

Effect of moderate exercise on salt and water transport in the human jejunum

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SUMMARY The effect of moderate exercise on jejunal absorption was examined in seven healthy subjects using a triple lumen perfusion technique. Moderate exercise on a bicycle ergometer significantly reduced net absorption of water from 32.0 (4.0) to 16.2 (6.1) ml/30 cm/50 min ($p < 0.02$), sodium from 2.4 (0.4) to 0.5 (0.9) mmol/30 cm/50 min ($p < 0.05$), chloride from 2.0 (0.4) to 0.3 (0.7) mmol/30 cm/50 min ($p < 0.05$), and potassium from 0.20 (0.02) to 0.01 (0.04) mmol/30 cm/50 min ($p < 0.01$). After exercise, water, sodium, and chloride absorption returned towards basal values, but potassium absorption remained significantly decreased. These results suggest that moderate exercise can influence jejunal absorption of salt and water in man. They support the possibility that the autonomic nervous system has a physiological role in the control of intestinal transport, although other mechanisms may be involved.

Although there is considerable evidence in animals and man, to suggest that the autonomic nervous system may influence intestinal absorption¹⁻¹⁶ most studies have used nerve stimulation, nerve resection, or pharmacological agents rather than physiological stimuli. Some studies have recently shown changes in absorption in response to such stimuli. Reduction of circulating volume increased human jejunal absorption¹⁷ while sham feeding¹⁸ and psychological¹⁶ or physical stress¹⁹ reduced absorption. The response to psychological stress was probably mediated through the parasympathetic nervous system as it was blocked by atropine.¹⁶ We have extended these observations to study the effect of moderate exercise on intestinal transport in human volunteers.

Methods

SUBJECTS

Experiments were carried out on seven healthy volunteers (five women, two men) aged between 20 and 29 years all of whom had given their informed consent, and for which the Ethical Committee of the Salford Health Authority had given permission. The subjects were physically active but none were in regular physical training.

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MEASUREMENT OF JEJUNAL TRANSPORT

Jejunal absorption was measured using a triple lumen perfusion technique.²⁰ After an overnight fast subjects were intubated with a triple lumen perfusion tube which incorporated a 10 cm mixing segment and a 30 cm test segment. Each aspiration lumen had an internal diameter of 1.5 mm. Once positioned with the infusion port distal to the duodenojejunal flexure, the jejunum was perfused at 10 ml/min using a peristaltic pump. The perfusate contained Na, 136; Cl, 105; K, 5; SO₄, 18 mM; and polyethylene glycol 4000 (5 g/l) with 0.5 μ Ci/l of ¹⁴C polyethylene glycol. Fluid entering the test segment was continuously sampled at 1.4 ml/min using a peristaltic pump, while fluid leaving the test segment was collected by free syphonage. After a 60 minute equilibration period there were three separate collection periods, each lasting 50 minutes, termed the control, exercise, and recovery periods. In all studies proximal aspirates were at least 88% of that expected (1.4 ml \times 50) and recovery by syphonage from the distal port was at least 50% of the fluid passing this port. Collections from the proximal port started and finished five minutes after those from the distal port in each period.

STUDY DESIGN

During the middle collection period subjects undertook moderate exercise by pedalling a bicycle ergometer at a constant 15 km/hour (approximately 40

revolutions per minute). The load on the ergometer was initially 0.5 kiloponds but was varied, to adjust for differences in physical fitness between subjects, so that the pulse rate was 40–50% above the mean resting rate, providing this did not induce a marked rise in systolic blood pressure or cause physical exhaustion. During the equilibrium, control, and recovery periods subjects sat upright on a high laboratory chair with their legs dependent.

To minimise stress, the following procedures were instituted. The subjects slowly advanced the perfusion tube into place over three to four hours while resting comfortably on the x-ray screening couch, thereby limiting exercise and distress from the tube. Once the tube was correctly positioned the subjects transferred to an adjacent room. Entry by staff into the room was restricted and 'visitors' were prohibited so that subjects remained physically and mentally rested during the exercise free period. At no time were the subjects able to smell or see food. Subjects who were unable to tolerate the tube were excluded.

ASSESSMENT OF CARDIOVASCULAR CHANGES

Throughout all the three collection periods the subjects' pulse and blood pressure were recorded ever six minutes on their right arm with a Critikon Dinamap 845 vital signs monitor.

ANALYSIS OF JEJUNAL SAMPLES

An LKB Wallac Minibeta liquid scintillation counter was used to determine ^{14}C in jejunal juice. Sodium and potassium concentrations were measured with a Corning 480 flame photometer and chloride with a Corning chloride analyser. Net movements of water and electrolytes were calculated as previously described.²⁰

Results are expressed as the mean and standard error (SE) of the mean and data from the three collection periods were compared by Student's paired *t* test.

Results

All subjects reported that the exercise was not difficult and did not exhaust them.

CARDIOVASCULAR RESPONSE

Exercise caused a significant increase in mean pulse rate but not in blood pressure (Table 1). The increase in pulse rate was noted at the first reading in the exercise period and compared with the equivalent time in the control period remained significantly raised throughout.

NET TRANSMUCOSAL TRANSPORT

Exercise significantly reduced jejunal absorption of

Table 1 Cardiovascular responses to moderate exercise

	Pulse/min	Blood pressure (mmHg)	
		Systolic	Diastolic
Control	67.8 (4.2)	121.7 (4.4)	77.9 (4.1)
Exercise	103.1 (7.1)†	124.2 (5.4)	78.6 (2.0)
Recovery	72.1 (5.4)	118.4 (3.3)	74.0 (3.4)*

* $p < 0.025$; † $p < 0.001$ compared with control period.
Mean values (SE) of blood pressure and pulse rate before (control), during, and after (recovery) exercise ($n = 7$).

Table 2 Jejunal absorption in response to moderate exercise

	Water ml/30 cm/ 50 min	Sodium mmol/30 cm/ 50 min	Chloride mmol/30 cm/ 50 min	Potassium mmol/30 cm/ 50 min
Control	32.0 (4.0)	2.4 (0.4)	2.0 (0.4)	0.20 (0.02)
Exercise	16.2 (6.1)‡	0.5 (0.9)*	0.3 (0.7)*	0.01 (0.04)§
Recovery	23.8 (4.2)	1.8 (0.4)	1.8 (0.4)	0.13 (0.02)†

* $p < 0.05$; † $p < 0.025$; ‡ $p < 0.02$; § $p < 0.01$ compared with control period.

Mean values (SE) of net jejunal water and electrolyte absorption before (control), during, and after (recovery) exercise ($n = 7$).

water, sodium, chloride, and potassium (Table 2). During the recovery period water, Na and Cl absorption returned towards control values but potassium absorption remained significantly decreased. Individual absorption rates are shown in the Figure.

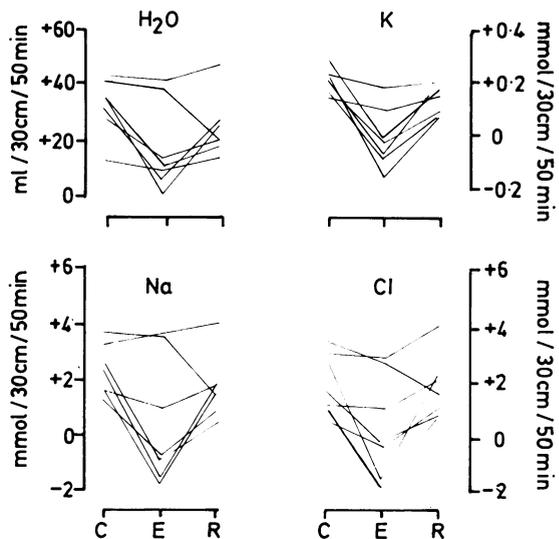


Figure Individual variations in water (H_2O), potassium (K), sodium (Na), and chloride (Cl) absorption in human jejunum before (C), during (E), and after (R) exercise ($n = 7$).

Discussion

Exercise is a known stimulant of the autonomic nervous system and much is known about its effects on cardiac, respiratory, and endocrine function.²¹⁻²⁵ To meet the increased metabolic needs of skeletal muscle during exercise these muscles receive an increased blood flow which is achieved by an increased cardiac output, with an associated increase in heart rate, and by a reduction in blood flow to the splanchnic vasculature.²¹⁻²³ Blood pressure does not increase as much as might be expected, and may even fall, because of a reduction in total peripheral vascular resistance.²² Respiratory rate, pulmonary blood flow, ventilation, total volume, oxygen consumption and carbon dioxide production are also increased.^{21 22 24 25} Multiple humoral mediators circulate in increased amounts during exercise including pituitary hormones, catecholamines and β endorphin, and there is also increased activity of the renin/angiotensin/aldosterone system.²⁵

In comparison, little is known about the effects of exercise on gastrointestinal function, although traditionally it is alleged to have a beneficial effect on constipation but an adverse effect on 'digestion'. Experimental studies have suggested that moderate and severe exercise decrease gastric secretion.²⁶ Severe exercise inhibits gastric emptying,²⁶⁻²⁸ but moderate exercise accelerates gastric emptying^{26 27 29} while having no effect on small intestinal transit.²⁹ Indirect assessment of intestinal absorption, using 3-O-methyl glucose, suggested that moderate exercise reduced absorption³⁰ whereas in the only study directly measuring small intestinal absorption severe exercise was reported to have no effect on the absorption of water, salt or glucose.²⁸ It has been postulated that the different gastrointestinal responses to exercise may be due to a relative predominance of parasympathetic tone during moderate exercise compared with a relative predominance of sympathetic tone during severe exercise.²⁹ We therefore decided to study the effect of moderate exercise, a common 'physiological' stimulus, on jejunal absorption of salt and water using a triple lumen perfusion technique.

To try to ensure a predominant parasympathetic effect on the intestine our subjects pedalled against a smaller load than that previously used for moderate exercise.²⁹ Furthermore, as subjects who are physically fitter have a lower resting pulse rate²² the load was varied so as to increase the pulse rate by 40-50% above the resting value rather than to increase the pulse above an absolute rate, which could result in greater variation between individual's degree of exercise. That our subjects were exercised less than those in other studies of moderate exercise is borne

out by their lower mean pulse rate, achieved without a sustained rise in blood pressure.^{25 29}

This modest degree of exercise significantly reduced jejunal absorption of water, Na, Cl, and K. These results are in contrast with those of Fordtran and Saltin who found no change in small intestinal absorption.²⁸ In their study, however, using a treadmill, subjects carried out severe rather than moderate exercise. In addition, their perfusion solution contained glucose which enhances absorption^{31 32} and could theoretically mask small reductions in absorption. Furthermore, the glucose concentration of the perfusate varied widely between subjects from 55 to 416 mM/l and these differences may have influenced the response.

Previous *in vitro* and *in vivo* studies, in animals and man, suggest that cholinergic agents induce small intestinal secretion¹⁻⁶ while adrenergic agonists enhance absorption.^{4 7-15} Cholinergic and adrenergic binding receptors have also been shown on small intestinal epithelial cells.^{33 34} We have recently reported that stimulation of the central nervous system by psychological stress reduced absorption of salt and water from the human jejunum *in vivo* and that this response was probably mediated through the parasympathetic nervous system since it was blocked by atropine.¹⁶ Therefore the changes observed in this study are compatible with a parasympathetic effect on mucosal transport, although there are several other possible explanations.

First, during exercise, increased sympathetic adrenergic activity produces vasoconstriction of, and reduced blood flow through, the splanchnic vessels^{23 24 35} which could reduce intestinal absorption. Indeed in the dog a decrease in mesenteric flow decreased glucose and xylose absorption.^{30 36} Conversely two other studies have failed to show any alteration in absorption with changes in intestinal blood flow.^{37 38}

Second, one or more of the humoral mediators liberated by exercise may have influenced mucosal transport. Adrenaline, noradrenaline, glucocorticoids, angiotensin, aldosterone, prolactin, and endogenous opiates, however, all of which are raised during exercise, are unlikely to have been responsible for the observed changes in jejunal transport as these enhance rather than reduce absorption.^{7 11 14 39 40} Nevertheless it is possible that exercise liberated some other neuropeptide or induced a paracrine secretion which influenced mucosal transport.

Third, changes in small intestinal motility and transit may have influenced mucosal transport. It is also feasible that changes in muscle 'tone', possibly induced by exercise, may influence the area of mucosa available for absorption. Cammock *et al*, however, reported that moderate exercise had no

effect on small bowel transit time²⁹ and previous small intestinal perfusion studies have failed to show any relationship between motility or transit time and intestinal transport.⁶

Thus it seems likely that the reduction in absorption noted during exercise reported in this study was mediated directly or indirectly *via* the parasympathetic division of the autonomic nervous system, although a reduction in mucosal blood flow, possibly induced by a sympathetic visceral vasoconstriction cannot be excluded.

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