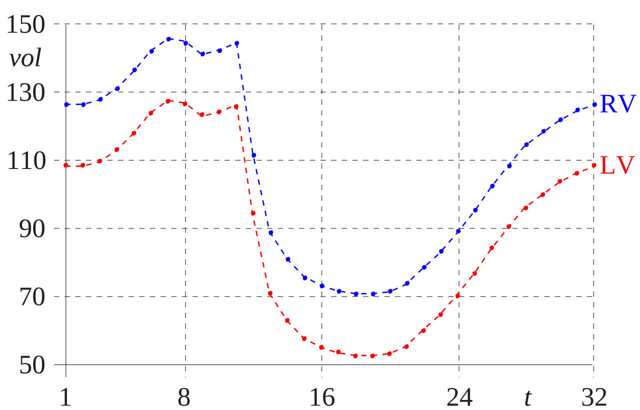
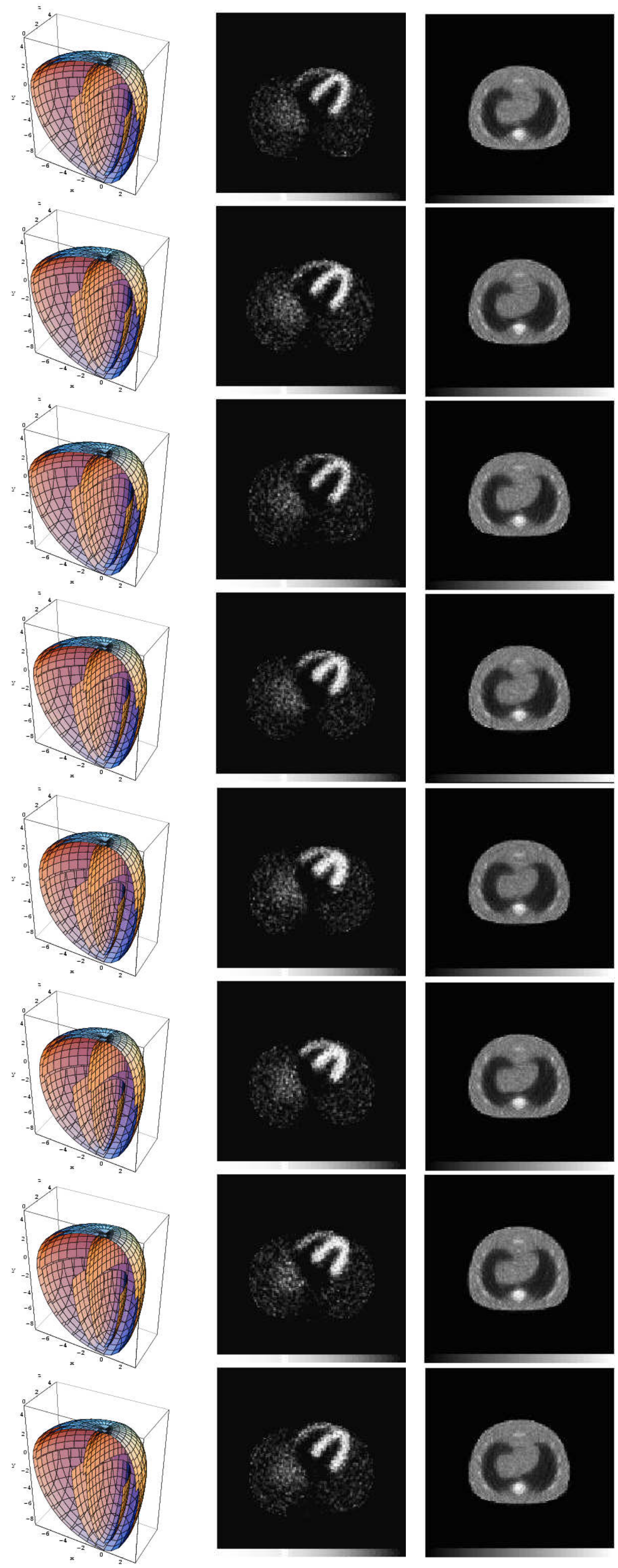
Four-Dimensional Superquadric-Based Cardiac Phantom for MC Simulation of Radiological Imaging Systems

Abstract: A four-dimensional (*x, y, z, t*) composite superquadric-based object model of the human heart for Monte Carlo simulation of radiological imaging systems has been developed. The phantom models the real temporal geometric conditions of a beating heart for frame rates up to 32 per cardiac cycle. Phantom objects are described by boolean combinations of super-quadric ellipsoid sections. Moving spherical coordinate systems are chosen to model wall movement whereby points of the ventricle and atria walls are assumed to move towards a moving center-of-gravity point. Due to the non-static coordinate systems, the atrial/ventricular valve plane of the mathematical heart phantom moves up and down along the left ventricular long axis resulting in reciprocal emptying and filling of atria and ventricles. Compared to the base movement, the epicardial apex as well as the superior atria area are almost fixed in space. Since geometric parameters of the objects are directly applied on intersection calculations of the photon ray with object boundaries during Monte Carlo simulation, no phantom discretization artifacts are involved.



Characteristic blood volume curve of the left ventricle and modeled volume curve for the right ventricle, discretized into 32 time frames

The phantom model can be used to investigate temporal resolution requirements for quantification of ventricular time-activity curves such as ejection function, systolic time intervals, or peak intervals of emptying and filling. It can also be used for investigating new reconstruction techniques or imaging geometries. The phantom can be modified for various cardiac disorders such as concentric hypertrophy, hypertrophic cardiomyopathy, or dilated cardiomyopathy as well as examples of perfusion defects. Measured ventricular function characteristics of the dynamic cardiac phantom agree well with reported values.



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