Available online at www.sciencedirect.com
ScienceDirect
Comparative Biochemistry and Physiology, Part A 148 (2007) 510–520
CBP
www.elsevier.com/locate/cbpa

The adrenergic regulation of the cardiovascular system in the South American rattlesnake, *Crotalus durissus*

Gina L.J. Galli [a,b,c,*], Nini Skovgaard [a,c], Augusto S. Abe [c], Edwin W. Taylor [b,c], Tobias Wang [a,c]

[a] *Zoophysiology, Department of Biological Sciences, University of Aarhus, Building 1131, 8000 Aarhus C, Denmark*
[b] *School of Biosciences, The University of Birmingham, Edgbaston, Birmingham B15 2TT, U.K.*
[c] *Departamento de Zoologia, Centro de Aquicultura, UNESP, Caixa Postal 199, 13506-970 Rio Claro, SP, Brazil*

Received 26 May 2006; received in revised form 24 June 2007; accepted 25 June 2007
Available online 30 June 2007

Abstract

The present study investigates adrenergic regulation of the systemic and pulmonary circulations of the anaesthetised South American rattlesnake, *Crotalus durissus*. Haemodynamic measurements were made following bolus injections of adrenaline and adrenergic antagonists administered through a systemic arterial catheter. Adrenaline caused a marked systemic vasoconstriction that was abolished by phentolamine, indicating this response was mediated through α-adrenergic receptors. Injection of phentolamine gave rise to a pronounced vasodilatation (systemic conductance (G_{sys}) more than doubled), while injection of propranolol caused a systemic vasoconstriction, pointing to a potent α-adrenergic, and a weaker β-adrenergic tone in the systemic vasculature of *Crotalus*. Overall, the pulmonary vasculature was far less responsive to adrenergic stimulation than the systemic circulation. Adrenaline caused a small but non-significant pulmonary vasodilatation and there was tendency of reducing this dilatation after either phentolamine or propranolol. Injection of phentolamine increased pulmonary conductance (G_{pul}), while injection of propranolol produced a small pulmonary constriction, indicating that α-adrenergic and β-adrenergic receptors contribute to a basal regulation of the pulmonary vasculature. Our results suggest adrenergic regulation of the systemic vasculature, rather than the pulmonary, may be an important factor in the development of intracardiac shunts.

Keywords: Reptile; Snake; Cardiovascular regulation; Adrenaline; Adrenergic stimulation; Pulmonary circulation; Systemic circulation

1. Introduction

Similar to mammals, the circulatory system of reptiles is under continuous autonomic nervous regulation by excitatory adrenergic sympathetic fibres as well as inhibitory cholinergic parasympathetic fibres (Morris and Nilsson, 1994). The overall regulation of systemic and pulmonary vascular tone has important implications for most reptiles, because their undivided hearts permit intracardiac shunting (Hicks, 1998). The degree and direction of the cardiac shunt flow depends on the relative vascular conductances of the systemic and pulmonary circulations (Hicks, 1994). Thus, an increase in systemic conductance (G_{sys}), or a reduction in pulmonary conductance (G_{pul}), will promote a right to left (R→L) cardiac shunt, so that blood by-passes the pulmonary circulation and is re-circulated within the systemic vasculature. Alternatively, if G_{sys} is reduced or G_{pul} increased, a net left to right (L→R) shunt will develop, with blood flow being directed towards the pulmonary circulation.

It is well established that regulation of reptilian cardiac shunts are primarily achieved via cholinergic vagal innervation of smooth muscle surrounding the pulmonary artery, where increased vagal activity causes pulmonary constriction and a subsequent decrease in G_{pul} (Berger, 1972; Burggren, 1977; Smith and Macintyre, 1979; Lillywhite and Donald, 1994). However, histochemical studies have also identified

* Corresponding author. Hopkins Marine Station of Stanford University, 120 Ocean View Boulevard, Pacific Grove, CA, 93950, USA.
E-mail address: ginaljgalli@hotmail.com (G.L.J. Galli).

1095-6433/$ - see front matter © 2007 Elsevier Inc. All rights reserved.
doi:10.1016/j.cbpa.2007.06.420

adrenergic nerves innervating the pulmonary vasculature of reptiles (Smith and Macintyre, 1979; Donald and Lillywhite, 1988; Donald et al., 1990a). In particular, the rat snake, *Elaphe obsoleta,* has extensive innervation throughout the entire pulmonary circulation, including the lung parenchyma, indicating sympathetic regulation of pulmonary blood flow in the lung itself (Donald et al., 1990a,b). Nevertheless, the extent to which the sympathetic nervous system affects pulmonary vascular conductance in the different species of reptiles is not clear (for a review see Hicks, 1994). Although it is well established that cholinergic vagal control of the pulmonary artery determines shunt patterns, altering vascular resistance through adrenergic stimulation of either the systemic or pulmonary circulations may also contribute to control of intracardiac shunting (Lillywhite and Donald, 1989). Increased adrenergic tone is mainly associated with exercise and the classic "flight or flight" response and is often associated with reduced vagal tone (*e.g.* Wang et al., 2001a for a study on snakes). These reciprocal responses reduce the R→L shunt, and may even cause the development of a L→R shunt. A reduction in the R→L shunt increases arterial oxygen levels, which increases systemic oxygen delivery as metabolic demands are elevated (Wang and Hicks, 1996, 2002; Wang et al., 2001b).

In the present study, we seek to determine the extent to which adrenergic stimulation affects systemic and pulmonary conductance, and how adrenergic stimulation affects intracardiac shunt patterns in the South American rattlesnake (*Crotalus durissus*). *C. durissus* is common in arid areas throughout South America and we have recently documented a strong vagal influence on heart rate and pulmonary blood flow in this species, and have previously shown that they exhibit a large R→L cardiac shunt

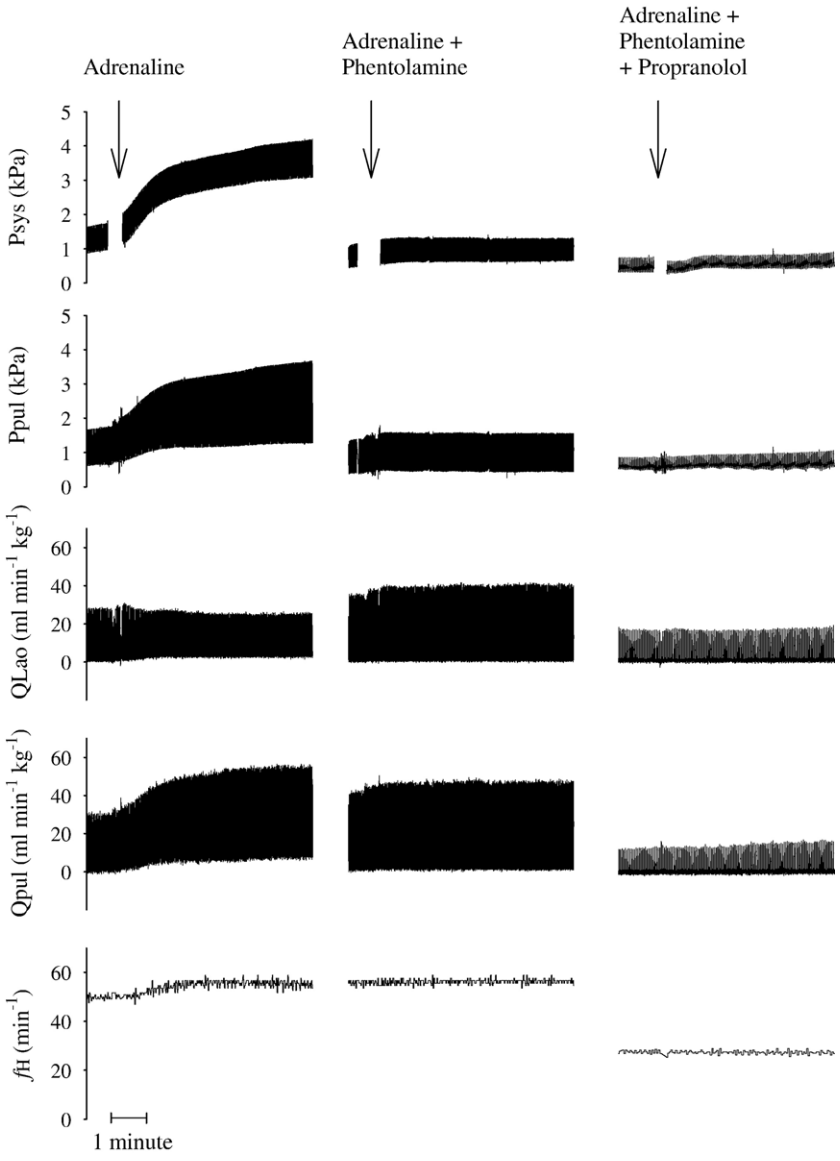

Fig. 1. Original traces obtained from a 550 g *Crotalus* showing haemodynamic variables during protocol 1, where adrenaline (2 μg kg^{-1}) was infused before and after phentolamine (2 mg kg^{-1}) and after complete adrenergic blockade following injection of propranolol (2 mg kg^{-1}).