3D Echo and Invasive Pressure Synchronization

Generating Real Time, Multi Cycle Pressure Volume Loops

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1 BACKGROUND

The ventricular pressure-volume loop (PVL) relates intracardiac pressure changes as a function of volume changes during the cardiac cycle and is a convenient method to understand major determinants of myocardial performance. Acquiring PVL is not simple in human models, the main limitation being accurate volume measurement. Traditionally PVL is obtained using conductance catheterization which is based on the measurement of the electrical conductivity of the blood volume by placing a multiple electrode catheter along the long axis of the ventricle (either right or left) during catheterization and delivering an alternating current between the most proximal and distal electrodes. -1- Although conductance catheterization is considered the gold standard for pressure volume relationship acquisitions, this technology and equipment is difficult to use and time consuming.

There has been considerable development in three-dimensional echocardiography and more recently display of cardiac structures in real time rather than as offline reconstructed images from multiple 2D echocardiographic slices. An important clinical application of three-dimensional real-time echocardiography (3D-RTE) includes delineation of ventricular morphology and volume quantification -2,3-

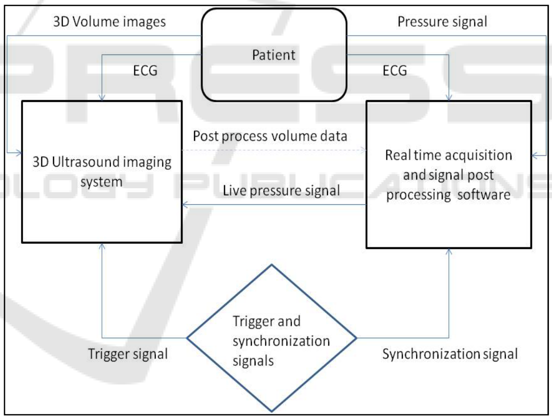
2 OBJECTIVES

Our objective was to explore the feasibility of using 3D-RTE together with cardiac catheterization to determine ventricular function derived from PVL.

We established that success of our experiment depends on several components and overall reproducibility of our technique. Consequently we identified signal synchronization (volume and pressure), optimal sampling rate and the possibility of multicycle acquisition as crucial requirements.

3 METHODS

3.1 Data Flow Diagram



3.2 Equipment

During cardiac catheterization ventricular volume was attained by 3D RTE using the Siemens Acuson SC2000 ultrasound system (Siemens Medical Solutions USA Inc., Mountain View, CA) with a 4Z1c real-time volume imaging transducer (2.8 MHz). The SC2000 has a unique ability to produce up to about 40 complete volumes per second in a true real time acquisition mode. It is capable of forming 64 parallel beams in real time and processing of 160M voxels per second. Volume data sets are free of multi-cycle averaging, regional interpolation and "stitching" interference.

Ventricular pressure was obtained by a high fidelity pressure cathether (Micro-Tip®, Millar, Houston, Texas) which was advanced into the left or right ventricle. Millar catheter frequency response is greater than 10 kHz and the pressure signal was acquired at 16 bit resolution by DT9804 (Data Translation Inc) analog to digital converter.

All pressure, trigger and ECG signals were recorded with Notocord hemodynamic software (Notocord Systems, France, v 4.2).

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3.3 Functional Integration and Acquisition

Data was collected in children and adolescents with congenital heart disease aged 0-18 years that underwent cardiac catheterization for interventional purposes. Different ventricular sizes and morphologies were included.

Pressure and 3D volume data set acquisitions were synchronized by common ECG source and activated by foot-switch signal. In addition the pressure signal was interfaced to the ultrasound system and displayed in real time for reference. Notocord software recorded real time pressure, ECG and trigger spike that initiated the volume recording. This trigger signal with the conjunction of ECG established proper cardiac cycle and a reference point (R wave) of the first collected volume. The typical length of a complete volume data set was between three to five cardiac cycles.

3.4 Post Processing and Data Plot

Ventricular volume quantification and analysis was done offline using Siemens software with the combination of automatic ventricular volume detection and manual user correction (Figure 1). The produced ventricular volume curve was exported to a text file. Based on this extract, the number of individual volumes per acquisition time defined absolute sampling frequency for pressure signal extraction. Furthermore, the pressure raw data from the trigger marker combined with QRS and with the same duration as a ventricle volume acquisition was resampled and averaged using imaging volume resolution (Figure 2). The produced pressure extract had the same time resolution as the acquired 3D ventricular volume. As a result, absolute values of both tracings could be plotted on the same XY axis.

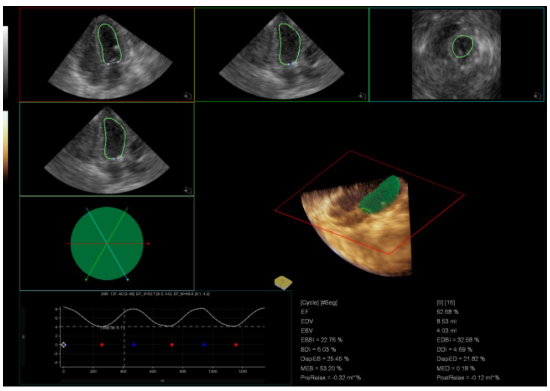

Figure 1.

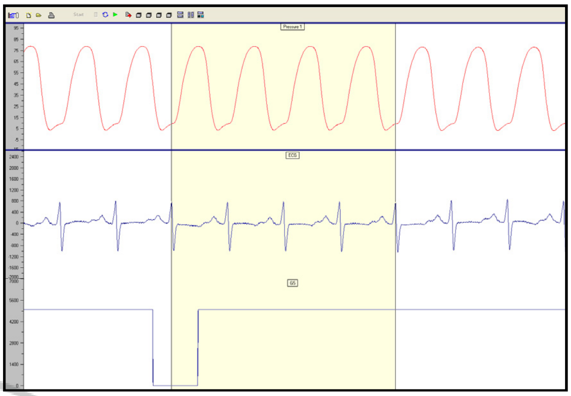

Figure 2.

4 RESULTS

PVL generated with this technique had reasonable resolution and demonstrated expected physiological characteristics. The real time volume sampling rate was sufficient to obtain accurate pressure-volume relationships of systolic and diastolic cardiac performance. Synchronisation between these different physiological sources was proven to be feasible and reproducible in different congenital heart conditions and after cardiac interventions.

4.1 PVL Examples

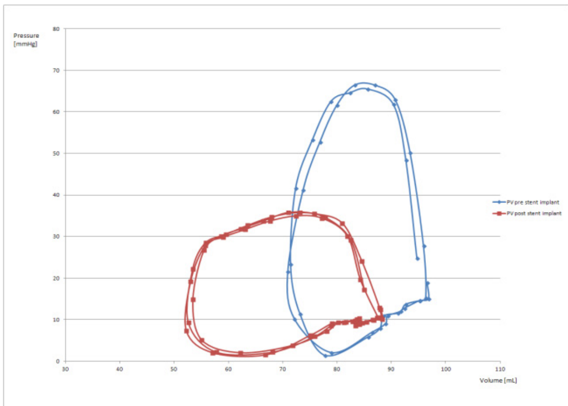

Figure 3: Right ventricle PVL after interventional procedure (acute response).

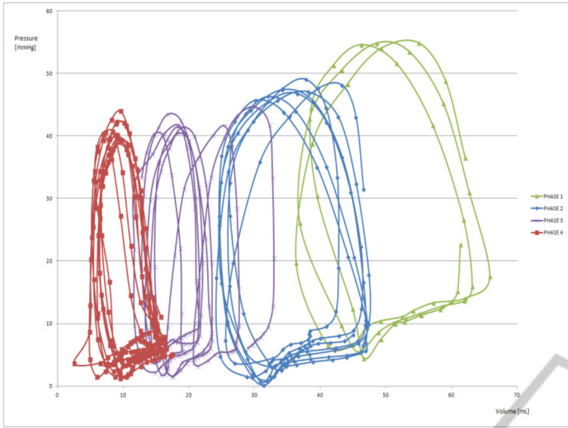

Figure 4: PVL generated in a patient under varying degrees of ventricular preload.

5 DISCUSSION

This described method is effective in acquiring PVL and creates a platform for full integration and synchronization of functional imaging and hemodynamic data. It eliminates the use of costly conductance catheters (a variety of them are usually needed for full spectrum of ventricle sizes), exposure to high frequency currents, flexibility of ventricle volume selection and it does not rely on complex volume calibration as is the case for conductance systems.

Post-procedure analysis requires several steps but can easily be integrated further and could eventually become a built-in feature wherein pressure-volume relationships could be calculated instantaneously during a procedure.

The opportunity to synchronize 3D-RTE and pressure data with a less invasive method such as this one will allow clinicians to obtain valuable insight of myocardial performance in a more simple and accessible way. Furthermore, the pressure data could potentially be used to gate volume acquisition and immediately obtain the end-diastolic pressure volume relationship (EDPVR) and end-systolic pressure volume relationship (ESPVR).

It is acknowledged that development in integration and automation is ongoing.

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