Effect of glucocorticoid treatment on glucose and glutamine metabolism by the small intestine of the rat

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SUMMARY

1. The effect of dexamethasone (30 μg day⁻¹ 100 g⁻¹ body wt.) on the metabolism of glucose and glutamine was studied in the small intestine of rats after 9 days of treatment.

2. Dexamethasone treatment resulted in negative nitrogen balance (P<0.001), and produced increases in the concentrations of plasma glucose (22%, P<0.09), alanine (32%, P<0.001) and insulin (127%, P<0.001), but a decrease in the plasma concentration of glutamine (20%, P<0.05).

3. Portal-drained visceral blood flow increased by approximately 22% (P<0.001) in dexamethasone-treated rats, and was accompanied by a decrease in the arteriovenous concentration difference of glucose (43%, P<0.001) and an increase in that of lactate (22%, P<0.05), glutamine (35%, P<0.01), glutamate (33%, P<0.01) and alanine (21%, P<0.05).

4. Enterocytes isolated from dexamethasone-treated rats showed decreased and increased rates of glucose and glutamine utilization, respectively.

5. The maximal activities of hexokinase, 6-phosphofructokinase, citrate synthase and oxoglutarate dehydrogenase were decreased (30–64%, P<0.001) in intestinal mucosal scrapings of dexamethasone-treated rats, whereas the activity of glutaminase was increased (35%, P<0.001).

6. It is concluded that glucocorticoid administration decreases the rate of glucose utilization but increases that of glutamine (both in vivo and in vitro) by the epithelial cells of the small intestine. This may be caused by changes in the maximal activities of key enzymes in the pathways of glucose and glutamine metabolism in these cells.

Key words: glucocorticoids, glucose, glutamine, metabolism, small intestine.

INTRODUCTION

Catabolic disease states such as trauma, sepsis, major surgery, burns and uncontrolled diabetes are characterized by accelerated muscle proteolysis and translocation of amino acids from the periphery to the visceral organs (for reviews, see [1-3]). Glutamine and alanine account for more than half of the amino acids released by skeletal muscle during stress states and hence are the principal nitrogen carriers from the periphery to the visceral organs [4, 5].

The major site of utilization of glutamine in the non-hepatic splanchnic bed is the mucosa of the small intestine. Most of the energy required by these cells is provided by the oxidation of glucose and glutamine in the fed state and of glutamine and ketone bodies in the starved state (for review, see [5]).

The plasma level of glucocorticoids is increased in sepsis and other stress states [2]. Raising the plasma level artificially by administration of glucocorticoids increases glutamine utilization but decreases glucose utilization by the gut of dogs: this change is accompanied by an increased rate of hepatic gluconeogenesis [6]. Moreover, after laparotomy, the rate of glutamine utilization by the small intestine is elevated despite the fall in the plasma concentration of glutamine and the diminished intestinal blood flow [7].

Recently, it has been shown that thermal injury of rats (33% of body surface area) increases the rate of intestinal glutamine utilization and decreases that of glucose at 3 days after injury [8].

The present work was designed to determine the effects of the administration of glucocorticoids to normal rats on the rates of glutamine and glucose utilization by the small intestine. This has been carried out by measurement of arteriovenous concentration differences across the small intestine, which, together with blood flow data, allow calculation of the rates of utilization of these fuels in vivo. In addition, the rates of glucose and glutamine utili-
zation in isolated incubated enterocytes have been investigated. Finally, maximum activities of key enzymes in the pathways of glucose and glutamine utilization have also been measured. The relevance of these changes to the overall regulation of gut energy metabolism is discussed.

EXPERIMENTAL

Animals

Male Wistar albino rats (210–240 g) were supplied by King Fahd Medical Research Center, College of Medicine and Allied Sciences, King Abdulaziz University, Jeddah, Saudi Arabia. Animals were maintained on a standard diet [commercial rat cubes containing (w/v) approximately 18% protein, 3% fat, 77% carbohydrate and 2% organic salt mixture with a vitamin supplement] (Grain Silos and Flour Mills Organization, Jeddah, Saudi Arabia) and water ad libitum, and were kept in a controlled environment (constant temperature 24°C, and a light cycle of 12 h on/12 h off). Animals were divided into two groups: a control (n = 104) and a dexamethasone-treated (n = 114) group. Rats were treated with dexamethasone (30 µg day⁻¹ 100 g⁻¹ body wt.) by a daily intramuscular injection (200–300 µl) for 9 days under light ether anaesthesia. The amount of dexamethasone injected daily corresponded approximately to the increased amount secreted by the adrenal steroids during a major stress state (see the Discussion section). All rats were housed individually. Body weights, volume of urine and weight of faeces, together with food intakes were recorded daily. Animals were killed by cervical dislocation 24 h after the ninth dexamethasone injection. Control rats were injected with 0.9% (w/v) NaCl (saline).

Chemicals and enzymes

All chemicals and enzymes were obtained from the sources described previously [9, 10]. p-Aminohippuric acid (PAH) was a gift from Mr Omer Saggaff, King Fahd Medical Research Center.

Methods

Nitrogen balance measurements. For the determination of the nitrogen balance of control and dexamethasone-treated rats, animals were placed in metabolic cages that allowed the separate collection of urine and faeces. Urine was collected during 24 h periods (from 08.00 hours to 08.00 hours) in a vessel containing 0.5 ml of concentrated H₂SO₄. The 24 h urine volume was measured and a sample was frozen at −100°C. Faeces were collected at 24 h intervals and weighed. The nitrogen content of urine, faeces and food was determined by the micro-Kjeldahl method [11]. Daily nitrogen input, excretion and balance were determined during the experimental period (i.e. 10 days) for control and dexamethasone-treated rats.

Arteriovenous concentration difference and blood flow measurements. Rats were anaesthetized with ether and blood was withdrawn simultaneously into heparinized syringes from the hepatic-portal vein and the abdominal aorta. Samples (1.0–1.5 ml) were quickly added to 1.0 ml of ice-cold HClO₄ (10%, v/v) and used for determination of concentrations of metabolites after deproteinization and neutralization [see [12]].

Intestinal blood flow was measured by the indicator dilution technique described by Katz & Bergman [13]. PAH, a non-metabolizable dye, was utilized to measure intestinal blood flow by the dye dilution technique. PAH was administered (30 µg min⁻¹ 100 g⁻¹ body wt.) via a tertiary branch of the mesenteric vein. After 30 min equilibration, three consecutive 10 min collection periods were observed, and arterial (abdominal aorta) and venous (portal vein) blood was obtained for measurement of the concentration of PAH. Intestinal blood flow was calculated according to the equation:

\[
\text{Blood flow (ml/min)} = \frac{\text{PAH administered (mg/min)}}{\text{venous [PAH] (mg/ml) – arterial [PAH] (mg/ml)}}
\]

The concentration of PAH was measured in a Somogy filtrate [10% (v/v) barium hydroxide and zine sulphate], treated with p-dimethylaminobenzaldehyde alcohol solution as described previously [14]. Substrate or metabolite net rates of utilization or production were calculated by multiplying intestinal blood flow by the respective substrate or metabolite arteriovenous concentration difference.

Preparation and incubation of enterocytes. Enterocytes were isolated from control or dexamethasone-treated rats using the whole of the small intestine, by a method similar to that described by Watford et al. [15]. Three different preparation media were used: (1) phosphate-buffered saline from which CaCl₂ was omitted (see [10]); (2) the same medium, to which 0.25% (w/v) dialysed bovine serum albumin and 5 mmol/l ethylenediaminetetra-acetate were added; (3) medium (1) to which 2.5% (w/v) dialysed bovine serum albumin was added. Animals were killed by cervical dislocation, and small intestines (from the duodenum to the caecum) were rapidly removed and washed with 100% O₂-saturated medium (1) and isolated small intestine was ligated at one end. To distend the small intestine, it was filled with (25 ml) 100% O₂-saturated medium (2). The other end of the small intestine was then ligated, and the distended small intestine was incubated in a 250 ml conical flask containing 100 ml of 100% O₂-saturated medium (1). Flasks were continuously gassed with 100% O₂ and incubated at 37°C in a Grant-type shaker (at 60–70 oscillations/min) for 20 min. The intestine was opened, drained and washed with ice-cold medium (3). Then it was refilled with medium (3) and patted with the fingertips for 1 min on an ice-block covered with polythene sheet to release cells into the lumen. The lumen was drained into polyethylene tubes and cells were centrifuged at 600 g for 3 min and washed once with approx. 5 vol. of medium (3). Packed cells were suspended in 5 vol. of 100% O₂-saturated medium (3) by drawing them up several times into a 10 ml wide-mouthed
polypropylene pipette. This suspension contained approximately 5–10 mg dry wt. of tissue/ml.

Freshly isolated enterocytes (equivalent to approximately 8–10 mg dry wt.) were incubated for 20 min in a total volume of 1.0 ml of incubation medium. The incubation medium consisted of phosphate-buffered saline that had been 100% O₂-saturated and supplemented with 2.5% (w/v) bovine serum albumin (fatty acid free). Incubations were performed at 37°C in 25 ml polypropylene flasks, gassed with 100% oxygen for 30 s and shaken continuously (60–70 oscillations/min); incubations were initiated by the addition of substrate. Incubations were terminated by the addition of 200 μl of HClO₄ (25%, w/v) to the incubation flask and cooling the mixture to 0°C. Precipitated protein was removed by centrifugation at 13,500 g for 2 min, the supernatant neutralized with KOH containing 0.5 mol/l triethanolamine, and the KClO₄ removed by centrifugation at 13,500 g for 3 min. Neutralized supernatants were kept in liquid N₂ until analysis.

Preparation of homogenates and assay of enzyme activities. Animals were killed by cervical dislocation and the small intestine from the duodenum to the caecum was rapidly removed, washed by forcing ice-cold 0.9% (w/v) NaCl through the lumen and then cut longitudinally. Intestinal mucosa was separated from the underlying muscle by scraping with a microscope slide, weighed and homogenized in 5 vol. of appropriate extraction medium by using a Polytron homogenizer (PCU-2 at position 4) for 10–20 s at 0°C. The whole homogenate was used for enzyme assays without further treatment except for the following: for the assay of citrate synthase, oxoglutarate dehydrogenase and phosphate-dependent glutaminase (hereafter referred to as glutaminase), the homogenate was treated immediately before assay with 0.05% (v/v) Triton X-100. The extraction media for all enzymes studied and the assay of enzyme activities were carried out as previously described [16]. The final volume of assay mixtures in all cases was 1.0 ml. All spectrophotometric measurements were performed in a Beckman DU-6 recording spectrophotometer; the temperature of assay was 25°C except for glutaminase, which was determined at 37°C. For all enzymes studied, preliminary experiments established that extraction and assay procedures were such as to provide maximum enzyme activities [17].

**Glucose and glutamine metabolism in the gut**

Table 1. Body weight, food consumption, small intestine weight and length, and plasma concentrations of glucose, lactate, glutamine, alanine and insulin for control and dexamethasone-treated rats

Values are means ± SEM for 12–14 rats. Dexamethasone-treated rats were used 24 h after the ninth injection of dexamethasone, as described in the Experimental section. Data on food consumption represent food intakes during the last 24 h before killing of the animals. Statistical significance: *P<0.05, **P<0.001, compared with control values.

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Dexamethasone</th>
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<tbody>
<tr>
<td>Initial body weight (g)</td>
<td>229 ± 3.17</td>
<td>234 ± 1.34</td>
</tr>
<tr>
<td>Final body weight (g)</td>
<td>276 ± 3.76</td>
<td>199 ± 1.07**</td>
</tr>
<tr>
<td>Food consumption (g/100 g body wt.)</td>
<td>7.25 ± 0.11</td>
<td>7.22 ± 0.18</td>
</tr>
<tr>
<td>Small intestine length (cm/g)</td>
<td>14.5 ± 0.40</td>
<td>19.22 ± 0.39*</td>
</tr>
<tr>
<td>Small intestine weight (% of body wt.)</td>
<td>2.73 ± 0.09</td>
<td>2.77 ± 0.06</td>
</tr>
<tr>
<td>Plasma glucose (mmol/l)</td>
<td>6.37 ± 0.10</td>
<td>7.22 ± 0.08*</td>
</tr>
<tr>
<td>Plasma lactate (mmol/l)</td>
<td>1.59 ± 0.05</td>
<td>1.83 ± 0.05</td>
</tr>
<tr>
<td>Plasma alanine (mmol/l)</td>
<td>0.59 ± 0.01</td>
<td>0.47 ± 0.01*</td>
</tr>
<tr>
<td>Plasma insulin (μ-units/ml)</td>
<td>0.41 ± 0.02</td>
<td>0.54 ± 0.01**</td>
</tr>
<tr>
<td></td>
<td>32.35 ± 1.67</td>
<td>73.43 ± 1.92**</td>
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</tbody>
</table>

Table 2. Effect of dexamethasone on nitrogen balance in rats

Values are means ± SEM for 12–14 rats. Nitrogen intake (food consumption) together with nitrogen excretion (urinary and faecal) were determined 24 h after the ninth dexamethasone injection, as described in the Experimental section. Nitrogen balance was determined from the difference between nitrogen intake and output. Statistical significance: *P<0.001, compared with control values.

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Dexamethasone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen intake (mg of N day⁻¹ 100 g⁻¹ body wt.)</td>
<td>239.3 ± 4.25</td>
<td>230.5 ± 3.72</td>
</tr>
<tr>
<td>Urinary nitrogen output (mg of N day⁻¹ 100 g⁻¹ body wt.)</td>
<td>73.6 ± 2.63</td>
<td>160.8 ± 3.24*</td>
</tr>
<tr>
<td>Faecal nitrogen output (mg of N day⁻¹ 100 g⁻¹ body wt.)</td>
<td>63.3 ± 2.57</td>
<td>77.3 ± 1.79</td>
</tr>
<tr>
<td>Nitrogen output (mg of N day⁻¹ 100 g⁻¹ body wt.)</td>
<td>136.9 ± 4.87</td>
<td>238.1 ± 3.61*</td>
</tr>
<tr>
<td>Nitrogen balance (mg of N day⁻¹ 100 g⁻¹ body wt.)</td>
<td>102.5 ± 7.40</td>
<td>10.1 ± 1.68*</td>
</tr>
</tbody>
</table>
methods, as described previously [10]. The plasma insulin level was measured by a radioimmunoassay technique (Diagnostic Products Corp., Los Angeles, CA., U.S.A.).

Statistical analysis

Data are presented as means±SEM and where appropriate comparisons between sets of data were made using Student's t-test.

RESULTS

The body weight gain of dexamethasone-treated rats was markedly less than that of age-matched controls (Table 1). Food consumption of control rats over the period of experiment was approximately 7.45±0.23 g day⁻¹ 100 g⁻¹ body wt. (n=14). In contrast, that of dexamethasone-treated rats was markedly decreased on the second day of the treatment (5.76±0.86 g day⁻¹ 100 g⁻¹ body wt., P<0.05, n=14). It then increased so that it was similar to that of controls by day 3 after completion of dexamethasone treatment when expressed in relation to body weight, but it was less in absolute values (results not shown).

Dexamethasone treatment resulted in a decrease in the weight of the small intestine, but it was not changed when expressed as percentage of body weight (Table 1). Dexamethasone treatment resulted in a marked increase in the length of the small intestine when expressed as cm/g (see Table 1), but it was not changed when presented as length, being 108.7±1.56 and 106.8±1.15 cm for control (n=12) and dexamethasone-treated (n=14) groups, respectively. (Care was taken to ensure a constant degree of stretch when measuring the length of the gut by laying the small intestine along the side of a wooden ruler and making five measurements over 30 min after removal of the small intestine without stretching the tissue, and the mean value was used.) The plasma levels of glucose, alanine and insulin were increased and the plasma glutamine concentration was decreased in dexamethasone-treated rats (Table 1).

Nitrogen balance

Control and dexamethasone-treated rats consumed approximately the same quantity of food during the last 7 days of dexamethazone treatment, resulting in essentially constant daily nitrogen intake. The urinary nitrogen excretion rate was increased by more than two-fold in dexamethasone-treated rats. Faecal nitrogen losses, however, were slightly increased by dexamethasone treatment (Table 2). Control animals were in positive nitrogen balance, whereas dexamethasone-treated rats were in negative nitrogen balance (Table 2).

Arteriovenous concentration difference measurements and net rates of utilization for glucose and glutamine

The arterial concentration of glucose was increased by approximately 22% but that of glutamine was decreased (21%) in dexamethasone-treated rats (Table 3). Arterio-
Glucose and glutamine metabolism in the gut

Venous concentration differences across the small intestine showed a net uptake of glucose, lactate and glutamine (Table 3), with a net release of glutamine, alanine and ammonia (the major nitrogenous end-products of glutamine) (Table 3). Dexamethasone treatment decreased the arteriovenous concentration difference for glucose, but increased it for lactate, glutamine, glutamate and alanine (Table 3).

Portal-drained visceral blood flow increased by approximately 22% in dexamethasone-treated rats (Table 4), confirming other work [6]. Calculation of the rates of utilization or metabolite production from substrate arteriovenous concentration differences and blood flow indicated a decreased rate of utilization of glucose but enhanced rates of utilization of lactate and glutamine in dexamethasone-treated animals (Table 4); this is in agreement with previous findings in dogs [6]. Enhanced rates of release of glutamate and alanine were also observed (Table 4).

Glucose and glutamine metabolism by isolated enterocytes

The rate of glucose utilization by incubated rat enterocytes was decreased in cells isolated from dexamethasone-treated rats (Table 5). Approximately 60% of utilized glucose was recovered as lactate by incubated rat enterocytes, confirming previous findings [8, 15]. The rate of glutamine utilization by incubated enterocytes was increased in cells isolated from dexamethasone-treated rats (Table 5). In both cases, glutamate and alanine and ammonia were the major nitrogenous end products (Table 5). However, other amino acids (e.g. citrulline, proline, serine and aspartate) are known to be formed from glutamine metabolized by intestinal mucosa (see [18]), but were not measured in the present work. Dexamethasone treatment increased the rates of production of glutamate, alanine and ammonia (Table 5). These findings are, in general, consistent with the findings observed in vivo (see above).

Maximum activities of enzymes of glycolysis, the tricarboxylic acid cycle and glutamine utilization in the intestinal mucosa

The maximal activities of hexokinase, 6-phosphofructokinase, citrate synthase, oxoglutarate dehydrogenase and glutaminase in intestinal mucosa of control and dexamethasone-treated rats are presented in Table 6. The activities of hexokinase and 6-phosphofructokinase were decreased in intestinal mucosa obtained from dexamethasone-treated rats (Table 6). These are consistent with the decreased ability of the intestinal cells to utilize glucose (see Table 5).

The maximal activities of citrate synthase and oxoglutarate dehydrogenase were decreased in intestinal mucosa isolated from dexamethasone-treated rats (Table 6); this suggests a decrease in the maximal capacity of the tricarboxylic acid cycle in this condition.

The activity of glutaminase was increased in the dexamethasone-treated rats (Table 6). This is consistent with the increased rate of glutamine utilization by the small intestine in vivo and in vitro (Tables 3 and 5).

DISCUSSION

The effects of dexamethasone treatment on glucose and glutamine metabolism by the small intestine of the rat have been studied. Dexamethasone was used in the present work because of its ease of administration by intramuscular injection with minimal mineralocorticoid activity, and for its long half-life which provides a consistent glucocorticoid effect throughout the day [19]. A dose of dexamethasone of 30 μg day⁻¹ 100 g⁻¹ body wt. is equivalent to 750 μg of cortisone day⁻¹ 100 g⁻¹ body wt., representing approximately a 25-fold increase above the amount of corticosterone normally secreted per day [19, 20]. This dose is approximately two to four times greater than the amount of corticosterone recommended for replacement therapy in adrenalectomized rats [21]. Extensive burns, physical stress or psychological stress can elevate the rate of secretion of corticosterone and its plasma concentrations to those used in the present work (i.e. two- to ten-fold increases in secretory rate) [22-25]. In addition, a three- to four-fold increase in the rate of urinary cortisol excretion can occur after a major operation in man [26] and prolonged elevations in blood cortisol concentrations of at least three to five times control levels have been reported in patients with major burns [27]. Therefore, the dose of dexamethasone used in the present work reasonably approximates the daily amount of adrenal steroids secreted during major stress.

Table 4. Blood flow measurements and gut net rates of utilization or production of glucose, lactate, glutamine, glutamate, alanine and ammonia in control and dexamethasone-treated rats

Measurements and calculations were made as described in the Experimental section; results are presented as means ± SEM with the numbers of animals used shown in parentheses. Negative values indicate uptake. Statistical significance: *P<0.001, compared with control values.

<table>
<thead>
<tr>
<th>Treatment group</th>
<th>Gut blood flow (ml min⁻¹ 100 g⁻¹ body wt.)</th>
<th>Net rates of utilization or production (nmol min⁻¹ 100 g⁻¹ body wt.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Glucose</td>
</tr>
<tr>
<td>Control</td>
<td>3.11 ± 0.082 (10)</td>
<td>-659 ± 72</td>
</tr>
<tr>
<td>Dexamethasone</td>
<td>3.78 ± 0.051* (10)</td>
<td>-465 ± 64*</td>
</tr>
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</table>
Dexamethasone administration resulted in a shift from positive to negative nitrogen balance. Similar findings were obtained in dogs (see [28]). On the basis of the present work, three lines of evidence support the view that dexamethasone treatment leads to decreased rates of glucose utilization but increased rates of glutamine utilization by the small intestine. Changes in the maximum catalytic activity of key enzymes (hexokinase and glutaminase, Table 6), rates of utilization of glucose and glutamine by isolated, incubated enterocytes (Table 5), and blood flow plus arterio-venous concentration difference measurement across the small intestine of the rat (Tables 3 and 4).

Previous work by Ardawi & Newsholme [8] has shown enhanced rates of glutamine utilization and decreased rates of glucose utilization by the small intestine of thermally injured rats. Moreover, it has been demonstrated that glutamine consumption by the intestinal tract in vivo is markedly increased after surgery [7], bacteraemia [29] or glucocorticoid treatment [30]. The present work suggests that the changes observed in all of these conditions could be explained, at least in part, by the increased plasma level of glucocorticoids. It has also been shown that the plasma levels of glucagon and insulin (see also Table 1) are also raised by glucocorticoid administration so that it is unclear if the reported effect on the small intestine is due directly to effects of glucocorticoids or indirectly to changes in other hormones, such as insulin and/or glucagon or to a combination of all three hormones.

It is suggested that the effect of the glucocorticoid treatment on the small intestine is to conserve glucose. Thus, the increase in glutamine utilization will provide more adenosine 5'-triphosphate through the available capacity of the tricarboxylic acid cycle, so that less glucose need be utilized. In addition, some of the carbon of the extra glutamine that is used is converted into alanine, which will provide glucose via hepatic gluconeogenesis. The latter is consistent with the accelerated hepatic gluconeogenesis which is accompanied by increased hepatic alanine uptake in response to glucocorticoid treatment (see [29]). It is concluded therefore that glucocorticoid administration decreases net rates of glucose utilization but increases that of glutamine (both in vivo and in vitro), by the epithelial cells of the small intestine. Such changes in the net rates may be caused by changes in the activities of key enzymes in these cells. Finally, an increase in glutamine utilization but a decrease in glucose utilization by the intestinal epithelial cells is consistent with the accelerated hepatic gluconeogenesis which is accompanied by increased hepatic alanine uptake in response to glucocorticoid treatment (see [29]).

Table 5. Effects of dexamethasone treatment on glucose and glutamine metabolism by isolated incubated enterocytes of the rat

<table>
<thead>
<tr>
<th>Group</th>
<th>Glucose (μmol min⁻¹ g⁻¹ dry wt.)</th>
<th>Lactate (μmol min⁻¹ g⁻¹ dry wt.)</th>
<th>Glutamine (μmol min⁻¹ g⁻¹ dry wt.)</th>
<th>Glutamate (μmol min⁻¹ g⁻¹ dry wt.)</th>
<th>Alanine (μmol min⁻¹ g⁻¹ dry wt.)</th>
<th>Ammonia (μmol min⁻¹ g⁻¹ dry wt.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glucose (10 mmol/l)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>-12.50 ± 0.54 (5)</td>
<td>14.88 ± 0.27 (5)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Dexamethasone</td>
<td>-9.09 ± 0.24* (7)</td>
<td>11.08 ± 0.28* (7)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Glutamine (5 mmol/l)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>-</td>
<td>-</td>
<td>-9.12 ± 0.27 (5)</td>
<td>3.42 ± 0.08 (5)</td>
<td>3.28 ± 0.08 (5)</td>
<td>7.30 ± 0.24</td>
</tr>
<tr>
<td>Dexamethasone</td>
<td>-</td>
<td>-</td>
<td>-13.07 ± 1.39* (7)</td>
<td>4.37 ± 0.18* (7)</td>
<td>4.33 ± 0.11* (7)</td>
<td>10.22 ± 0.26*</td>
</tr>
</tbody>
</table>
plays an important role in the altered glucose and glutamine metabolism seen in critically ill patients (e.g., patients with trauma, sepsis, burns).

ACKNOWLEDGMENTS

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REFERENCES


Table 6. Maximal activities of hexokinase, 6-phosphofructokinase, citrate synthase, oxoglutarate dehydrogenase and glutaminase in intestinal mucosal scrapings of control and dexamethasone-treated rats

<table>
<thead>
<tr>
<th>Activity (μmol min⁻¹ g⁻¹ fresh wt.)</th>
<th>Control</th>
<th>Dexamethasone</th>
</tr>
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<tbody>
<tr>
<td>Hexokinase</td>
<td>1.95 ± 0.14 (6)</td>
<td>1.31 ± 0.08* (6)</td>
</tr>
<tr>
<td>6-Phosphofructokinase</td>
<td>5.52 ± 0.53 (6)</td>
<td>3.31 ± 0.26* (6)</td>
</tr>
<tr>
<td>Citrate synthase</td>
<td>8.38 ± 0.40* (6)</td>
<td>5.45 ± 0.47* (6)</td>
</tr>
<tr>
<td>Oxoglutarate dehydrogenase</td>
<td>1.25 ± 0.06 (6)</td>
<td>0.87 ± 0.02* (6)</td>
</tr>
<tr>
<td>Glutaminase</td>
<td>10.13 ± 0.42 (14)</td>
<td>13.63 ± 0.32* (14)</td>
</tr>
</tbody>
</table>


