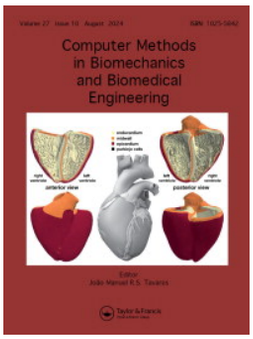

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Advancement in computational simulation and validation of congenital heart disease: a review

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ABSTRACT

The improvement in congenital heart disease (CHD) treatment and management has increased the life expectancy in infants. However, the long-term efficacy is difficult to assess and thus, computational modelling has been applied for evaluating this. Here, we provide an overview of the applications of computational modelling in CHD based on three categories; CHD involving large blood vessels only, heart chambers only, and CHD that occurs at multiple heart structures. We highlight the advancement of computational simulation of CHD that uses multiscale and multiphysics modelling to ensure a complete representation of the heart and circulation. We provide a brief future direction of computational modelling of CHD such as to include growth and remodelling, detailed conduction system, and occurrence of myocardial infarction. We also proposed validation technique using advanced three-dimensional (3D) printing and particle image velocimetry (PIV) technologies to improve the model accuracy.

Abbreviations: *CHD*: congenital heart disease; *PDA*: patent ductus arteriosus; *DORV*: double outlet right ventricle; *VSD*: ventricular septal defect; *ASD*: atrial septal defect; *TOF*: tetralogy of fallot; *HLHS*: hypoplastic left heart syndrome; *mBTS*: modified Blalock-Taussig shunt; *RVPA*: right ventricle-to-pulmonary artery; *BG*: bidirectional Glenn; *HF*: hemi-Fontan; *CFD*: computational fluid dynamics; *FSI*: fluid structural interaction; *OSI*: oscillatory shear index; *WSS*: wall shear stress; *CT*: computed tomography; *HOLMES*: highly oscillatory and low magnitude shear; *TransWSS*: transverse wall shear stress; *TEVG*: tissue-engineered vascular grafting; *ESAA*: end-to-side aortic anastomosis; *2D*: two-dimensional; *0D*: zero-dimensional; *IVT*: intraventricular tunnel; *3D*: three-dimensional; *PIV*: particle image velocimetry; *G&R*: growth and remodelling; *PVA-H*: poly (vinyl alcohol) hydrogel

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KEYWORDS
Congenital heart disease; computational simulation; multiscale modelling; multiphysics modelling

1. Introduction

Congenital heart disease (CHD) is defined as a gross structural abnormality of the heart or intrathoracic great vessels (i.e. aorta, superior vena cava, and inferior vena cava) that presents at birth (Bouma and Mulder 2017). CHD affects nearly 1% of all newborn babies (Chaix et al. 2016; Bouma and Mulder 2017) and is the leading cause of infant death. About 0.21% or 41,494 deaths in the United States between 1999 and 2006 are related to CHD (Gilboa et al. 2010).

There are several possible causes of CHD, namely the defect in genes associated with non-cardiac malformation (e.g. Alagille syndrome, Holt–Oram syndrome, and Noonan syndrome), chromosomal imbalance (e.g. Down syndrome, Turner syndrome, DiGeorge syndrome), maternal diabetes mellitus and obesity, alcohol usage, rubella infection, febrile illness, use of certain drugs for genes treatment (e.g. thalidomide and retinoic acid), and exposure to organic solvents (e.g. benzene and toluene) (Chaix et al. 2016; Bouma and Mulder 2017).

In some patients, CHD involves structural abnormality at a particular location. For instances, defect at large blood vessels occur in patients with patent ductus arteriosus (PDA), aortic coarctation, and double outlet right ventricle (DORV). On the other hand, ventricular septal defect (VSD), atrial septal defect (ASD) and atrioventricular defect involve structural abnormalities of the heart chambers (Hoffman et al. 2004). Some CHD patients have multiple structural abnormalities, such as in the case of tetralogy of

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