Estimating Patent Ductus Arteriosus from Pulse Wave Transition Time in Newborn Infants

Doriela Grabocka
dgrabocka@student.ethz.ch
Department of Computer Science,
ETH Zürich
Zürich, Switzerland

Alain Ryser
alain.ryser@inf.ethz.ch
Department of Computer Science,
ETH Zürich
Zürich, Switzerland

Sven Wellman
Department of Computer Science,
ETH Zürich
Zürich, Switzerland

Holger Michel
Department of Neonatology,
University Hospital Regensburg
Regensburg, Germany

Julia E. Vogt
Department of Computer Science,
ETH Zürich
Zürich, Switzerland

ABSTRACT

Patent Ductus Arteriosus (PDA) is a heart condition that affects newborn infants. One way to estimate the severity of PDA is by measuring the Cardiac Output (CO) of the infants. Current techniques for estimating CO include echocardiography or invasive methods. While invasive methods generally provide a more accurate CO estimate, they are difficult procedures for premature infants due to the infants’ size and potential complications. On the other hand, echocardiography CO estimates do not allow for continuous CO monitoring. In this work, we examine the relationship between Pulse Wave Transition Time (PWTT) and stroke volume (SV-VTI), a clinical measure from which it is possible to derive CO. In addition, we build a machine-learning model to predict SV-VTI from PWTT, which provides a novel way of estimating CO inexpensively and non-invasively.

CCS CONCEPTS
- Applied computing → Health informatics; Health care information systems.

KEYWORDS
cardiac output, pulse wave transition time, stroke volume prediction, newborn infants, machine learning, ANOVA

1 INTRODUCTION

Cardiac Output (CO) estimation in newborn infants is essential for diagnosing Patent Ductus Arteriosus (PDA). PDA is a heart condition where the ductus fails to close after a child’s birth. When it fails to close within 72 hours of birth, it may cause complications that may lead to death [1]. Some of the most common consequences include heart failure, slow growth, or altered nutrition [1]. So far, the standard method to estimate the size of the ductus is through echocardiography. However, echocardiograms do not allow for continuous monitoring and require manual evaluation by an expert. Recent studies on adults have shown that CO can be derived from the Pulse Wave Transition Time (PWTT) [4, 5]. PWTT is the time the blood needs to travel from the aortic vessel to a peripheral oximeter device. In other words, it is the time from the R-peak of the ECG wave until the rise point of the $SpO_2$ wave. This is important in newborn infants because it can give doctors a continuous estimation of the size of the ductus.

In this work, we analyze the relationship of PWTT with SV-VTI and PDA in newborn infants and design a machine-learning model that estimates SV-VTI from PWTT features, providing doctors with the option of continuous CO monitoring non-invasively.

2 DATA

Our data consists of a total of 201 measurements from 55 patients, out of which we used 198 for our analysis. For each measurement, we have the patient’s physical data (e.g. weight (g), age (weeks), etc.), clinical data from echocardiography (e.g. left ventricular outflow tract function (LVOT), Stroke Volume (SV-VTI), Cardiac Output (CO)) and the wrist and foot PWTT time-series (see Figure 1). For our analysis, we aggregate the PWTT time-series by averaging the PWTT wrist and foot values as $PWTT_w$ and $PWTT_f$, respectively. Figure 1 shows the PWTT of the wrist and foot for a patient. Additionally, for each patient, we add a feature $\Delta PWTT =$
\[ \text{PWTT}_f - \text{PWTT}_w \text{ to compare results with past findings [2].} \]

To disregard the effect of physical features, we also consider normalized PWTT values by dividing \( \text{PWTT}_w, \text{PWTT}_f, \text{ and } \Delta \text{PWTT} \) by the KOF (an estimate for body surface), arm length, and body length.

### 3 EXPERIMENTS & RESULTS

**Hypothesis I:** PWTT inversely correlates with the ventricular function/stroke volume measured by echocardiography. Past research has found that for adult patients, the SV-VTI [3] and CO[5] estimated with linear models through PWTT correlate with invasive measurements. To validate this hypothesis for prematurely newborn infants, we examine the correlation between all the PWTT values in our dataset and the LVOT, SV-VTI, and SV-VTI normalized by KOF.

From the correlation analysis of our data, we **confirm a negative correlation between SV-VTI and normalized PWTT values.** For SV-VTI, the highest negative correlation is between SV-VTI and the PWTT values normalized by KOF (see Figure 2), which confirms the important role of physical features of infants. At a 5% confidence level, these correlations are significant, confirming our hypothesis.

**Hypothesis II:** The size of the ductus correlates with \( \Delta \text{PWTT} \). Previous studies have shown that there is an increase in \( \Delta \text{PWTT} \) as PDA becomes larger [2]. In our data, the size of the ductus is an ordinal feature with values 1-4 (Score-PDA), indicating the smallest size and 4 the largest. We consider Score-PDA as a factor with 4 levels and use Analysis of Variance (ANOVA) to examine the effect Score-PDA has on the PWTT values.

We demonstrate that the **size of the ductus does not affect the \( \Delta \text{PWTT} \),** thus contradicting our initial beliefs. However, at 5% confidence level, there is **evidence that \( \text{PWTT}_w \) is affected by the size of the ductus** (p-val < 0.05), as can be seen in Figure 3.

![Figure 2: Correlation between PWTT and cardiac function features.](image)

From the correlation analysis, we try to find a model that can estimate SV-VTI based on the PWTT features. We fit a linear regression model and a LASSO regression model \((\lambda = 0.1)\) to the data. In both models, we exclude features measured by echocardiography and estimate SV-VTI using \( \text{PWTT}_w, \text{PWTT}_f, \text{ and } \text{PWTT}_{w-KOF} \) or \( \text{PWTT}_{f-KOF} \) which are the respective wrist and foot PWTT mean values normalized by the patient’s KOF, \( \text{PWTT}_{w-al} \) is the wrist PWTT mean value normalized by the arm length and \( \text{PWTT}_{f-1} \) is the foot PWTT mean value normalized by the patient’s length and weight and age of the patient. Before training and evaluating the models, we split the data into train and test sets (80-20%, ensuring that patients are either part of the train or test set) and standardize it.

Our linear models can predict SV-VTI from PWTT, weight, and age of the patient. We measure performance in terms of mean squared error (MSE) and Pearson correlation (R2) and present the results in Table 1. Linear Regression is the best-performing model.

<table>
<thead>
<tr>
<th>Model/Metric</th>
<th>MSE-train</th>
<th>MSE-test</th>
<th>R2-train</th>
<th>R2-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear Regression</td>
<td>0.2571</td>
<td>0.3397</td>
<td>0.8289</td>
<td>0.7571</td>
</tr>
<tr>
<td>L1-Regression</td>
<td>0.2928</td>
<td>0.3542</td>
<td>0.8053</td>
<td>0.7518</td>
</tr>
</tbody>
</table>

1The past studies derive \( \Delta \text{PWTT} \) from concurrent wrist and foot measurements. We do not have concurrent wrist and foot measurements and thus estimate this value as the difference of the means of the foot/wrist PWTT.

![Figure 3: p-values of the ANOVA analysis between some of the PWTT features and Score-PDA](image)

**4 CONCLUSIONS & FUTURE WORK**

In this work, we analyzed the relationship between PWTT and SV-VTI. We demonstrated that PWTT inversely correlates with SV-VTI in newborn infants. Given our findings, we designed a model to predict SV-VTI from PWTT, weight, and age of the infant. Further, we revealed that PDA affects \( \text{PWTT}_w \), while \( \Delta \text{PWTT} \) does not share such a relationship, as it was shown in past studies [2].

One drawback of our data is the absence of a real-time \( \Delta \text{PWTT} \), making it difficult to compare to previous work [2]. Reproducing their results using concurrent measurements of PWTT on foot and wrist is an interesting direction for future work. Further, incorporating more sophisticated models to predict SV-VTI from PWTT could lead to improved performance and better applicability in clinical practice.

Our study is an important first step in helping doctors estimate CO from PWTT in newborn infants in a data-driven fashion without the need for echocardiography or invasive methods. Further clinical trials should be done to assess the suitability for clinical application.

### REFERENCES


