Coronary and visceral vasoactivity associated with eating and digestion in the conscious dog

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VATNER, STEPHEN F., DEAN FRANKLIN, AND ROBERT L. VAN CITTERS. Coronary and visceral vasoactivity associated with eating and digestion in the conscious dog. Am. J. Physiol. 219(5):1380-1385. 1970. The modifications in regional blood flow and vasoactivity in response to eating and digestion were studied in conscious dogs after full recovery from instrumentation with ultrasonic or electromagnetic flow probes on the ascending aorta, left circumflex coronary, mesenteric, renal and iliac arteries, and miniature pressure gauges in the aorta. The presentation and ingestion of food by the resting conscious dog caused cardiac output (62%), arterial pressure (33%), heart rate (79%), mesenteric resistance (48%), and renal resistance (24%) to increase transiently while iliac (33%) and coronary (62%) resistance decreased transiently. Mesenteric flow began to increase within 5 min after eating and reached a peak of 139% above control within 30-90 min (av 55 min) and gradually returned to preprandial control levels over the next 2-6 hr. Iliac flow was decreased slightly (10%) 30-60 min postprandially as long as the dog did not walk about. Within 10-30 min renal and coronary flow and resistance returned to preprandial control levels and remained there during peak mesenteric vasodilatation.

mesenteric blood flow; coronary blood flow; cardiac output; renal blood flow; blood pressure; food intake; iliac blood flow

“THOSE WHO ARE AFFLICTED with it are seized, while they are walking, and more particularly when they walk soon after eating, with a painful and most disagreeable sensation in the breast” (14). This description of angina pectoris, delivered by Heberden in 1786 to the Royal College of Physicians, marks the beginning of clinical interest in the relationship of cardiovascular pathophysiology to eating and digestion. This interest gained momentum from Sir William Osler when he alluded to the three major causes of angina as “muscular exertion, mental emotion, and digestive disturbances” (18). Cardiovascular research in this field has concentrated on three aspects of the effects of eating and digestion: the effects on the mesenteric circulation; the effects on cardiac output, blood pressure, and heart rate; and the effects on regional blood flow distribution with special emphasis on the effects on the coronary circulation.

Direct measurements in other laboratories (3, 8) and in ours (25) have shown that eating significantly increases mesenteric flow (up to threefold) and decreases mesenteric resistance in the postprandial period in conscious dogs. Earlier work on humans has indicated that the increase in mesenteric flow was accompanied by 30-50% increases in cardiac output in the postprandial period (4, 12, 13, 19, 23). This view was reinforced by animal experiments that showed similar increases in blood flow to all circulatory beds as well as the mesenteric (15, 20). Recently these views have been questioned as a result of measurements made in conscious dogs with ultrasonic and electromagnetic flowmeters. These studies have demonstrated that cardiac output remained at control levels (3, 8, 25) during the postprandial period and that limb flow actually decreased (8).

Less information is available as to the effects of a meal on the coronary circulation. Animal experiments have indicated that increases in coronary flow paralleled those in the gut, muscle, and kidney (5). In contrast, other evidence indicated that gastric distension caused reflex coronary constriction in dogs and man (10, 11, 17). This view was supported by electrocardiographic signs of coronary insufficiency after meals (2, 9, 16, 22).

The purpose of the present paper is to examine the effects of eating and digestion on the regional circulations, especially the coronary, with the goal of resolving some of these problems. Specifically, answers are being sought to the questions of 1) whether an increase in mesenteric flow is associated with a general increase in flow to all circulatory beds with consequent increases in cardiac output, and 2) whether coronary vessels constrict in response to eating or dilate as a result of the increased left ventricular work and increased myocardial oxygen requirements.

METHODS

Experiments were conducted on 24 mongrel dogs (25-43 kg). Blood flow transducers and blood pressure gauges were implanted during sterile surgery with Nembutal anesthesia (30 mg/kg). Flow transducers were placed on the ascending aorta (12 dogs), the left circumflex coronary artery (10 dogs), the cranial mesenteric artery (20 dogs), left renal artery (8 dogs), and left iliac artery (12 dogs). Pulsed ultrasonic flowmeters (6) were used in 10 dogs, Doppler ultrasonic telemetry flowmeters (7) in 10 dogs, and Zepeda 400-cycle square-wave electromagnetic flowmeters in 4 dogs (21). The Doppler device enabled telemetry of blood flow and pressure from animals outside the laboratory. Volume calibrations, performed with beaker and stopwatch
in six representative animals, verified accuracy and linearity of the flowmeters. Aortic blood pressure was measured with miniature solid-state gauges chronically implanted in the thoracic or abdominal aorta (24). These gauges were calibrated in vivo against a Statham P23Db strain gauge manometer. In some dogs, aortic blood pressure was sampled through a catheter placed in the aorta through the femoral artery and measured with a Statham P23 db strain-gauge manometer.

Mean aortic pressure and mean blood flow were derived by electronic R-C filters with a 3-sec time constant. Vascular resistance was calculated as the quotient of mean aortic blood pressure and mean arterial blood flow. Changes in resistance, flow, and pressure are expressed as percentage of change from resting control values. A Beckman cardiotechometer (type 9851 B) triggered by the electrical signal from aortic pressure, provided instantaneous and continuous records of heart rate. Data were recorded on a Sanborn strip-chart recorder (no. 358-100) and on a Sanborn magnetic tape recorder (no. 3907 A).

The experiments were conducted 1–4 weeks postoperatively. During the recovery period, the dogs were fed in the laboratory to condition them to the experimental environment. On the day of the experiment care was taken that the dog did not see food prior to the experiment. After standing and reclining control values were obtained, the dogs were fed according to their taste and appetite: meat-flavored dog food, condensed milk, horse meat and gravy, raw or cooked hamburger, dry dog food, and in one case beef fat. Noise and movement were kept to a minimum after eating. The untethered dogs were free to roam about, but would generally lie quietly or sleep in their doghouse after eating. All dogs were monitored for at least 2 hr postprandially and six were monitored for 7 hr.

RESULTS

Cardiac output, blood pressure, and heart rate. Transient increases in cardiac output (62 ± 6% se) arterial blood pressure (33 ± 4%) and heart rate (79 ± 7%) occurred with the presentation and ingestion of food (Fig. 1). These increases reached a maximum while the dog ate. Control levels were gradually regained within 10–30 min and remained there as long as the animals continued to rest up to 7 hr postprandially.

Mesenteric bed. Mesenteric blood flow initially and transiently decreased (10 ± 2%) during presentation and ingestion, but quickly returned to control levels while the dog continued to eat. Within 2–5 min mesenteric flow began to increase, gradually reaching a maximum (15–200% above control) 30–90 min (average: 55 min) postprandially. Over the next several hours (up to 7 hr after eating), mesenteric flow gradually returned to control levels. The average and extreme changes in calculated mesenteric resistance are shown in Fig. 1, whereas a typical mesenteric flow response is shown in Fig. 2.

Iliac bed. During the anticipation-ingestion phase iliac flow increased, resulting in a dilatation, i.e., calculated resistance decreased by an average of 33 ± 4% from resting control. However, after the animals had eaten and once again rested, iliac flow quickly returned to control levels, and 30–60 min postprandially slight constriction was evident (+10 ± 2% in calculated resistance). However, if the animal arose or changed position, iliac resistance would decrease well below control. The variability in calculated resistance is shown in Fig. 1; Fig. 2 shows a typical example.

Renal bed. The anticipation-ingestion phase was characterized by a transient increase in calculated resistance (24 ± 3%) which gradually disappeared over the next 10–30 min. Postprandial changes in renal flow paralleled changes in aortic pressure, resulting in no change in calculated resistance. Figure 1 shows average results of calculated resistance, whereas Fig. 2 shows a typical example.

Coronary bed. Left circumflex coronary flow uniformly increased during the anticipation-ingestion phase and returned to control levels within 15–30 min. The most marked increase in coronary flow and decreases in calculated resistance (62 ± 5%) occurred within 30 sec of eating. The decrease in resistance averaged 30% in the 1st minute of eating and gradually returned to control levels ±10% within 10–30 min postprandially, remaining unchanged as long as the animal rested. At no time did a sustained constriction occur in this bed. The average and extreme changes in calculated resistance are seen in Fig. 3; a typical response is shown in Fig. 4.

DISCUSSION

The anticipation and ingestion of food caused profound changes in the circulation of the conscious dog. The abrupt increases in cardiac output, heart rate, and arterial pressure are consistent with activation of the sympathetic nervous system, and we have previously shown that the anticipation-ingestion phase is modified by sympathetic blockade (25). These changes were associated with changes in all
vascular beds studied. Resistance to hindlimb and coronary circulation decreased, whereas resistance to the mesenteric and renal circulations increased. After alpha-adrenergic blockade with phenoxybenzamine, the increases in arterial pressure and resistance in the mesenteric and renal beds during the anticipation-ingestion phase were not observed; yet the postprandial mesenteric vasodilatation was still evident (see Fig. 5).

Postprandial circulatory adjustments were much less dramatic, but more protracted. Peak response in the conscious dog occurred 50-60 min after eating when heart rate, arterial pressure, and cardiac output were at preprandial resting control values. The mesenteric vascular response was the most apparent in that flow increased to the gut up to threefold and gradually returned to control levels within 3-7 hr after eating. During peak mesenteric dilatation renal and coronary resistance were at control levels, whereas iliac resistance was slightly elevated (10%). Iliac constriction quickly disappeared when the animal walked or changed position.

It is generally accepted that mesenteric blood flow increases after meals and the calculated resistance of that bed decreases (3, 8, 15, 20, 25). We have previously shown that this dilatation is neither sympathetically nor vagally mediated but can be blocked with atropine, suggesting a nonvagal cholinergic pathway (25). We have also previously shown that an attenuated mesenteric vascular response occurs when fasted, muzzled dogs were presented food but were unable to eat (25).

Until recently, it has been generally accepted that cardiac output increased 30-50% during the resting postprandial period. This concept was largely based on the acetylene or ballistocardiogram method of measuring...
Fig. 4. Phasic and mean arterial pressure and left circumflex coronary blood flow are shown in a typical response of a conscious dog to eating a meal.

Fig. 5. A: challenge dose of norepinephrine, 1 μg/kg, illustrating increased pressure and resistance in mesenteric and renal beds. B: feeding response after alpha-adrenergic blockade, phenoxybenzamine 15 mg/kg, showing reversal of pressure and mesenteric and renal resistance responses to eating, followed by mesenteric vasodilatation. C: challenge dose of norepinephrine, 1 μg/kg, 2 hr later illustrating adequate alpha blockade.
cardiac output in man (4, 12, 13, 19, 23). The concept was reinforced by measurements of regional flow in man, dogs, and rats showing increased blood flow to limbs, kidney, brain, and heart as well as to the mesenteric circulation (1, 3, 15, 20). These studies indicated that cardiac output must double to account for increases in flow to all beds. In contrast, we have found that renal and coronary flow remain constant in the postprandial period, whereas iliac flow decreases slightly. Furthermore, we did not observe any sustained coronary constriction during the postprandial period of mesenteric vasodilatation. This is in agreement with more recent work of Burns (3) and Fronek (8), who measured mesenteric flow and cardiac output with electromagnetic flowmeters in conscious dogs.

Thus, the increased flow to the gut after meals could be compensated for partly by a decrease in flow in the inactive muscle bed. However, this mechanism was apparent only in the resting or sleeping dog and not in the ambulating animal in which the muscle bed was always observed to be dilated. Small changes in cardiac output (less than 5–10%) could be missed due to the error involved in measuring aortic root flow with either the electromagnetic or ultrasonic flowmeter. However, 30–50% increases in cardiac output as reported earlier would not be missed and were not found.

Despite much clinical speculation about coronary constriction after meals, coronary flow has been measured in the conscious animal after feeding in only one previous study, in which left circumflex coronary flow was found to be increased 55–127% postprandially (5). This corresponded to the postprandial increases in flow to other beds studied (19). We have found that flow increases only transiently during the anticipation- ingestion phase and that coronary flow returns to control levels along with blood pressure, heart rate, and cardiac output. At no time did we observe any sustained coronary constriction during the prolonged period of mesenteric vasodilatation.

Blood pressure, heart rate, and cardiac output increased in the anticipation- ingestion phase, resulting in increased myocardial oxygen requirements. In normal dogs the increased oxygen requirements are met by an increase in coronary blood flow and a calculated dilatation in that bed. Although extrapolation from normal dogs to diseased man is hazardous, inability of the coronary circulation to meet the increased metabolic demands, as in coronary artery disease, could result in coronary insufficiency.

SUMMARY

Circulatory adjustments in the resting conscious dog to a meal consist of two phases: a brief anticipation- ingestion phase and a more prolonged digestive phase. The anticipation- ingestion phase was characterized by increases in cardiac output, heart rate, and arterial pressure. Resistance transiently increased in the renal and mesenteric beds and decreased in the iliac and coronary beds. Mesenteric blood flow began to increase above preprandial control within 5 min of eating and reached a peak 30–90 min postprandially and gradually returned to control levels 2–6 hr postprandially. During peak mesenteric vasodilatation, renal and coronary flow were at preprandial control levels while iliac flow had decreased slightly. Iliac flow remained below control only if the animal did not change position or walk about.

During the digestive phase in the resting dog a slight compensatory vasodilatation occurred in the inactive muscle bed. This mechanism was not observed in ambulatory dogs. Although increases in cardiac output of less than 5% could not be excluded, previously reported increases in cardiac output of 30–200% during the postprandial period did not occur.

No evidence was found for redistribution of blood flow from the coronary circulation to the mesenteric or for reflex vasoconstriction. The increases in coronary flow could be associated with the increased metabolic demands of the heart resulting from increased arterial pressure, cardiac output, heart rate, and left ventricular work.

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