Differential responses of regional sympathetic activity and blood flow to visceral afferent stimulation

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Pan, Hui-Lin, Dwight D. Deal, Zemin Xu, and Shao-Rui Chen. Differential responses of regional sympathetic activity and blood flow to visceral afferent stimulation. Am J Physiol Regulatory Integrative Comp Physiol 280: R1781–R1789, 2001.—The sympathetic nervous system is essential for the cardiovascular responses to stimulation of visceral afferents. It remains unclear how the reflex-evoked sympathetic output is distributed to different vascular beds to initiate the hemodynamic changes. In the present study, we examined changes in regional sympathetic nerve activity and blood flows in anesthetized cats. Cardiovascular reflexes were induced by either electrical stimulation of the right splanchnic nerve or application of 10 μg/ml of bradykinin to the gallbladder. Blood flows were measured using colored microspheres or the Transonic flow meter system. Sympathetic efferent activity was recorded from the left splanchnic, inferior cardiac, and tibial nerves. Stimulation of visceral afferents decreased significantly blood flows in the splanchnic (from 49 ± 4 to 25 ± 3 ml/min) and superior mesenteric (from 35 ± 4 to 23 ± 2 ml/min) arteries, and the vascular resistance in the splanchnic bed was profoundly increased. Consistently, stimulation of visceral afferents decreased tissue blood flows in the splanchnic organs. By contrast, activation of visceral afferents increased significantly blood flows in the coronary artery and portal vein but did not alter the vascular resistance of the femoral artery. Furthermore, stimulation of visceral afferents increased significantly sympathetic efferent activity in the splanchnic (182 ± 44%) but not in the inferior cardiac and tibial nerves. Therefore, this study provides substantial new evidence that stimulation of abdominal visceral afferents differentially induces sympathetic output to the splanchnic vascular bed.

sympathetic efferent nerves; celiac ganglia; mesenteric blood flow; portal vein; splanchnic circulation; vascular resistance

ISCHEMIC STIMULATION OF ABDOMINAL sympathetic afferents reflexly excites the cardiovascular system (34). Many ischemic metabolites produced during abdominal ischemia, such as bradykinin, contribute to activation of ischemically sensitive afferent nerve endings (32). Previous studies have established that thinly myelinated Aδ- and unmyelinated C-fiber afferents mediate these cardiovascular reflex responses (34). Furthermore, increased sympathetic nervous activity is ultimately responsible for the excitatory cardiovascular reflex responses to stimulation of visceral afferents because such reflexes are diminished in the presence of α-adrenergic receptor antagonists (22). It remains uncertain how the sympathetic outflow induced by stimulation of visceral afferents is distributed and integrated to cause these hemodynamic alterations. Because stimulation of visceral sympathetic afferents often simultaneously increases the blood pressure, heart rate, and cardiac contractility, it has been proposed that sympathetic outflows are evenly distributed to the heart and various vascular beds during cardiovascular reflex responses (21, 23). However, the role of regional sympathetic and blood flow responses to stimulation of visceral afferents has not been fully defined.

There is some evidence suggesting that sympathetic nerves supplying the heart and different vascular beds are not equally involved in cardiovascular reflexes (35, 38). Differential responses of sympathetic nerves can result in nonuniform redistribution of blood flows to the visceral and somatic tissues (2, 14, 15). In this regard, the splanchnic bed has been considered as the primary blood volume reservoir for reflex control of cardiovascular homeostasis during exercise (29). But its role often is overlooked for cardiovascular reflexes originating from visceral organs. Further support for the importance of splanchnic circulation in cardiovascular reflexes comes from clinical observations that patients receiving celiac plexus blocks for pain relief frequently manifest orthostatic hypotension, indicating inadequate cardiovascular control (9). On the other hand, it has been reported that cardiac transplant patients have normal cardiovascular responses to squatting and cold pressor test (12, 27), suggesting that sympathetic innervation of the heart is not actively involved in the physiological regulation of circulation. The blood vessels are tonically controlled by the sympathetic nervous system, and the sympathetic outflow to various vascular beds is indirectly reflected in alterations in regional blood flows. Blood redistribution among different vascular beds likely plays an important role in the overall cardiovascular reflex responses

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to stimulation of visceral afferents. Because the splanchnic bed is tonically involved in the neural control of circulation, we tested a hypothesis that stimulation of abdominal visceral afferents induces predominantly constriction of the splanchnic vascular bed. Furthermore, because the blood flow response is a combination of autoregulation and neural influences, we also examined specifically the regional distribution of sympathetic outflows in response to stimulation of abdominal visceral afferents.

MATERIALS AND METHODS

Surgical Preparations

The experimental procedures and protocols were approved by the Institutional Animal Care and Use Committee and adhere to the Guide for the Care and Use of Laboratory Animals (United States Public Health Service). Adult cats of either sex were anesthetized with ketamine (30 mg/kg im), and anesthesia was maintained with α-chloralose (5–10 mg/kg) were given as necessary to maintain adequate depth of anesthesia, assessed by lack of nociceptive reflexes and fluctuation of blood pressure and heart rate. A femoral artery and vein and a carotid artery were catheterized for measurement of blood pressure and administration of fluids or drugs. The trachea was intubated, and respiration was maintained artificially with an animal ventilator (model CIV-101; Columbus Instruments, Columbus, OH). Arterial blood pressure was measured with a pressure transducer and monitored on a thermal sensitive recorder. The experimental procedures and protocols were approved by the Institutional Animal Care and Use Committee and adhere to the Guide for the Care and Use of Laboratory Animals (United States Public Health Service). Adult cats of either sex were anesthetized with ketamine (30 mg/kg im), and anesthesia was maintained with α-chloralose (60–80 mg/kg iv). Adequate depth of anesthesia was determined by withdrawal reflex to paw pinch. Supplemental doses of α-chloralose (5–10 mg/kg) were given as necessary to maintain adequate depth of anesthesia, assessed by lack of nociceptive reflexes and fluctuation of blood pressure and heart rate. A femoral artery and vein and a carotid artery were catheterized for measurement of blood pressure and administration of fluids or drugs. The trachea was intubated, and respiration was maintained artificially with an animal ventilator (model CIV-101; Columbus Instruments, Columbus, OH). Arterial blood pressure was measured with a pressure transducer and monitored on a thermal sensitive recorder. The trachea was intubated, and respiration was maintained artificially with an animal ventilator (model CIV-101; Columbus Instruments, Columbus, OH). Arterial blood pressure was measured with a pressure transducer and monitored on a thermal sensitive recorder.

The regional blood flow values (ml·g⁻¹·min⁻¹) were determined by the following equation:

\[ Q_m = \frac{(C_m \times Q_c \times V_c)}{Cr} \]

where \( Q_m \) is regional blood flow, \( C_m \) is microsphere count per gram of tissue, \( Q_c \) is withdrawal rate of the reference blood sample, and \( C_r \) is microsphere count in the reference blood sample. Tissue blood flows from the right and left kidneys were compared to ensure even distribution of the microspheres in each animal. Two to three pieces of tissues from each organ were used for microsphere counting, and the values were averaged.

In separate cats, sympathetic efferent nerve activity was recorded from the central cut end of the left splanchnic, inferior cardiac, and tribial nerves in cats anesthetized as described above. Previous studies have demonstrated that these nerves innervate splanchnic viscera, heart, and the skin and skeletal muscle in the hindlimb (14, 17, 18, 26). Briefly, the target nerve was isolated from the surrounding tissues under a surgical microscope and immersed in warm mineral oil. Small nerve filaments containing a few active units were attached to a stainless steel electrode. The nerve-discharge activity was amplified and filtered (bandwidths of 100 and 1,000 Hz) with an alternating current amplifier and processed through an audioamplifier (PS11 and AM8; Grass Instruments, W. Warwick, RI) and displayed on an oscilloscope. The nervegram and blood pressure were simultaneously monitored on a recorder (model K2G, Astro-Med). Nerve activity was fed into a Pentium computer through an analog-to-digital interface card for subsequent offline quantitative analysis. Discharge frequency was quantified by a software window discriminator by setting an amplitude threshold for all the recorded action potentials of nerve fibers (Experimental Workbench, DataWave Technology, Longmont, CO).

Experimental Protocols

Reflex-induced blood flow redistribution in different vascular beds. Eleven animals were used for this protocol. The animals were allowed to stabilize for 60 min after surgical preparations, and the arterial blood gases were measured and corrected, if necessary. Abdominal visceral afferents were activated by application of 10 μg/ml of bradykinin on the gallbladder (20, 31). Bradykinin was applied by placing a
1-cm² Whatman filter paper soaked with the bradykinin solution on the surface of the gallbladder. After the maximum pressor reflex was attained (typically 1–2 min), the filter paper was removed and the gallbladder was washed twice with normal saline using cotton-tipped applicators. Our previous studies have shown that bradykinin is produced during mesenteric ischemia and contributes to activation of sympathetic visceral afferents during abdominal ischemia (32). The blood flows of different vascular beds were randomly measured in pairs because only blood flows from two vessels could be examined at the same time using the dual-channel flow meter. Thirty minutes were allowed after repositioning flow probes before repeat bradykinin application. During control and the pressor response to afferent activation, the blood flow and arterial blood pressure were continuously monitored and recorded into a Pentium computer using WinDaq data-acquisition and analysis software (Dataq Instruments, Akron, OH). In 4 of 11 animals, reproducibility of cardiovascular responses and the blood flow change in the celiac artery was examined by washing off the bradykinin, waiting 30 min for recovery, then reapplying the bradykinin solution. This interval is sufficient to prevent tachyphylaxis (20, 31). In the remaining seven animals, the pressor response and the celiac blood flow were measured again after ganglionic blockade produced by intravenous injection of 10 mg/kg of hexamethonium (Sigma Chemicals, St. Louis, MO).

**Tissue blood flow changes caused by afferent stimulation.** A total of 12 animals was used. The animals were first allowed to stabilize for 60 min. Cardiovascular reflexes were induced by electrical stimulation of the central cut end of the right splanchnic nerve, which contains a major portion of afferent fibers innervating the upper abdominal viscera (17). The nerve was electrically stimulated (0.5 ms and 30 V, S48 Stimulator; Grass Instruments), and the frequency of stimulation was adjusted so that the magnitude of the pressor response produced was similar to that obtained with bradykinin application, as we described previously (33). This approach was used because, unlike bradykinin-induced short-lasting hemodynamic responses, the pressor response can be maintained constant for at least 2–2.5 min during the entire period of microsphere injection and withdrawal of reference blood samples. The colored microspheres were injected during control and the pressor response elicited by electrical stimulation of the central cut end of the right splanchnic nerve. The pressor response was repeated again 30 min later to ensure reproducibility of changes in tissue blood flows in 8 of 12 animals. To minimize the effect of blood loss on the organ blood flow, an equal volume of blood was transfused from a donor cat after withdrawal of each blood reference sample.

**Reflex-induced regional sympathetic outflow.** A total of 11 animals was used for electrophysiological recording of sympathetic nerve activity. On the basis of the blood flow experiments, three representative nerves, the splanchic, inferior cardiac, and tibial nerves, were selected to examine the sympathetic outflow to the splanchic region, heart, and the skin and skeletal muscle of the hindlimb. After spontaneous discharge activity was recorded, we first tested the nerve response to increase in blood pressure (220–250 mmHg) by briefly constricting the descending thoracic aorta. The nerve was selected for further study only if its activity was attenuated at least 50% by activation of baroreceptors (6, 14, 26). The nerve response to topical application of 10 µg/ml of bradykinin on the gallbladder was tested after a stabilization period of 15–20 min. Each nerve response was tested two times to ensure the reproducibility. In each animal, two of the above three nerves were randomly recorded. In some animals, a ganglionic blocker, hexamethonium (10 mg/kg), was injected intravenously to ensure that the recorded nerve was postganglionic efferent nerve.

Data were expressed as means ± SE. The discharge activity of efferent nerves was averaged for 1 min during control and the peak response to bradykinin application. Due to the variability of nerve activity in each animal, the nerve-discharge activity was normalized and presented as percent changes, based on the control baseline activity. The flow data over 10 s immediately before bradykinin application were averaged as the baseline control. To calculate the peak changes in vascular resistance, the blood flow and mean arterial pressure (MAP) were averaged over 10 s during the reflex response, when the greatest increases occurred. Indexes of vascular resistance in the individual vessels were calculated as the quotient of MAP and the respective arterial blood flow. Comparisons between control and experimental interventions were made by either a paired Student's t-test or a repeated-measures ANOVA followed by Dunnett's post hoc test. Differences were considered to be statistically significant when P < 0.05.

**RESULTS**

**Hemodynamic profiles.** The mean arterial blood pressure and heart rate in all animals studied during control were 86 ± 9 mmHg and 136 ± 8 beats/min, respectively. Topical application of 10 µg/ml of bradykinin to the gallbladder in 11 animals increased significantly the mean blood pressure from 84 ± 15 to 145 ± 22 mmHg and the heart rate from 135 ± 8 to 147 ± 11 beats/min (P < 0.05). Electrical stimulation of the central cut end of the right splanchnic nerve also elicited a significant increase in the blood pressure from 82 ± 6 to 144 ± 18 mmHg and the heart rate from 138 ± 8 to 150 ± 11 beats/min (P < 0.05, n = 12), which were similar to those observed with bradykinin. The frequency of electrical stimulation applied to the right splanchnic nerve was 4.2 ± 0.8 Hz.

**Changes in organ blood flows and vascular resistances evoked by afferent activation.** Topical application of 10 µg/ml of bradykinin to the gallbladder decreased significantly the blood flows in the celiac, renal, and superior and inferior mesenteric arteries (Figs. 1 and 2). By contrast, the coronary arterial blood flow and the portal vein flow were increased significantly after bradykinin application (Figs. 2 and 3). The blood flow in the femoral artery was also increased during this reflex response (Figs. 2 and 3). The peak changes in the resistance for the above vascular beds are shown in Fig. 2B. By examining the timing of the peak responses of blood pressure and splanchnic flows after afferent activation, we observed that maximal reduction of blood flows in celiac and superior mesenteric arteries occurred 16–22 s before the peak increase in the blood pressure (Fig. 1). Maximal increase in the coronary blood flow, on the other hand, occurred 34–42 s after the peak increase in the blood pressure (Fig. 3). The reflex-induced pressor responses and flow changes in the celiac artery, caused by three-time repeated applications of bradykinin on the gallbladder, separated by 30 min, were reproducible (Fig. 4A). Ganglionic blockade with hexamethonium abolished the pres-
Fig. 1. Original records showing the time course of changes in the arterial blood pressure and blood flows in the celiac artery and portal vein caused by topical application of bradykinin to the gallbladder in 1 animal.

Fig. 2. A: alterations in the blood flow in the portal vein and celiac, renal, coronary, superior (S), and inferior (I) mesenteric arteries during the pressor response to topical application of bradykinin to the gallbladder. B: peak changes in the resistance in the above vascular beds during the pressor response compared with the baseline control (0). Data presented as means ± SE (n = 11). *P < 0.05 compared with control.
sor response and the reflex-evoked changes in the blood flow of the celiac artery (Fig. 4B).

Alterations of tissue blood flows induced by afferent stimulation. Electrical stimulation of the right splanchnic nerve decreased significantly tissue blood flows in the splanchnic organs. Blood flows in the splanchnic viscera were reduced from 68% (jejunum) to 96% (spleen) after stimulation of the central cut end of the right splanchnic nerve, compared with the respective controls (Fig. 5). The magnitude of reduction of blood flow in splanchnic viscera was identical in eight animals in which nerve stimulation was repeated (data not

Fig. 4. Changes in blood flow of the celiac artery induced by topical application of bradykinin on the gallbladder. A: celiac arterial blood flow during repeat application of bradykinin (n = 4). B: changes in celiac arterial blood flow before and after treatment with hexamethonium (n = 7). Data presented as means ± SE. *P < 0.05 compared with control.

Fig. 5. Tissue blood flow changes in splanchnic viscera in response to electrical stimulation of the central cut end of the right splanchnic nerve. Data presented as means ± SE (n = 12). *P < 0.05 compared with control.
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![](image.png)

**Fig. 6.** Tissue blood flow changes in the kidney, myocardium, adre-
nal gland, skin, and skeletal muscles in response to electrical stim-
ulation of the central cut end of the right splanchnic nerve. Data
presented as means ± SE (n = 12). *P < 0.05 compared with control.

shown). Similar to the changes of the coronary blood
flow, the myocardial tissue flow also was increased
significantly by splanchnic nerve stimulation (Fig. 6).
Compared with the baseline controls, the blood flows in
the adrenal glands and skin were not altered signifi-
cantly, whereas the blood flow in the skin and skeletal
muscle was only increased slightly after stimulation of
abdominal visceral afferents (Fig. 6).

**Regional sympathetic outflows induced by afferent stimulation.** Topical application of 10 μg/ml of brady-
kinin onto the gallbladder increased significantly the
sympathetic outflow in the splanchnic nerve (182 ±
44%, n = 8, Figs. 7 and 8). Intravenous injection of 10
mg/kg of hexamethonium abolished the response of the
splanchnic nerve to bradykinin application in six of
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importantly, we have provided new electrophysiologi-
evidence that stimulation of abdominal visceral afferents induces differential responses of regional sympathetic nerve activity, indicating that a selective
increase in sympathetic output to the splanchnic bed is essential for this visceral-cardiovascular reflex.

In the present study, we measured initially regional
tissue and organ blood flows to examine the extent of
blood flow redistribution evoked by stimulation of ab-
dominal visceral afferents. Two methods were com-
bined to quantify the changes in regional blood flows.
The microsphere technique is most suitable for this
experiment because it can simultaneously measure
blood flow changes in many different tissues. However,
one limitation of this method is that it is not possible to
continuously monitor the time course of flow changes.
Thus, as a complementary approach, the Transonic
flow meter system was used to provide a continuous
monitoring of arterial flows in several important re-
ions. This study provides substantial evidence that
vasoconstriction of the splanchic bed and, to a lesser
extent, the renal vascular bed is involved primarily in
blood flow redistribution caused by stimulation of vis-
ceral afferents. Data obtained with the microsphere

tique indicate that even within the splanchic region, the magnitude of reflex-evoked flow reduction
is not identical in different visceral organs. This new
information suggests that blood flows to some splanch-
ic viscera (e.g., spleen, pancreas, and stomach) are
more susceptible to increased sympathetic outflow
evoked by stimulation of visceral afferents, although
species differences of neural control of circulation
should be recognized.

The vasculature in the skin and skeletal muscles is
actively involved in thermal regulation and cardio-
vascular adjustments during exercise (8, 29). We
found that the peak femoral blood flow was signifi-
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![Fig. 7. Original recordings showing the discharge activity of the
splanchnic (A), inferior cardiac (B), and tibial (C) nerves during
control and responses to bradykinin (BK) application to the gallblad-
er.](image.png)
dominal visceral afferents. This observation suggests that sympathetic innervation of these somatic vascular beds is not responsible for the cardiovascular reflex originated from abdominal viscera. A lack of significant increase in blood flow to the skin and skeletal muscle during this reflex could be due to the limitation of the microsphere technique. In this regard, the blood flow to these tissues is very low, and alteration of blood flows elicited by this reflex is transient, which might prevent accurate counting of microspheres deposited in the tissue after single injection of microspheres. As to the coronary blood flow, we found no evidence of reflex vasoconstriction of the coronary vessel after stimulation of visceral afferents. Unlike what was reported previously (23), we observed that the coronary flow increased consistently in all animals studied after stimulation of abdominal visceral afferents. Because a decrease in splanchnic blood flow preceded the increase in myocardial blood flow, we believe that an increase in the myocardial blood flow is secondary to increased myocardial oxygen demand due to a substantial increase in blood pressure caused by blood redistribution. In fact, the cardiac responses (increases in heart rate and cardiac contractility) after stimulation of visceral afferents are likely due to the blood redistribution initiated by constriction of the splanchnic bed and increased circulating catecholamines released from the adrenal gland. Consistent with this notion, it has been shown that the enhanced cardiac output caused by activation of $\alpha_1$-adrenergic receptors with phenylephrine is due entirely to the decrease in splanchnic intravascular volume, because cardiac output does not increase after the splanchnic vasculature has been removed (37). Thus the decreased splanchnic volume leads to an increased cardiac output through an increase in preload (37). Additionally, surgical removal of the adrenal glands or treatment with $\alpha$-adrenergic receptor antagonists diminishes the increased cardiac contractility associated with the cardiovascular reflex elicited by stimulation of gastric afferents (22), which further supports the notion that an increase in the heart rate and cardiac contractility after stimulation of abdominal visceral afferents is a secondary effect of strong activation of the splanchnic sympathetic nerve. By simultaneously measuring the blood pressure and regional blood flows, we were able to determine the sequence of changes in the hemodynamics and regional vascular reactivity after stimulation of visceral afferents. We demonstrated that stimulation of abdominal visceral afferents predominantly reduced splanchnic blood flow, which induced a blood redistribution leading to an increase in the blood pressure. The sympathetic reflex nature of the blood flow changes evoked by afferent stimulation was documented in the present study that treatment with a ganglionic blocker, hexamethonium, abolished the changes in the blood pressure as well as regional blood flows induced by activation of visceral afferents. We also have shown previously that surgical removal of the celiac and mesenteric ganglia eliminates the reflex cardiovascular responses to mesenteric ischemia (34), further indicating the importance of the splanchnic sympathetic innervation in cardiovascular reflexes originated from abdominal viscera.

The capacitance function of the venous system is critical for the regulation of regional and circulatory blood volume (10). Splanchnic veins, which contain 25% of the total blood volume, are richly supplied with sympathetic nerves (36). The $\alpha_1$-adrenergic mediated decrease in splanchnic volume is due to active constriction of both splanchnic resistance and capacitance vasculatures (30). With the use of the radio-nuclide imaging technique, it has been demonstrated that stimulation of $\alpha_1$-adrenergic receptors with phenylephrine causes a dramatic decrease in splanchnic volume, which acts to increase cardiac output (4). The splanchnic bed accounts for almost all of the reflex capacitance response that buffers systemic circulatory volume changes associated with activation of $\alpha_1$-adrenergic receptors (11). We have shown previously that complete occlusion of the celiac and superior and inferior mesenteric arteries can only slightly elevate the blood pressure (34). Thus the profound hemodynamic response induced by visceral afferent activation cannot be explained fully by constriction of the splanchnic resistance vessels. In the current study, the importance of splanchnic capacitance vessels in this reflex was examined indirectly by measuring the blood flow in the portal vein draining the splanchnic bed. We
observed a substantial and persistent increase in the portal vein blood flow after stimulation of abdominal visceral afferents, strongly indicating an intense constriction of the splanchnic veins. Therefore, the splanchnic capacitance vessels likely play a key role in initiation of blood redistribution and the cardiovascular reflex responses to activation of visceral afferents.

It should be acknowledged that the local blood flow response is a combination of autoregulation and neural influences, and measurement of blood flow does not reflect accurately changes in the regional sympathetic outflow. Thus direct recording of the regional sympathetic nerve activity was also performed in the present study. We found that stimulation of abdominal visceral afferents induced a differential increase in regional sympathetic nerve activity. Although stimulation of visceral afferents evoked a profound increase in the splanchnic sympathetic activity, the sympathetic outflow to the somatic structures was little influenced. These nerve recording data are consistent with the changes in estimated vascular resistance for the splanchnic and femoral arteries. Also, the lack of increase in sympathetic efferent outflow to the heart is consistent with the concept that the coronary blood flow is largely influenced by autoregulation, and no sympathetic constriction of coronary arteries was evident in this reflex response. Interestingly, we observed that although the coronary vascular resistance was reduced significantly during this reflex, the efferent nerve activity recorded from the inferior cardiac nerve did not change. Therefore, it is inadequate to predict the sympathetic outflow based on the measurement of regional blood flow or vascular resistance. Accumulating evidence on regionally diverse changes of sympathetic activity has considerably modified the classic concept that the sympathetic nervous system responds in a massive and generalized manner. It has been increasingly appreciated that the regional diversity or differentiation of the sympathetic outflow to the peripheral effectors plays an important role in various integrative physiological responses (35, 38, 39). By comparing spillover of norepinephrine to the portal vein and arterial and hepatic sites as an index of sympathetic outflow, Aneman et al. (1) found that a major proportion of sympathetic outflow is directed to mesenteric organs in patients undergoing abdominal surgery. The diverse responses of the sympathetic nervous system also have been revealed by the studies on the recording of whole nerve and single-unit activity of sympathetic efferent nerves in anesthetized animals (2, 14, 15). A differential response of sympathetic efferent nerves innervating the mesenteric organs and somatic structures to stimulation of baroreceptors has been demonstrated previously (26). Furthermore, stimulation of intestinal mechanoreceptors or chemoreceptors is found to excite mesenteric nerve activity more than renal nerve activity (39).

In summary, the present study demonstrates that stimulation of abdominal visceral afferents causes predominantly vasoconstriction of the splanchnic vascular bed, leading to a substantial decrease in the splanchnic blood flow and reservoir volume. Furthermore, differential increase in the sympathetic outflow to the splanchnic viscera, but not to the heart and somatic tissues, is largely responsible for the blood flow redistribution in responses to stimulation of abdominal visceral afferents. Thus the primary (splanchnic bed constriction) and secondary (effect of catecholamines on the myocardium) effects of strong adrenergic activation of splanchnic sympathetic activity are critical mechanisms of excitatory hemodynamic responses to stimulation of abdominal visceral afferents. On one hand, increased sympathetic outflow to the splanchnic bed causes profound vaso- and venoconstriction. The substantial increase in blood pressure is primarily due to an increase in the splanchnic vascular resistance and an increase in cardiac preload resulting from the decreased splanchnic volume. On the other hand, increased splanchnic sympathetic activity to the adrenal gland could elicit massive release of catecholamines into the general circulation, which, in turn, increase the cardiac contractility and heart rate.

Perspectives

The current study should stimulate new interest in the role of sympathetic innervation of splanchnic vasculature in the cardiovascular control during physiological and pathophysiological conditions. Data from the present study cannot directly address the question of why stimulation of abdominal visceral afferents causes selective activation of sympathetic efferent nerves innervating the splanchnic bed. Differential sympathetic outflows may be the result of the complex generation and integration of sympathetic nerve activity both at spinal and supraspinal levels elicited by activation of visceral afferents (2, 3, 25). Previous studies suggest that several subpopulations of vasomotor neurons are present in the medulla area that are associated with the regulation of different vascular beds (5, 24, 25, 28). Thus the differential vascular and sympathetic responses to stimulation of visceral afferents may reflect the specific medullary organization of presympathetic neurons. Further studies are warranted for the neuroanatomic and neurophysiological basis of this differential sympathetic response to stimulation of abdominal visceral afferents in the spinal and supraspinal sites. Additionally, differences in the myogenic response among different vascular beds also need to be investigated because myogenic factors may contribute to the changes in vascular resistance during this pressor response to stimulation of visceral afferents (19).

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