

ECHO E-WAVES INSTRUCTIONS

Version 1.0

Echo E-waves is a free software application implemented in MATLAB for the analysis of DICOM images of PW Doppler acquisitions of left ventricular filling in the parameterized diastolic filling formalism (PDF) framework.

SOME POINTS OF IMPORTANCE:

1. Organize your DICOM files in patient specific folders. When opening a case in Echo E-waves, you will select a folder, not a specific file. Place only PW Doppler files in the folder to minimize the risk of unexpected behavior and errors.
2. The ultimate quality control is your own appreciation of physiology, and Doppler image quality and artifacts.
3. Pay close attention to the starting point of the E-wave and make sure to have an informed opinion about the shape of the E-wave velocity profile.
4. The purpose of the program is to facilitate the finding of a PDF curve (with associated numerical descriptors) that closely describes the E-wave. The program has various methods for obtaining and adjusting the curves, offering different ways of achieving the same goal.
5. The program can be used to mark parts of the data set as acquired during "free breathing" or "load manipulation". These are only labels, corresponding to methods of acquisition that we are currently exploring, and have no implication for the results of PDF analysis per se. Use the labels as you see fit.

STEB BY STEP EXAMPLE

Open a folder containing DICOM images of transmitral PW Doppler acquisitions using "Open DICOM folder" (Ctrl + O). Single frame files and GE multi frame files are displayed automatically, multi frame acquisitions from Philips scanners require user interaction, see below under "Preparing Philips files for analysis".

Navigate the "heartbeat browser" containing thumbnails of the loaded images to acquaintance yourself with the data set. Navigation can be performed by clicking on the thumbnails or by using the arrow keys.

Identify the start of the E-wave and the shape of the maximum velocity contour visually, optionally pressing "C" several times to cycle through colormaps. Move the vertical cursor to the exact starting point of the E-wave, hold down the left mouse button and move the mouse to the right. The velocity profile is detected live. When you release the mouse button, a PDF curve will be calculated based on the velocity profile detected.

Make adjustments in order to get the best fit between the curve and the E-wave velocity profile. This can be done in three ways.

- 1: Changing the input to the curve fitting algorithm by moving the start and end point. Drag the vertical lines by holding down the left mouse button, or use shift and alt keys plus left and right arrow keys. The edge detection threshold can be adjusted by using shift in combination with the up and down keys.
- 2: Move the start, peak and end points by selecting with the left mouse button and holding down while moving. Please note that using this method will disregard the results from the edge detection, and the curve will be calculated based on the relationship between the start, peak and end points only. You can move these points with the arrow keys, after cycling through them by pressing "P".
- 3: Change c , k , and x_0 directly by using the on screen plus and minus buttons or by clicking on the respective values next to "Current E-wave" in the results table, and entering a numerical value.

Regardless of method, use the "F", "G", and "H" keys to toggle the visibility of the detected edge, the PDF curve and both at once, respectively. Press "Esc" to clear.

When you are satisfied, press "Enter" or click the Accept button.

Accepted results can be retrieved by clicking in the bottom left results table, on the corresponding thumbnail, point in the *M* graph or PDF curve in the Fitted curves and mean curve graph. If any changes are made to retrieved results, they must be Accepted again to be stored. Individual E-waves can be deleted using Backspace.

Press "Ctrl + A" for automatic fitting of the remaining E-waves.

The images and any accepted results can be saved (Ctrl + S) in a single file that can be reopened on any computer running Echo E-waves. This file can be anonymized. It is also possible to export results directly to an Excel file or to the computers clipboard.

ACCEPTED FILES

Echo E-waves has been tested with DICOM files from GE, Philips, Siemens and Acuson. Raw DICOM files from GE can also be opened. A sweep speed of 100 mm/s is preferred, but acquisitions at any sweep speed can be opened in the program. Save and export the DICOM files from your echocardiography system and organize them in folders, each folder representing a patient case at a certain time. From GE and Philips systems, it is possible to open multi frame or cine files. If you are analyzing multiple E-waves, using this methodology will speed up your workflow. GE multi frame files are parsed automatically using DICOM metadata, for Philips files follow the instructions below.

PREPARING PHILIPS MULTI FRAME FILES FOR ANALYSIS

Echo E-waves can open multi frame cine recordings of PW Doppler from Philips scanners. When such a file is opened, the first screen width will be displayed in a pop-up window. Using the mouse and its left button, drag a rectangle from the start of the first E-wave to the start of the second. Make sure that the height of the rectangle is somewhat higher than expected maximum velocity of the data set. When releasing the mouse button, a new window will open, consisting of the whole recording stretched out as a long image, with vertical

lines suggesting E-wave starting points. Adjust these following the on-screen directions. The vertical lines must only be roughly at the start of the E-waves. Press "Enter" to close.

PROGRAM DESCRIPTION

In the following sections, the functions of the program will be described. Also, watch the video at echoewaves.org.

FILE MENU

OPEN DICOM FOLDER

Select the folder where the DICOM files for the case in point are stored. If there are subfolders, the program will look through these too. The program will automatically identify DICOM files and prepare these for analysis. Please note that is not currently possible to open a specific DICOM file, therefore all files belonging to a case must be collected in a folder prior to analysis in Echo E-waves.

OPEN DATA FILE

Opens a data file containing images and saved curve fits. Adjustment of stored data and new curve fits are possible.

SAVE DATA FILE

Saves all current data (images and curve fits) in a file that can be reopened at a later time or transferred to another computer. The saved file contains all necessary data for PDF analysis, however it only contains the DICOM data necessary for PDF analysis.

SAVE ANONYMIZED DATA FILE

Same basic functionality as "Save data file", but this option removes the DICOM file name data, and all identifiers of original files and file locations. When saving with this option, a case name must be chosen.

OPEN WITH DIAGNOSTICS

Replicates the "Open DICOM folder" function, but will attempt to return an error report detailing why some, if any, files could not be loaded. Intended for bug finding and future development, as well as checking. Brief details regarding unloadable files are presented in a pop-up window.

QUIT

Closes the program.

EXPORT MENU

COPY... OPTIONS

These functions copy the currently stored results to the computers clipboard, akin to basic ctrl-c functionality. The copied data can be pasted into any program that supports standard paste commands, using ctrl-v. "Results" are the results per E-wave, "mean results" are the mean results, as well as the means for E-waves marked respectively not marked as load manipulated. Copy options with headers will include variable names in the first row of the clipboard data.

USE STUDY RESULTS FOLDER

This option is intended to facilitate collecting data from different cases intended to be analyzed together. When a results folder has been set, all case specific files will be saved in this folder, and the mean values for every patient will be appended to a file (Excel or .txt depending on availability), creating a new row for every case added. This essentially creates a PDF database for your cases.

SAVE... OPTIONS

These options will save numerical results in Excel format if this program is installed on your computer, otherwise the results will be stored in a text file. The "save all..." option saves individual and mean results, as well as the plots for the load independent index of filling (M) and the plot of all PDF curves.

OPTIONS MENU

MARK COLUMN AS LOAD MANIPULATED

E-waves can be marked as "load manipulated" either by checking the box under the "Accept" button, or by choosing this option, which will mark all E-waves in the same column of the Heartbeat Browser as the current E-wave. N.B. that this is only a way of splitting your data in two parts for the calculation of means et c, the calculations performed are identical.

SAVE FITTED IMAGES AS .PNG

When this option is selected, a copy of the Doppler image with any current PDF curve will be saved in .png format when the result is Accepted.

COLORMAP, CYCLE THROUGH COLORMAPS

By default, Doppler images are displayed using the image in the original DICOM file. However, the same data can be represented using other colormaps. Visualizing your images using other colormaps can often make it easier to discern the true E-wave profile. The "cycle" option will change colormap to the next available map. Colormap choices do not affect the Doppler data, only its visual representation.

COLORMAP CHOICE PERSISTS

When this option is enabled, the last actively chosen colormap will be applied when retrieving stored PDF curves with their corresponding Doppler images. Otherwise, the default behavior is to display stored results using the same colormap that was used when the image data was stored in the program.

CONTRAST STRETCH

Contrast stretching entails making the dark parts of the image darker and the bright parts brighter. This may be beneficial when analyzing noisy images, however please note that this changes the data that is used for curve fitting, making visual inspection even more important.

APPLY GAIN SETTING TO COLUMN

The will apply the gain setting of the current image to all images in the same column.

SHOW TRADITIONAL DT

Displays a line approximation the way the deceleration time is described in clinical echocardiography. This can be used as a visual reference point, in most cases it should be close to the PDF curve.

FITTING MENU

ACCEPT FIT <ENTER>

Accepting a fit stores it in memory, it can be retrieved for review and modification, and the accepted results can be saved in various formats.

CLEAR FIT FROM E-WAVE <ESC>

This clears the current fit from the main analysis window, but does not delete any saved result.

DELETE E-WAVE <BACKSPACE>

This deletes the currently selected E-wave result.

DELETE RESULTS FOR THIS COLUMN

Deletes all accepted results for the current column in the heartbeat browser.

SET MAXIMUM VELOCITY LIMIT <Z>, REMOVE VELOCITY LIMIT

Use this if there are image elements (*e.g.* artifacts, ECG tracings) above the E-wave interfering with the velocity profile detection algorithm.

MOVE START BACK/FORWARD <SHIFT+ LEFT/RIGHT ARROW>

The starting point for velocity profile detection, which also defines the start of the E-wave, can be adjusted with these key combinations, as well as by dragging the vertical starting line with the mouse.

MOVE END BACK/FORWARD <ALT + LEFT/RIGHT ARROW>

The ending point for velocity profile detection can be adjusted with these key combinations, as well as by dragging the vertical ending line with the mouse. This line should usually *not* be set at the end of the E-wave, as this will often lead to inclusion of non E-wave signal.

DECREASE/INCREASE THRESHOLD < SHIFT + UP/DOWN ARROW>

The pixel brightness threshold can be altered with these key combinations, resulting in a looser or tighter fit of the edge detection line around the E-wave.

DEFINE START-PEAK-END MANUALLY

This option lets you define three points which will be used for calculation of the PDF curve. The first point is the starting time point, automatically set to 0 velocity. The second point is the peak of the E-wave defining both the maximum velocity and the time point at which this occurs. The final point is the ending time point of the E-wave, automatically set to 0 velocity. Accurate placement of these points are important, as no other data will be used to calculate the PDF curve.

ADJUST START-PEAK-END <P>

The start, peak and end points can be dragged using the mouse. The points can also be adjusted using the arrow keys, after activating the point of interest by repeatedly pressing P, which will cycle activation through the points. Notice that this disables the arrow keys' function for selecting E-wave in the heartbeat browser. Pressing P again when the ending point is activated will return the arrow keys to normal functionality, *i.e.* navigating the thumbnails.

START/STOP AUTOMATIC FITTING <CTRL+A, SPACEBAR>

The automatic fitting function can speed up analysis of larger sets of E-waves. It is important to first adjust the threshold, starting and ending time points for one E-wave manually. This is then used as a template for automatic fitting. If the algorithm cannot find a fit for an E-wave image, or if the fit would results in constants far from those of the original fit, no result is stored and the E-wave thumbnail is marked red. The speed of the automatic function is highly dependent on your computer specifications. Make sure to control all fits carefully, as results may vary.

END AT ZERO

This option, which is enabled by default, will make the deceleration time of the PDF curve shorter. Consider disabling this option when analyzing E-waves with long deceleration times.

DT INTERPOLATION

This option, which is enabled by default, will make the deceleration time of the PDF curve shorter. Consider disabling this option when analyzing E-waves with long deceleration times.

HIDE/UNHIDE CURVES, FIT INPUT AND EXCLUDED VELOCITIES <H,G,F,E>

Use these functions to view the Doppler image with and without the detected velocity profile and fitted PDF curve. The "Excluded velocities" are the red circles, and represent the velocities which the velocity profile detection algorithm has discarded on the grounds of them being too far from their neighbors.

EXTRAS

PLOT KAPPA AND SAVE

Calculates the diastatic stiffness as described by Mossahebi and Kovacs 2012. The results are plotted and saved as .png file.

SHOW DICOM IMAGE <W>

Displays the original DICOM image, not just the cropped Doppler part, with the PDF curve superimposed if there is one visible in the main window. Pressing W again closes the window. This option is only available when working directly with a set of DICOM files. If the data set has been stored using the programs save function, only the Doppler part of the images are stored, and the original image cannot be shown.

SHOW DICOM METADATA

Displays the DICOM tags of the currently active DICOM file. DICOM tags consisting of multiple fields are not shown. This option is only available when working directly with a set of DICOM files. If the data set has been stored using the programs save function, the DICOM tags are not saved (except for information directly describing the properties of the Doppler data).

CHECK GRAPHICS CAPABILITIES

Checks and displays the OpenGL version and graphics processor model of your system. Intended for bug finding and optimization purposes.

OPEN ERROR LOG FILE

If an error arises during execution of Echo E-waves, most often this will produce a description of the error in the MATLAB runtime environment. These errors are saved in a txt file. Intended for bug finding purposes.