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Review

Ambulatory blood pressure variation: Allostasis and adaptation

Gary D. James *

Decker School of Nursing, Department of Anthropology, Department of Bioengineering, Binghamton University, Binghamton, NY 13902-6000, USA

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ABSTRACT

Allostasis is defined as achieving stability through change and was originally coined as a term to describe the adaptive variability of blood pressure. While there have been a growing number of studies using ambulatory blood pressure monitors that have examined the sources of blood pressure variation in everyday life, these studies have largely not conceptualized that variation in allostatic terms. This brief overview evaluates ambulatory blood pressure variability and its sources in the context of allostasis and adaptation. The effects of job strain and the impact of evolutionary aspects of population biology on blood pressure variation are also discussed.

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1. Introduction

In 1628, William Harvey published *An Anatomical Treatise on the Motion of the Heart and Blood in Animals* in which he proved that the heart was muscular, that its most important movement was contraction and not dilation, and that it was the beat of the heart that produced a continuous circular motion of blood in the body (Magner, 1992). In 1733, more than 100 years later, Stephen Hales made the first measure of systemic blood pressure in a horse, where he also found that the pressure was not fixed, but variable (Pickering, 1991). Over the next 170 years, methods for blood pressure assessment were slowly refined and the specific relationships between the cardiac rhythm and arterial pressure were discovered (O'Rourke, 1990; Paskalev et al., 2005). However, a simple and reproducible blood pressure measurement that described both the maximum and minimum pressures of the pulsatile blood flow as it left the heart remained elusive. Finally, in 1905, Nikolai Korotkoff using the arterial occlusion method of Riva-Rocci discovered the auscultatory technique of blood pressure measurement, reporting on the sounds that bear his name in a paper presented to the Imperial Military Medical Academy in St. Petersburg, Russia (Paskalev et al., 2005). Since that time, other methods of assessment have been added, including oscillometric and ultrasound techniques (Pickering, 1991), but the quantitation of blood pressure as a ratio of the maximum (systolic) and minimum (diastolic) of the pressure pulse wave that is based on Korotkoff sounds remains the standard for describing blood pressure.

Throughout the 20th century and into the 21st, ausculted blood pressures taken by Korotkoff's technique have been used as an indicator of cardiovascular health, and a condition, hypertension, has been defined as seated systolic/diastolic blood pressure that exceeded 140/90 mm Hg

* Tel.: +1 607 777 6086; fax: +1 607 777 6162.
E-mail address: gdjames@binghamton.edu.

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in the clinical setting. Data from numerous clinical and epidemiological studies show that hypertension is a risk factor for cardiovascular diseases and stroke (e.g. JNC VII, 2003), and because of this association, the pharmaceutical industry has produced a cornucopia of vasoactive agents designed to lower blood pressure as a means of lessening the burden of cardiovascular morbidity and mortality (JNC VII, 2003).

While the level of ausculted blood pressure has been the focus of medical attention for over 100 years, the diurnal variability of blood pressure, until relatively recently, has been of minimal interest. The increasing use of automated ambulatory blood pressure monitors in medical practice over the past 30 years has demonstrated that there is enormous intraday variability in blood pressure (James, 2007a). By employing these monitors, white coat hypertension (Pickering et al., 1988; Ohkubo et al., 2005) and masked hypertension (Ohkubo et al., 2005; Pickering et al., 2007; Angeli et al., 2010), conditions defined by the difference in blood pressure between the clinic and daily life and which likely also differentially influence cardiovascular morbidity risk (e.g. Konstantopoulou et al., 2010) have been identified. Furthermore, other aspects of the diurnal variation in blood pressure, such as the waking–sleep difference in blood pressure (dipping) (Fagard et al., 2009; Cuspidi et al., 2010; Hansen et al., 2011) and the surge in pressure upon awakening (Kario, 2010; Yano and Kario, 2012) have also been shown to predict cardiovascular morbidity and mortality. These studies suggest that blood pressure variability is perhaps as important as the mean level of blood pressure when it comes to defining cardiovascular health.

Although the literature on blood pressure is dominated by its role as an indicator of cardiovascular health, the fundamental nature of blood pressure as a biological phenomenon has also come into sharper focus. In the 1980s, Sterling and Eyer (1988) introduced the concept of "allostasis" defined as "achieving stability through change" using blood pressure as an exemplar of the process. Blood pressure changes dramatically and continuously to adapt individuals to their changing daily circumstances (James, 1991). Because it continuously changes, the individual does not have a single "homeostatic" blood pressure state, but rather has many stable blood pressure states that are related to their ever-changing internal and external environments (Ice and James, 2012).

Sterling and Eyer (1988) have argued that in the process of allostasis, the brain coordinates multiple systems of local control in an integrated fashion which allows for anticipation of change in systemic demand. Thus, allostatic regulation (such as with blood pressure) has two components: the parameter variation and anticipated demand from that variation. Sterling (2004) has further suggested that allostasis can be used to explain the connections between social conditions, behavior, and health, such that poor social conditions can place an individual in a state of constant arousal and encourage negative health behaviors leading to the development of disease. From this perspective, essential hypertension (high blood pressure) can be seen as arising from sustained neural input that emerges from "unsatisfactory social interactions" (Sterling, 2004). Thus, how people appraise their social circumstances is a key element of allostatic regulation (Ice and James, 2012). Adverse appraisal might necessarily lead to a continued enhanced allostatic response which in turn could create an allostatic load resulting in metabolic failure (McEwen, 2004). Several studies have shown that appraisal of common life phenomena, such as job strain has a significant effect on blood pressure variation which may also lead to hypertension (Schnall et al., 1990; Landesbergis et al., 2003).

In the discussions of allostasis, there is also an implication that it is a process that acts in a similar fashion in all people. This may not be the case. Missing from most discussions of allostasis and blood pressure is an evaluation across populations; specifically the impact that evolution has had on allostatic variation in blood pressure among diverse populations living in contrasting ecologies. Several studies have found that there are significant physiological differences between populations that are related to climatic factors (James, 2010). These differences can influence how blood pressure is regulated (James and Baker, 1995; James, 2010).

While blood pressure allostasis has been discussed theoretically, there has been little discussion of its operationalization based on real life data. The purposes of this brief overview are 1) to evaluate ambulatory blood pressure variability, both in terms of how it is measured and the factors that drive it, 2) to assess the impact of the appraisal of common life phenomenon (specifically job strain) on diurnal blood pressure variation and allostasis, and 3) to summarize the possible impact of evolutionary aspects of population biology on allostatic blood pressure variation.

2. Ambulatory blood pressure measurements

Ambulatory blood pressure monitors continue to use a cuff occlusion method to take blood pressures; they either have a microphone attached to the cuff that is placed above the brachial artery to detect Korotkoff sounds, or employ an oscillometric method using a manufacturer proprietary algorithm to calculate the pressures (James, 2007a). Typically when blood pressure variation is studied, pressures are examined for their variability over the course of one 24-hour period, although it should be noted that in making this evaluation, pressures may be measured over the course of several days (e.g. Kamarck et al., 2002) and there has also been interest in determining whether blood pressure variability differs across different types of days (e.g. a weekend non-work day vs. a mid-week workday) (e.g. Pieper et al., 1993). Since each heart beat generates a systolic and diastolic pressure (defined as the maximum and minimum of the pulse wave of blood that is produced when the heart ejects blood into the aorta as it contracts), depending upon the heart rate, upwards of 100,000 blood pressures occur over 24 h (James, 2007a). Monitors can be programmed to take a blood pressure as often as every 5 min, but for the purpose of diurnal variation studies, monitors are programmed to take pressures between 15 and 30 min while awake and every 30 to 60 min while sleeping (James, 2007a). Thus, diurnal studies of blood pressure variation have evaluated samples of blood pressures in the range of 40 to 80 measurements per subject per day, a relative few considering how many are actually generated daily.

3. Modeling the sources of blood pressure variation

To understand why blood pressure varies, it is critical to have information regarding the conditions of measurement. That is, if blood pressure is responding to ambient conditions during everyday life, in order to show the relationship, there needs to be a means of defining the conditions.

While direct observation of subjects wearing the monitor has been used (e.g. Ice et al., 2003), for most studies of diurnal blood pressure variation, subjects have self-reported the ambient conditions of each blood pressure measurement in a diary, which have taken on a variety of forms, from pencil and paper to hand held computers (James, 2007b). Most studies of blood pressure variation have not been conducted with a focus toward allostasis, or even understanding cardiovascular adaptation for that matter. Rather the interest has either been in simply understanding the sources of diurnal blood pressure variation, or evaluating whether people with specific characteristics differ in their responses to similar stimuli (Gerin and James, 2010; Ice and James, 2012).

To assess the sources of diurnal ambulatory blood pressure variation two general approaches have been used (James, 2007b). The first employs what might be termed a "natural experimental" approach in which there are a priori design elements that define predictable dynamically changing behaviors or situations that occur during a typical day (James, 2007b). This approach has its roots in the study of blood pressure reactivity in the laboratory, where blood pressure change to various "stressful" tasks has been evaluated (see for example, Pickering