Universiteit
Leiden
The Netherlands

Blood flow dynamics in the total cavopulmonary connection long-term after Fontan completion

Rijnberg, F.M.

Citation
Rijnberg, F. M. (2023, December 20). *Blood flow dynamics in the total cavopulmonary connection long-term after Fontan completion*. Retrieved from https://hdl.handle.net/1887/3674148

Version:	Publisher's Version
License:	Licence agreement concerning inclusion of doctoral thesis in the Institutional Repository of the University of Leiden
Downloaded from:	https://hdl.handle.net/1887/3674148

Note: To cite this publication please use the final published version (if applicable).

Blood flow dynamics in the total cavopulmonary connection

long-term after Fontan completion

Friso M. Rijnberg

© copyright Friso Rijnberg, 2023

Cover design: Friso Rijnberg en Minaananda | https://www.fiverr.com/s/radawy

Lay-out & printing: ProefschriftMaken || www.proefschriftmaken.nl

ISBN 978-94-6469-658-5

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, without prior permission of the author or the copyright-owning journals for previous published chapters.

Blood flow dynamics in the total cavopulmonary connection

long-term after Fontan completion

Proefschrift

ter verkrijging van
de graad van doctor aan de Universiteit Leiden,
op gezag van rector magnificus prof.dr.ir. H. Bijl,
volgens besluit van het college voor promoties
te verdedigen op woensdag 20 december 2023
klokke 16.15 uur

door

Friso Matthijs Rijnberg
geboren te Rotterdam
in 1990

Promotor
Prof. dr. M.G. Hazekamp

Co-promotores:
Dr. A.A.W. Roest
Dr. ir. J.J.M. Westenberg

Promotiecommissie:
Prof. dr. N.A. Blom
Prof. dr. H.J. Lamb
Dr. ir. J.J. Wentzel (Erasmus Medisch Centrum, Rotterdam)
Prof. dr. K. François (Universitair Ziekenhuis Gent, Gent, België)
Prof. dr. Y.A.C. d'Udekem d'Acoz (Children's National, Washington, USA)

Financial support by the Dutch Heart Foundation for the publication of this thesis is gratefully acknowledged.

The research described in this thesis was supported by a grant from the Dutch Heart Foundation (2018-T083) and by a grant from Stichting Hartekind.

The printing of this thesis was financially supported by Pie Medical Imaging B.V. and Krijnen Medical Innovations B.V.

Table of contents

Chapter 1	General introduction and thesis outline	11
PART I	**LONG-TERM OUTCOME AFTER THE FONTAN PROCEDURE**	**23**
Chapter 2	A 45-year experience with the Fontan procedure: tachyarrhythmia, an important sign for adverse outcome *Interactive Journal of Cardiovascular and Thoracic Surgery 2019*	25
Chapter 3	Long-term outcome of direct relief of subaortic stenosis in single ventricle patients *World Journal for Pediatric and Congenital Heart Surgery 2018*	47
PART II	***IN VIVO* BLOOD FLOW DYNAMICS OF THE FONTAN CIRCULATION**	**63**
Chapter 4	The influence of respiration on blood flow in the Fontan circulation: insights for imaging-based clinical evaluation of the total cavopulmonary connection *Frontiers Cardiovascular Imaging 2021*	65
Chapter 5	Reduced scan time and superior image quality with 3D flow MRI compared to 4D flow MRI for hemodynamic evaluation of the Fontan pathway *Scientific Reports 2021*	89
Chapter 6	Segmental analysis of blood flow dynamics in the TCPC	113
	Segmental assessment of blood flow efficiency in the total cavopulmonary connection using 4D flow MRI: vortical flow is associated with increased viscous energy loss *European Heart Journal open 2021*	115
	Four-dimensional flow magnetic resonance imaging-derived blood flow energetics of the inferior vena cava-to-extracardiac conduit junction in Fontan patients *European Journal of CardioThoracic Surgery 2019*	135

Tornado-like flow in the Fontan circulation: insights from quantification and visualization of viscous energy loss rate using 4D flow MRI 153
European Heart Journal 2019

Chapter 7 Assessment of extracardiac conduit adequacy 157

Hemodynamic consequences of an undersized extracardiac conduit in an adult Fontan patient revealed by 4D flow MRI 159
Circulation Cardiovascular Imaging 2021

Extracardiac conduit adequacy along the respiratory cycle in adolescent Fontan patients 167
European Journal of CardioThoracic Surgery 2021

Chapter 8 4D flow MRI derived energetics in the Fontan circulation correlate with exercise capacity and cT1 liver mapping 193
Journal of Cardiovascular Magnetic Resonance 2022

PART III COMPUTATIONAL FLUID DYNAMICS OF THE FONTAN CIRCULATION 213

Chapter 9 Energetics of blood flow in cardiovascular disease: concept and clinical implications of adverse energetics in patients with a Fontan circulation 215
Circulation 2018

Chapter 10 Non-uniform mixing of hepatic venous flow and inferior vena cava flow in the Fontan conduit 251
Journal of the Royal Society Interface 2021

Chapter 11 Hemodynamic performance of 16-20mm extracardiac conduits in adolescent Fontan patients 273
European Journal of CardioThoracic Surgery 2022

Chapter 12 Summary and future perspectives 293

Chapter 13 Dutch summary 307

APPENDICES **323**
List of publications 325
About the author 329
Acknowledgements 330

Voor Elise, Emilie en Hugo