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# The role of aortic compliance in determination of coarctation severity: Lumped parameter modeling, *in vitro* study and clinical evaluation

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ABSTRACT

Early detection and accurate estimation of the extent of coarctation of the aorta (COA) is critical to long-term outcome. Peak-to-peak trans-coarctation pressure gradient ($P_K dP$) higher than 20 mmHg is an indication for interventional/surgical repair. Patients with COA have reduced proximal and distal aortic compliances. A comprehensive study investigating the effects of variations of proximal COA and systemic compliances on $P_K dP$, and consequently on the COA severity evaluation has never been done. This study evaluates the effect of aortic compliance on diagnostic accuracy of $P_K dP$. Lumped parameter modeling and *in vitro* experiments were performed for COA severities of 50%, 75% and 90% by area. Modeling and *in vitro* results were validated against retrospective clinical data of $P_K dP$, measured in 54 patients with COA. *Modeling and in vitro*. $P_K dP$ increases with reduced proximal COA compliance (+36%, +38% and +53% for COA severities of 50%, 75% and 90%, respectively; $p<0.05$), but decreases with reduced systemic compliance (−62%, −41% and −36% for COA severities of 50%, 75% and 90%, respectively; $p<0.01$). *Clinical study*. $P_K dP$ has a modest correlation with COA severity ($R=0.29$). The main determinants of $P_K dP$ are COA severity, stroke volume index and systemic compliance. Systemic compliance was found to be as influential as COA severity in $P_K dP$ determination ($R=0.30$ *vs.* $R=0.34$). In conclusion, $P_K dP$ is highly influenced by both stroke volume index and arterial compliance. Low values of $P_K dP$ cannot be used to exclude the severe COA presence since COA severity may be masked by reduced systemic compliance and/or low flow conditions.



## 1. Introduction

Coarctation of the aorta (COA) is the most common congenital heart defect, accounting for 5% to 8% of all congenital heart defects, occurring in 8–11% of births annually (Roger et al., 2011). Despite ongoing advances in surgical techniques for COA repair the long-term results are not always satisfactory. The incidence of recurrence is significant (8–54%) and frequently requires repeat surgery (Cohen et al., 1989; Kopf et al., 1986). Surgical management of recurrent or residual COA is associated with some morbidity (Williams et al., 1980). The long-term prognosis after repair of COA is not entirely benign. Associated structural cardiovascular lesions such as mitral or aortic valve disease, ventricular septal defect and cerebrovascular malformations are responsible for considerable postoperative morbidity and mortality. Hypertension may persist even after a successful correction of COA (Nanton and Olley, 1976; Maia et al., 2000).

Early detection and accurate estimation of COA severity are of primary importance for successful long-term outcome following the initial repair (Cohen et al., 1989). In the clinical setting, several invasive and non-invasive modalities have been used to determine the severity of COA before surgery as well as to evaluate residual hypertension and/or obstruction after balloon dilatation or after surgery. Among them, cardiac catheterization with angiography

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and hemodynamic evaluation is considered as the gold standard for definitive evaluation of COA severity (Yetman et al., 1997; Maheshwari et al., 2000; Warnes et al., 2008). Current AHA guidelines suggest a peak-to-peak systolic trans-coarctation pressure gradient ($P_K dP$) > 20 mmHg as a measure of pressure overload and an indication for interventional/surgical repair (Brili et al., 1998; Vogt et al., 2005). Although many studies (Gardiner et al., 1994; Xu et al., 1997; Brili et al., 1998; Vogt et al., 2005) reported that patients with COA have a localized enhancement of pressure-wave reflections not only towards the ascending aorta but also towards the lower body, and reduced compliances, in the proximal and distal aorta, little is known about the impact of variations in the arterial compliance on trans-coarctation pressure gradient (Xu et al., 1997). To the best of our knowledge a comprehensive study investigating the effects of variations of proximal COA and systemic compliances on the $P_K dP$, and consequently on the evaluation of COA severity has never been done in the past.

The aim of the present work was to perform such a comprehensive study using combined lumped parameter modeling, *in vitro* measurements and retrospective clinical study.

## 2. Methods

### 2.1. Lumped parameter model

We introduced a lumped parameter model (Fig. 1, Table 1) that describes the interaction between left ventricle (LV), COA, and arterial dynamics. The validation of the model has already been performed using *in vivo* MRI data (Keshavarz-

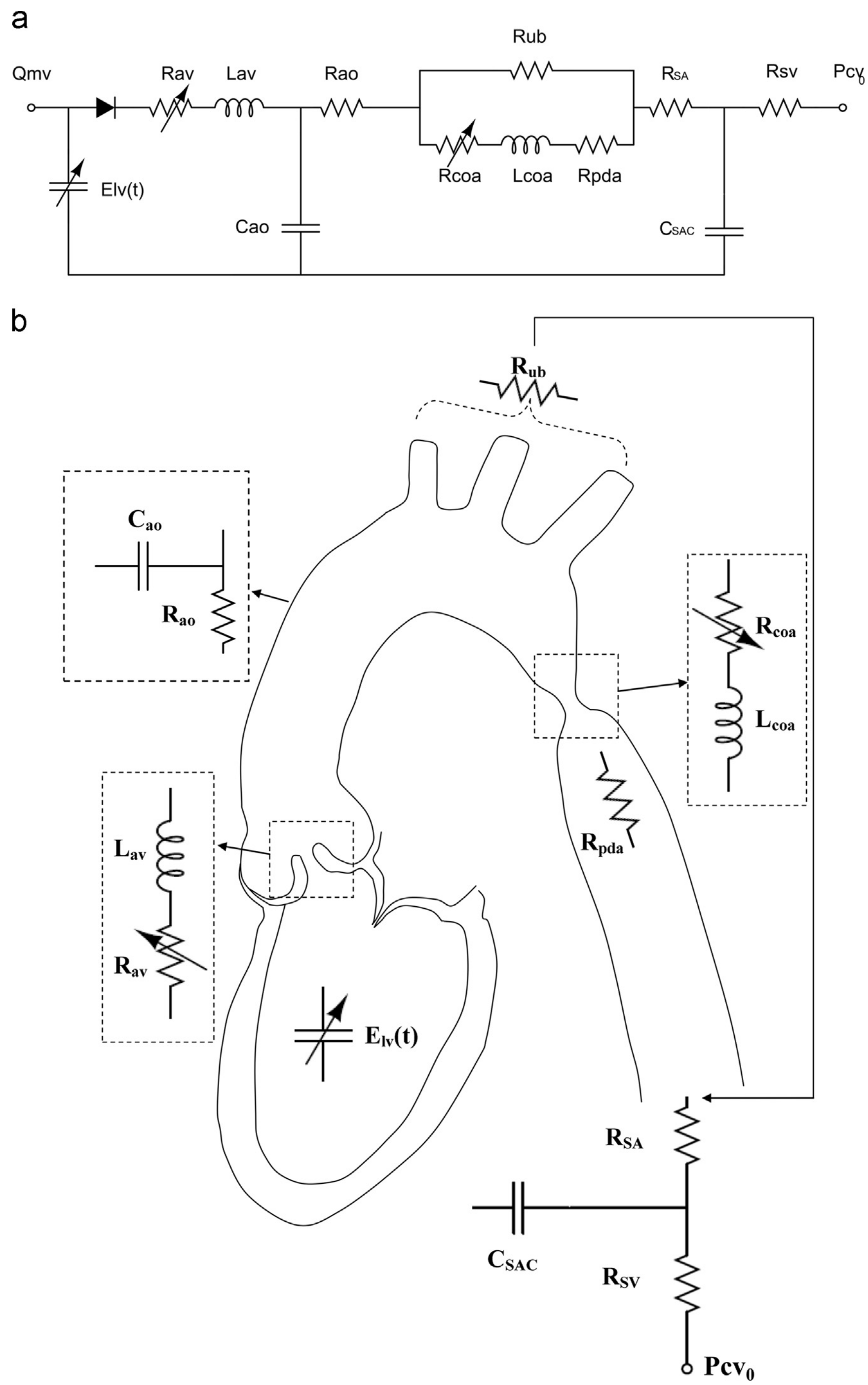


**Fig. 1.** Schematic diagram of the lumped parameter model. (a) electrical representation, and (b) anatomical representation. Abbreviations are similar as in Table 1.