CARDIOSIM©: Numerical Simulator of the Cardiovascular System

CARDIOSIM© is a software simulator of the human cardiocirculatory and respiratory system, developed in the Cardiovascular Numerical/Hybrid Modelling Lab of the CNR Institute of Clinical Physiology (Rome). The cardiovascular simulator runs on PC with Microsoft Windows operating system.

This software simulator platform has a modular structure that consisting of seven different general sections, which can be assembled to reproduce different patho-physiological conditions. The complexity of the assembled model depends on the context in which it must be used.

This numerical simulator can reproduce the most important circulatory phenomena in terms of pressure and volume relationships. It represents the whole circulation using a lumped-parameter model and enables the simulation of different cardiovascular conditions on the basis of the Starling's law of the heart.

CARDIOSIM© reproduces the heart's behaviour using a modified time-varying elastance model. Two different numerical models have been implemented into the software simulator, each with specific features, which are described below.

- In the first one, the left and right ventricular filling and ejection phases are described separately. The contraction and ejection phases are implemented using a modified time-varying elastance model. The left (right) ventricular loop, the End-Systolic Pressure-Volume Relationship (ESPVR) and the End-Diastolic Pressure-Volume Relationship (EDPVR) can be plotted on the pressure-volume plane. The behaviour of left (right) atrium is described as a linear capacity with a constant value of compliance and unstressed volume neglecting the contractile atrial activity.
- In the second one, a modified time-varying elastance model is used to describe left and right ventricular function and applied for the analysis of ventricular interdependence through the inter-ventricular septum, where the properties of one ventricle are a function of the properties of the contra-lateral one. Left and right atrial function is described in a similar manner. This setting is useful for the analysis and simulation of inter-ventricular and/or intra-ventricular conduction delay (dyssynchrony). Ventricular dyssynchrony may cause a number of deleterious effects on cardiac function such as reduced diastolic filling time, weakened contractility, severe mitral regurgitation and regional wall motion abnormalities. The atrioventricular delay that occurs in atrioventricular block and atrial fibrillation can also be simulated.

Patients with advanced heart or pulmonary failure may need mechanical assistance to keep their heart pumping enough blood. Mechanical Circulatory Support Systems (MCSS) are designed to replace or assist heart function in patients with advanced heart failure. Short- and mid-term ventricular assist devices are frequently used to bridge patients with severe heart failure either to recovery or heart transplant.

Preoperative assessment, planning and timing for intervention play a key role for a successful outcome. Numerical modelling and simulation may be used as an additional tool for device selection and optimisation with potential for outcome prediction.

Different MCSS have been implemented in **CARDIOSIM©** such as:

- Pulsatile Flow Pump
- Continuous Flow Pump (Axial Flow Pump)
- Impella 2.5® Heart Pump
- ExtraCorporeal Membrane Oxygenation (ECMO)
- Intra-Aortic Balloon Pump (IABP)
- Biventricular Pacemaker (BiV)

Pulsatile and Continuous Flow Pumps are mechanical assist devices that can be used as:

- Biventricular assist Devices (BVAD)
- Left Ventricular Assist Device(LVAD) - Right Ventricular Assist Device (RVAD)
- Total Artificial Heart (TAH)

The connection between the native heart and an assist device is either "*in series*" or "*in parallel*". The pump is connected "in parallel" with the native ventricle when aspirates blood from the atrium and pumps it into the aorta (or pulmonary arterial tree). An "in series" connection is obtained when the device aspirates blood from the native ventricle and ejects it into the aorta (or pulmonary arterial tree).

CARDIOSIM© software simulator may become an aid for a more quantitative approach for patient assessment, selection and device treatment suitability where the clinician has the final say based on the available data.

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