal and, consequently, a sampling

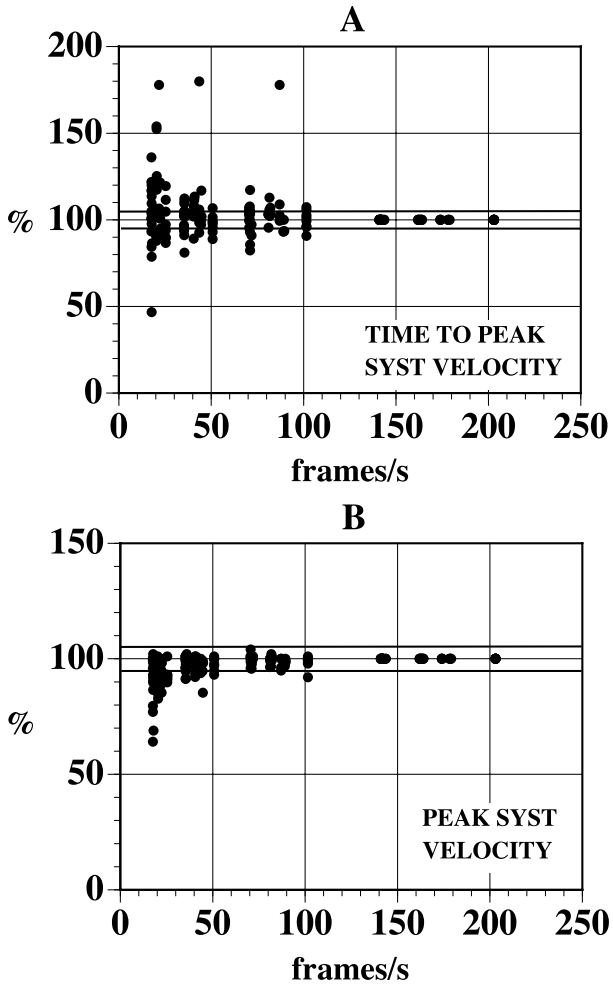


**Figure 3.** The distribution of the values of the measured systolic tissue velocity imaging parameters at different acquisition frame rates. All values are expressed as a percentage of the values obtained at the highest frame rates employed and the ± 5% threshold levels are indicated. (a) Time period from the onset of electrocardiographic Q wave to peak systolic myocardial tissue velocity; (b) peak systolic myocardial tissue velocity.

frequency higher than twice bandwidth of the input signal is required for accurate imaging of myocardial wall motion with Doppler technique. Even if myocardial tissue velocities usually do not exceed 0·2 m/s, there occurs a considerable spatial and temporal variation during cardiac cycle, and the low frame rates of about 20–30 frames/s employed in the first generation of tissue velocity imaging equipment certainly restricted the possibilities of a proper reconstruction of the sampled signal. Our present results clearly show that a sampling rate of at least 100 frames/s, but preferably even higher, is required for an acceptable accuracy of the tissue velocity imaging measurements. As a matter of fact, an accurate assessment of derivative parameters such as myocardial acceleration or retardation during isovolumic phases would require sampling frequencies in order of at least additional 5–6 harmonics to the frequencies employed in this study[5].

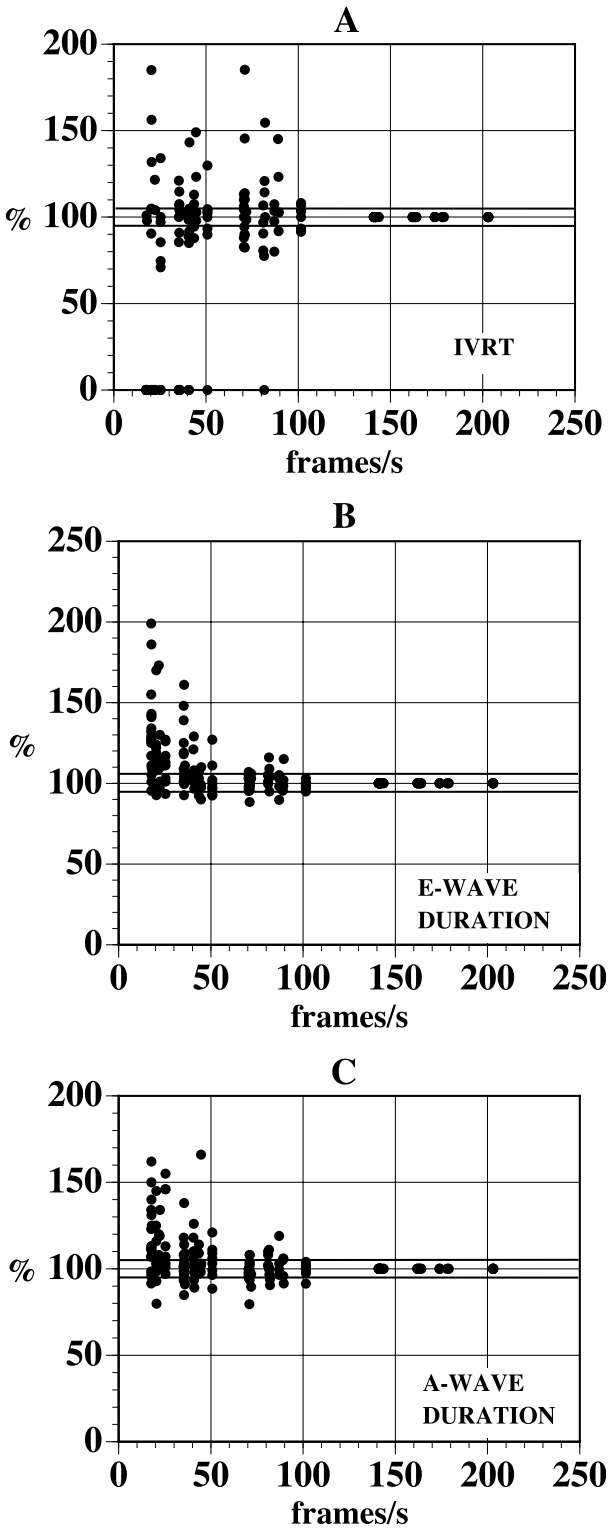


**Figure 4.** The distribution of the values of the measured diastolic tissue velocity imaging parameters at different acquisition frame rates. All values are expressed as a percentage of the values obtained at the highest frame rates employed and the ± 5% threshold levels are indicated. (a) Isovolumetric relaxation time; (b) duration of the diastolic E wave; (c) duration of the diastolic A wave.

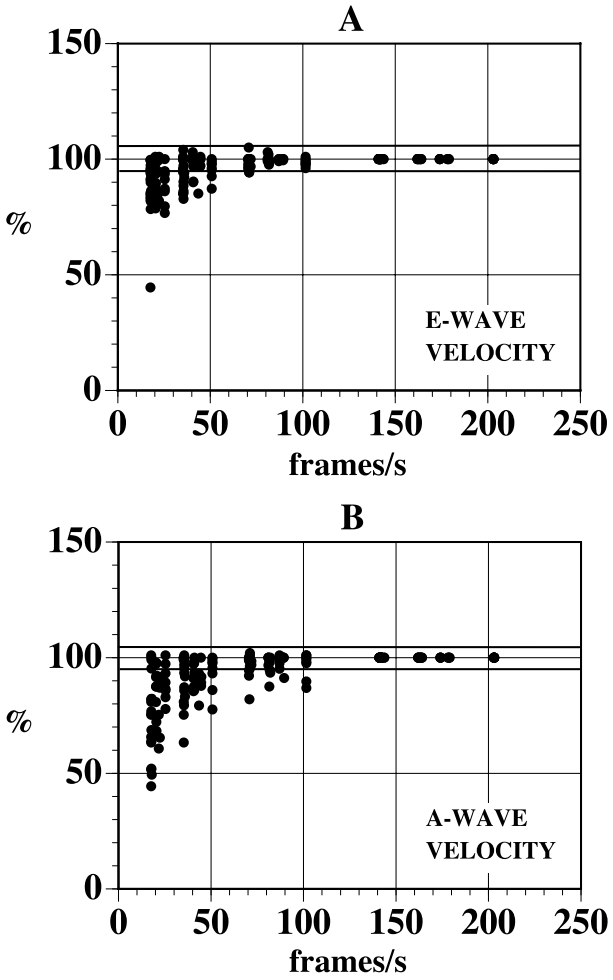


**Figure 5.** The distribution of the values of the measured diastolic tissue velocity imaging parameters at different acquisition frame rates. All values are expressed as a percentage of the values obtained at the highest frame rates employed and the ± 5% threshold levels are indicated. (a) Peak myocardial tissue velocity during diastolic E wave; (b) peak myocardial tissue velocity during diastolic A wave.

The initial sampling rate for the acquisition of tissue velocity imaging data in the present study varied between 141 and 203 frames/s. The variation in the initial frame rate was caused by two factors. Firstly, the frequency of data sampling that can be used for tissue velocity imaging scanning is influenced by 2D and tissue velocity imaging sector angle as well as depth and pulse repetition frequency, and all of these parameters varied between the studied individuals. Secondly, the software used allowed for a stepwise decrease in the initial frame rate, but only in 50% steps. Hence, in order to cover as many different sampling frequencies as possible, varying initial sampling frequencies had to be chosen.

Data sampling with frequencies higher than those available with tissue velocity imaging technique used in our study would be theoretically possible with on-line recording of pulsed wave Doppler signal. However, using the on-line pulsed wave Doppler technique, it would be impossible to keep the acquisition point fixed while switching between different sampling frequencies and it would also not be possible to perform data acquisition on the same heart cycle. Furthermore, the larger size of pulsed wave sample produces a spectral broadening of the myocardial velocity waveform. This, together with the usual low frequency filtering around baseline would significantly reduce, if not eliminate, any possibility of an accurate measurement of various systolic and diastolic cardiac events.

The sampling of the data with frame rates below 100 frames/s caused a considerable inaccuracy in the performed tissue velocity imaging measurements. The deviation of the results of the measurements from the initial values was striking at the frame rates lower than 50 frames/s thus implying an inadequate reconstruction of the myocardial velocity signal. Low sampling rates resulted in a considerable overestimation of the duration of systole as well as isovolumetric relaxation time and the duration of the diastolic E and A wave. This is not surprising, since low frame rates preclude the detection of rapid tissue movements during both isovolumetric phases making their separation from other components of systolic and diastolic wall movement impossible. The isovolumetric phases are consequently smoothed out and concealed inside systolic and diastolic waves of lower frequency, thus increasing the duration of both systolic contraction wave and the diastolic E and A waves. Similarly, the inability to detect high frequency velocity components at low sampling rates resulted in smoothed velocity curves and underestimation of true peak systolic and diastolic velocities.

An adequate reconstruction of tissue velocity imaging signal using sufficiently high sampling rate is of considerable clinical interest. A prolongation of isovolumetric relaxation time and a decrease in the early diastolic velocity (E wave) has been described in ischaemic myocardial segments[6]. A decreased peak systolic and early diastolic velocity was observed in affected segments in patients with myocardial infarction[7] and a reduction in early diastolic negative velocity has been shown to indicate clinically relevant heart transplant rejection with a sensitivity of 90%[8]. The preliminary results of a currently ongoing multicentre (MYDISE) study suggest a decrease in peak systolic velocity and an increase in the time to peak systolic velocity as a sensitive indicators in the quantification of myocardial ischaemia during stress echocardiography[9], a suggestion that has been recently confirmed by others[10]. In addition, recent tissue Doppler imaging data obtained at high sampling rates in animal experiments indicate isovolumetric myocardial acceleration as a sensitive index of left ventricular contractility[11].

A correct evaluation of regional myocardial function using tissue velocity imaging parameters presupposes a proper definition of normal myocardial velocity profile with all its components and the knowledge of normal velocity values for all the different components of velocity curve. Since the first report on normal pulsed

Doppler velocity curves and peak velocity values at different sites around mitral annulus[12], the normal velocity values for systolic and diastolic motion of the myocardial walls have been published[13–16] and a longitudinal transmyocardial velocity gradient as well as age dependent variability of the diastolic velocities has been described[16]. However, our present results clearly demonstrate the need to view the reported normal myocardial velocity values in close relation to the employed sampling rates. Indeed, there are differences between the systolic and diastolic velocity values reported in the above-mentioned studies[14–16], probably at least partly caused by low frame rates in earlier echocardiography equipment.

Modern tissue velocity imaging scanning with the acquisition of a complete, high resolution 2D-image set using multiple line technique offers the possibility to retrieve Doppler velocity information from any location in the myocardium, and the myocardial velocity profiles can be studied in considerable spatial details. The present results demonstrate that in order to secure optimal temporal resolution and acceptable accuracy of the tissue velocity imaging information thus obtained, specific sampling requirements have to be fulfilled. This should be kept in mind when viewing reported tissue velocity imaging data.

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## References

[1] Isaaz K, Thompson A, Ethevenot G, Cloez JL, Brembilla B, Pernot C. Doppler echocardiographic measurement of low velocity motion of left ventricular posterior wall. *Am J Cardiol* 1989; **64:** 66–75.

[2] McDicken WN, Sutherland GR, Moran CM, Gordon LN. Colour Doppler velocity imaging of the myocardium. *Ultrasound Med Biol* 1992; **18:** 651– 654.

[3] Gaballa M, Lind B, Storaa C *et al.* Intra- and interobserver reproducibility in off-line extracted cardiac tissue Doppler velocity measurements and derived variables. *Proc of IEEE. Engineering in Medicine and Biology* 2001; **1:2:** 4–6.

[4] Shannon CE. Communication in the presence of noise. *Proc of the IRE* 1949; **37:** 10–21.

[5] Sigwart U. In: Sigwart U, ed. *Automation in Cardiac Diagnosis*. Basel: Schwabe & Co. AG, 1978: 25–28.

[6] Garcia-Fernandez MA, Azevedo J, Moreno M *et al.* Regional diastolic function in ischaemic heart disease using pulsed wave Doppler tissue imaging. *Eur Heart J* 1999; **20:** 496–505.

[7] Palmes PP, Masuyama T, Yamamoto K *et al.* Myocardial longitudinal motion by tissue velocity imaging in the evaluation of patients with myocardial infarction. *J Am Soc Echocardiogr* 2000; **13:** 818–826.

[8] Dandel M, Hummel M, Müller J *et al.* Reliability of tissue Doppler wall motion monitoring after heart transplantation for replacement of invasive routine screenings by optimally timed cardiac biopsies and catheterizations. *Circulation* 2001; **104** (Suppl I): I184–I191.

[9] Madler CF, Payne N, Fraser AG *et al.* Quantitative stress echocardiography using tissue Doppler can estimate the severity of coronary artery disease. *Eur Heart J* 2001; **22** Abstr (Suppl): 1883.

[10] Cain P, Marwick TH, Case C *et al.* Assessment of regional long-axis function during dobutamine echocardiography. *Clin Sci* 2001; **100:** 423–432.

[11] Vogel M, Kristiansen S-B, White P *et al.* Myocardial acceleration during isovolumic contraction: a novel load-independent index of contractility derived from TDI. Comparison with LV pressure-volume relations in an animal model. *Eur Heart J* 2001; **22** Abstr (Suppl): 583.

[12] Isaaz K, Munoz del Romeral L, Lee E *et al.* Quantitation of the motion of the cardiac base in normal subjects by Doppler echocardiography. *J Am Soc Echocardiogr* 1993; **6:** 166–176.

[13] Hada Y, Itoh N, Tohyo Y, Yonekura K, Tamiya E, Kiritani H. Intramyocardial pulsed Doppler echocardiography as a new modality for evaluation of left ventricular wall motion: assessment in normal subjects. *J Cardiol* 1996; **28:** 85–92.

[14] Palka P, Lange A, Fleming AD, Sutherland GR, Fenn LN, McDicken WN. Doppler tissue imaging: myocardial wall motion velocities in normal subjects. *J Am Soc Echocardiogr* 1995; **8:** 659–668.

[15] Müller S, Bartel T, Schurger D, Gassmann B, Erbel R. Quantitative tissue Doppler in comparison with two-dimensional and Doppler echocardiographic indices in normal subjects. *Int J Cardiol* 1997; **61:** 183–192.

[16] Galiuto L, Ignone G, DeMaria A. Contraction and relaxation velocities of the normal left ventricle using pulsed-wave tissue Doppler echocardiography. *Am J Cardiol* 1998; **81:** 609–614.