QUALITATIVE FEATURES OF A NOVEL BARORECEPTOR MODEL

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ABSTRACT

Blood pressure regulation by the cardiovascular system is a complex physiological process. Cardiovascular modeling can offer a valuable insight often beyond the reach of experiments. In this study we provide a new mathematical model of the afferent component of the baroreflex feedback system. The model takes advantage of the so-called quasi-linear viscoelastic theory, which has been widely used to describe the nonlinear viscoelastic response of living tissue. It also uses a simple integrate-and-fire model to predict the baroreceptor response and therefore takes into account the conceptual structure of the baroreceptor. Our objective is to test our new baroreceptor model for its ability to reproduce experimental data qualitatively and demonstrate known pressure-response relationships. We also highlight that the model can be coupled with an existing model of the efferent pathways, eventually predicting heart rate.

Keywords: heart rate regulation, baroreflex, blood pressure dynamics, mathematical modeling

1. INTRODUCTION

Understanding the cardiovascular control system is crucial for gaining more insight into the physiology not only for the healthy individual, but also in order to detect pathologies. Its main role is to provide adequate perfusion of all tissues, which is achieved by maintaining blood flow and pressure at a fairly constant level. To accomplish this, a number of control mechanisms are imposed regulating vascular resistance, compliance, pumping efficiency and frequency. An important contributor to this control system is the *baroreflex* (or *baroreceptor reflex*), which uses specialized neurons called *baroreceptors* for signaling. The baroreceptor neurons are activated via mechano-sensitive channels located in the aortic arch and carotid sinuses. It is believed that the baroreceptor nerves are the main contributer to the short-term regulation of vascular efferents including: heart rate, cardiac contractility, and vascular resistance and vessel tone (Levick 2010).

Prediction of heart rate from blood pressure involves two main pathways: afferent and efferent. *Afferent* pathways integrate firing of the baroreceptors in the nucleus solitary tract. *Efferent* pathways modulate sympathetic and parasympathetic signals, which lead to release or inhibition of the neuro-transmitters: acetylcholine and noradrenaline, which in turn modulate the effectors. In this study, we focus on regulation of heart rate. See Figure 1 for overall, conceptual division of the model predicting heart rate.

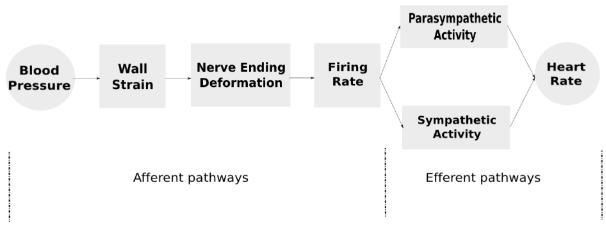

Figure 1: Conceptual division of the mathematical model for the baroreflex feedback control of heart rate.

This study focuses on analyzing qualitative aspects of a new model for the afferent signaling, whereas the efferent dynamics can be predicted using either the existing model developed by Olufsen et al. [2006], or any other model. In Section 2, after reviewing the main qualitative characteristics of the baroreceptor dynamics we introduce our model, which will be analyzed and discussed in Section 3.

2. METHODS

In this section we describe the principal physiological elements of the baroreceptors; identify the most prominent qualitative features of their discharge observed in experiments; and introduce a mathematical model that reflects all those characteristics.

2.1. Basic physiological facts and experiments

For most mammals baroreceptors are found in the aortic arch and the carotid sinuses (Sharwood 2001). These neurons are stimulated via activation of stretch receptors, which are able to detect changes in the wall strain induced by changes in blood pressure. Besides water, which makes up to 70% of arterial wall, it consists of: muscles, elastin, collagen and ground substance. The wall is commonly divided into three layers: the *tunica intima*, a thin layer of endothelial cells lining the arterial wall; the *tunica media* (the middle layer), the primary contributor to the arterial wall deformation; and the *tunica adventitia* (the outer layer) connecting the vessels to their surrounding tissue. Understanding the mechanics and the viscoelastic properties of the arterial wall is essential for modeling the baroreceptor response.