Computational Fluid Dynamics and Related Predictive Approaches to Study Type B Aortic Dissection: A Narrative Review

Kristina Montez[1] Maham Rahimi, MD PhD[2]

[1]School of Engineering Medicine, Texas A&M University, [2]Houston Methodist Hospital, Houston, TX 77030

Introduction

- Type B aortic dissection (TBAD) is a tear in the inner layer of the descending thoracic aorta, allowing blood to enter the separation and create a false lumen, potentially leading to rupture, malperfusion, or aneurysmal degeneration.
- Computational fluid dynamics (CFD) is a non-invasive technique that utilizes numerical analysis to simulate and analyze fluid flow and physical phenomena.
- Clinically, CFD has the potential to serve as a powerful tool in the prediction of patient-specific disease progression and positively affect treatment decision-making in all centers treating TBAD.
- With the development of a feasible CFD workflow in the clinical setting for TBAD, all participating centers can provide well-informed treatment plans that ultimately improve patient outcomes.

Objectives

- This narrative literature review explores the use of computational fluid dynamic (CFD) methods to study TBAD.
- The review aims to provide an overview of the pathophysiology and clinical significance of TBAD and aneurysmal degeneration, the principles, methodologies, and parameters used in these models, the current challenges and limitations in recent studies, and potential future directions within this field.

Methods

- Search conducted using Google Scholar, PubMed, arXiv, and Web of Science. Search terms included "aortic dissection," "Type B," "computational fluid dynamics," "fluid-structure interaction (FSI)" and "4D flow MRI."
- Additional articles were obtained from manual searches of the references found in the retrieved literature.
- Sources were selected based on relevance to the topic, including peer-reviewed articles, case reports, conference papers and pre-prints, ranging from older, foundational articles to more recent, forefront works.
- Articles not previously described in published reviews included until February 20, 2025; English language only; international included.

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Results

Table 1. Summary of studies identified by category: (a) number of literature reviews focused on TBAD CFD as the main topic versus those that mentioned it as a sub-category within the review, (b) number of TBAD CFD studies each year between 2019-2024, (c) number of studies identified for seven categories related to methods, including boundary conditions (BCs) of the models, segmentation (referring to the process of generating models), meshing (referring to the computational domain used on the generated models), morphology (referring to the physical characteristics identified in the models), other models (i.e. new mathematical approaches, in vivo with ex vivo data analysis), and endovascular (referring to TBAD CFD studies pre- and post-opertively repairs).

(a) Literature Reviews	
Focused	Mentioned
6	6

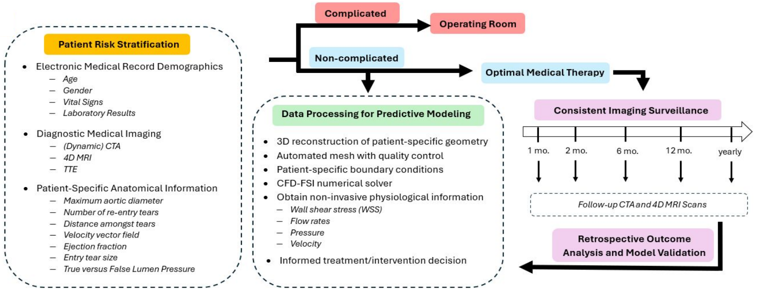
(b) CFD Studies					
2024	2023	2022	2021	2020	2019
9	5	3	3	0	1

(c) Methods						
BCs	Segmentation	Meshing	Morphology	Materials	Other Models	Endovascular
10	3	3	4	1	14	52

Table 2. Summary of key methodologies and clinical relevance of recent (2023-2024) TBAD CFD studies. Green indicates that the feature was fully present in the study, yellow indicates that the feature was included but was not entirely patient-specific and red for absent. Computed tomography (CT), computed tomography angiography (CTA), magnetic resonance imaging (MRI), phase contrast MRI (PC), 4D flow MRI (4DfMRI), fluid structure interaction (FSI). Model refers to the 3D geometric model constructed for the CFD simulation where "Specific" indicates patient-specific data was used to construct the model and "Ideal" indicates no patient-specific data was used. Boundary conditions (BCs) are prescribed to the 3D model for the simulation where "Specific" indicates completely informed by patient-specific data.

Author	Year	n =	CT	MRI	4DfMRI	FSI	Model	BCs	Clinical Relevance
Cebull et al.	2024	1	CTA	-	-	-	Specific	Specific	predict failure of medical therapy in acute uncomplicated TBAD
Forneris et al.	2024	22	CT	PC	-	-	Specific	-	predict aneurysmal degeneration in uncomplicated residual TBAD
Bäumler et al.	2024	1	CTA	MRI	-	-	Specific	-	longitudinal aortic remodeling in Marfan syndrome
Tajeddini et al.	2024	10	CT	MRI	-	-	Specific	-	effect of David procedure causing TBAD development in Marfan syndrome
Kim et al.	2024	1	CT	-	-	-	Ideal	-	biomechanic and hemodynamic factors in TBAD dynamic obstruction
Messou et al.	2024	3	CT	-	-	-	Specific	-	thrombosis, fenestration, and false lumen orbital orientation on TBAD
Liu et al.	2024	1	CT	-	-	-	Specific	-	TBAD entry tear surgical closure location selection
Zhang et al.	2024	6	CTA	-	-	-	Ideal	-	length and tortuisity of thoracic aorta as a predictor for acute TBAD
Ritter et al.	2024	5	CTA	-	-	-	Specific	-	favorable TBAD hemodynamic changes in STABILISE technique
Tomasi et al.	2023	1	CT	PC	-	-	Specific	-	faster closed-loop CFD analysis for patient-specific TBAD management
Wen et al.	2023	16	CTA	-	-	-	Specific	-	predict development of TBAD with anatomical and hemodynamic features
Moretti et al.	2023	4	CT	PC	-	-	Specific	-	increased likelihood of degeneration in partially thrombosed false lumen
Zimmerman et al.	2023	1	CTA	PC	-	-	Specific	-	quantitative and qualitative effects of entry or exit tear size on TBAD
Li et al.	2023	27	CTA	-	-	-	Specific	-	loss of helical flow as a predictor for the risk of developing acute TBAD

Figure 1. Proposed workflow for TBAD CFD model construction, analysis and validation for clinical translation.



Discussion

- Since 2019, the number of TBAD CFD studies for predictive modeling to inform clinical practice has notably increased.
- Few TBAD CFD studies focus on uncomplicated cases prior to surgical intervention; the majority simulate endovascular repairs to characterize morphologic and hemodynamic features and predict post-operative outcomes.
- Patient-specific CFD simulations informed by integrating multiple imaging modalities (CT, dynamic CT, MRI, dynamic MRI, 4dfMRI) with FSI have yet to be consistently applied to large TBAD sample sizes.

Conclusion

- Developing CFD protocols can focus on patient-specific cases for prospective and retrospective analysis to study and validate uncomplicated TBAD.

Future Directions

- Obtain periodic diagnostic medical imaging data sets (i.e. (dynamic) CTA, 4DfMRI, TTE) to provide anatomical and physiological information to inform patient-specific CFD simulations, validate simulated results with actual observed disease progression, and ultimately develop a clinically implementable predictive analysis protocol to guide treatment in patients with uncomplicated TBAD undergoing optimal medical therapy to improve patient outcomes.

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