Method of preparing isolated colonic epithelial cells (colonocytes) for metabolic studies

W. E. W. ROEDIGER AND S. C. TRUELOVE

From the Nuffield Department of Surgery and Clinical Medicine, University of Oxford, Radcliffe Infirmary, Oxford

SUMMARY Suspensions of isolated colonic epithelial cells (colonocytes) have been obtained from rats by incubating everted lengths of colon with EDTA at 37°C in Krebs-Henseleit saline from which calcium was omitted and containing 0.25% (w/v) bovine serum albumin. Measurements of oxygen consumption and lactate production by cell suspensions indicate that they are metabolically active for at least one hour. The method has been modified for the preparation of isolated epithelial cells from the human colon by including an enzyme digestion step and by increasing the concentration of EDTA to 10 mM. Human colonocytes have been obtained either from normal mucosa (ascending and descending colon) or from the mucosa in ulcerative colitis (descending colon). Oxygen consumption of human cell suspensions is lower than in the rat but in colonocytes from both species the rate is increased by glucose and by n-butyrate, a normal constituent of the colonic lumen. The method yields metabolically active cell suspensions from diseased colonic mucosa and promises to be of value for biochemical studies of ulcerative colitis.

There is hardly any information available on the metabolism of the epithelial cells of the human colonic mucosa. A study of the metabolism of these cells may help to elucidate colonic diseases such as ulcerative colitis and pseudomembranous colitis which affect the surface epithelial cells. We have therefore devised a method of isolating viable epithelial cells from normal and diseased mucosa of the human colon as well as from the rat colon for purposes of metabolic studies. These isolated cells are termed 'colonocytes' in order to distinguish them from enterocytes, a term generally used to describe absorptive cells of the small bowel (Johnson, 1976). The present usage of 'colonocytes' refers to all cells, columnar, goblet, crypt, and endocrine cells constituting the colonic epithelium.

The procedures are based, with modification, on the methods of Kimmich (1970), Culling et al. (1973), Hülsmann et al. (1974), and Watford (1977) for the preparation of isolated cell suspensions from the small intestine of various laboratory animals. In principle mucosal cells are exposed to the chelating agent EDTA which weakens the intercellular junctions to allow mechanical disaggregation of the surface epithelium. Several methods were tried before the following procedure was routinely adopted as it produced cells of optimal metabolic performance.

Methods

PREPARATION OF ISOLATED RAT COLONOCYTES

Three male rats of the Cobb-Wistar strain (Charles River, Margate, Kent), 200-250 g were killed by a blow to the head and subsequent cervical fracture. The colons, from the caecum to the rectal ampulla, were rapidly removed and flushed clear with an electrolyte solution (Krebs and Henseleit, 1932) from which calcium was omitted, kept at 22°C and saturated with O₂ + CO₂ (19:1 v/v). Each colon was everted, distally ligated, and then distended as much as possible by means of a syringe containing calcium-free Krebs-Henseleit (K-H) saline with 0.25% w/v dialysed bovine serum albumin (BSA). BSA was prepared and dialysed against calcium-free physiological saline as described by Krebs et al. (1974). The proximal end of the colon was ligated and the everted colon was placed in a plastic flask containing 100 ml calcium-free K-H saline, 5 mM EDTA, and 0.25% BSA. The flask was continuously gassed with O₂ + CO₂ (19:1 v/v) and incubated at 37°C in a Dubnoff type shaker at 60-70 oscillations per minute for 30 minutes. Thereafter the colons were...
rinsed in fresh calcium-free saline to remove excess EDTA and placed in a plastic beaker with 50 ml K-H saline with 0·25% w/v BSA. Vigorous manual stirring with a plastic stirrer for two minutes readily disaggregated colonocytes, which were then separated by centrifugation at 500 g for 60 seconds. The cells were twice washed in oxygenated K-H saline containing normal amounts of calcium, 5 mM DL-dithiothreitol (DTT), and 2·5% w/v BSA. The pellet of cells was resuspended in 15 ml of the same saline by being taken up several times into a 10 ml polypropylene pipette. Aliquots of the cell suspension were used for the procedures outlined below.

**Preparation of isolated human colonocytes**
The human material was obtained from surgical specimens of patients subjected to inhalation anaesthesia with halothane, nitrous oxide, and oxygen. The mesenteric vascular supply of a pre-selected section of a colectomy specimen was preserved at the time of operation until the vessels to this section remained as the only tether. The vascularly perfused portion of the colon was collected in the operating theatre, cut open, thoroughly washed with water (37°C) and pinned out on a corkboard. Strips of mucosa were lifted with forceps and cut from the underlying muscle layers. The time taken from clamping off the blood supply to placing the mucosa in calcium-free K-H saline was less than six minutes. Mucosal tissue from 80-120 sq cm of colon was collected and placed in calcium-free K-H saline with 5 mM DTT, previously gassed with O₂ + CO₂ (19:1 v/v). Mucosal strips were then processed as shown in Fig. 1.

**Efficiency of harvesting and metabolic performance of isolated colonocytes**

*Efficiency of cell removal*
In order to assess the efficiency of colon cell removal, pieces of mucosa were fixed in 10% formalin saline both before and after separation of the surface epithelium. The tissue was processed for paraffin embedding and sections stained with haematoxylin and eosin.

*Integrity of cell membranes*
The integrity of the cell membrane of colonocytes was assessed by the ability of cells to exclude dyes and sodium succinate. The cell suspension (0·1 ml) was mixed with 0·2 ml of 0·2% (w/v) trypan blue in 150 mM NaCl or with 0·02 ml of a succinate-tetrazolium salt mixture (13 mM of 2-(4-indophenyl)-3-(4-nitrophenyl)-5-phenyl tetrazolium chloride, 60 mM sodium succinate, and 80 mM sodium chloride). Cells were permeable to sodium succinate if a brown red formazan deposit occurred in the mitochondria or were permeable to trypan blue if nuclear staining occurred. Nuclear staining of trypan blue and appearance of a formazan deposit are of equivalent value in detecting damaged cell membranes of hepatocytes (Hems, unpublished observation, 1978). Both methods were used in the present study, as albumin in which isolated cells are suspended may inhibit staining by trypan blue. The proportion of permeable cells is expressed as a percentage of the total cell population counted in haemocytometer chambers.

*Measurement of glycolysis*
Production of lactic acid was used as a measure of

---

**Fig. 1** Stages in the preparation of isolated human colonocytes.
glycolysis. Cell suspensions, 1 ml, representing approximately 5 mg dry weight of cells were incubated at 37°C in 1 ml K-H saline containing 2-5% w/v BSA with or without 10 mM glucose. The reaction was stopped at 20, 40, and 60 minutes by adding 0-5 ml of 10% perchorlic acid. The protein precipitate was separated by centrifugation and the supernatant neutralised with 20% potassium hydroxide. The lactic acid content was measured enzymatically by the method of Hohorst (1970) and the results expressed as μmol/g (dry weight) of cells. The dry weight was obtained by drying 1 ml of the cell suspension to constancy at 100°C, and corrected for the dry weight of the albumin containing medium.

Oxygen consumption of isolated colonocytes

Oxygen uptake was measured manometrically in manometer cups designed by Krebs et al. (1974). Each cup contained 2 ml of cell suspension, substrates (10 mM glucose and/or 10 mM n-butyrate), and K-H saline with 2-5% w/v BSA to a volume of 4 ml. The centre well contained 4 ml of CO₂-absorbing buffer (Krebs et al., 1974) and the gas phase was O₂ + CO₂ (19:1 v/v). The manometer vessels were shaken at 60 oscillations per minute at 37°C with an amplitude of 2-5-3-⁰⁰ cm. The oxygen consumption was expressed as μmol O₂/min/g tissue (dry weight).

Bacteria and colonocyte suspensions

In spite of thorough colonic lavage bacteria could have contributed towards lactate formation observed in cell suspensions. Lactate formation was therefore measured in rat cell suspensions containing 180 U/ml benzyl penicillin (Glaxo Laboratories) and 180 μg/ml streptomycin (Glaxo Laboratories) and compared with lactate formation by cell suspensions without these antibiotics.

Aliquots of colonocytes, with and without the above antibiotics, were plated on McConkey's medium, blood agar, and cooked meat broth to observe bacterial growth. In addition, the bacterial content was observed at the beginning and end of a one hour incubation of cell suspensions with 10 mM glucose as outlined above.

Results

With the present method more than 95% of the available surface epithelium of the rat colon was harvested as isolated cells. The efficiency of cell removal in rats was consistent and in every case the lamina propria, on histological section, seemed to be intact. Efficiency of epithelial cell removal in man was good and consistent in the ascending colon (Fig. 2) but varied in the rectosigmoid region where mainly surface but not crypt cells were removed. Very efficient harvesting of human colonocytes was observed from any site of the colon if patients had previously been treated with corticosteroids.

Cell suspensions, both in rat and man, contained a mixture of single colonocytes and clumps of cells conforming to the shape of colonic crypts. Mucus and occasional lymphocytes were also seen but no muscle or connective tissue structures.

There was no staining of colonocytes with trypan blue. This observation was probably an artefact as dye may bind to albumin contained in the cell suspension. A formazan deposit was seen in 15-30% of rat and human colonocytes. This value was lower in cells prepared without mucolytic agents but such agents were nevertheless routinely used as they improved cell dispersion and oxygen consumption (Table 1).

The rate of oxygen consumption of rat colonocytes with or without substrates was linear over 60 minutes. The rate of consumption was increased by

Fig. 2 Human colonic mucosa (a) intact mucosa and (b) after harvesting surface epithelial cells. Normal ascending colon. Sections a and b are not strictly comparable as they are taken from different areas of the same colectomy specimen. Haematoxylin and eosin, × 156 (original magnification).
glucose or n-butyrate and generally improved in the presence of mucolytic agents (Table 1). The rate of oxygen consumption of human colonocytes was also linear over 60 minutes but human cells under the conditions of preparation generally had a lower rate of consumption than rat colonocytes (Table 2).

The rate of lactate production from glucose was linear over 60 minutes and, as expected, was low in the absence of glucose (Fig. 3). Mean lactate production by cell suspensions with antibiotics was not significantly different from lactate production by cells without antibiotics.

Culture of suspensions of colonocytes revealed a scanty growth of enterobacteraceae which were eliminated by antibiotics. The concentration of microorganisms at the end of a one hour experiment was $1 \times 10^{-4}$ to $2 \times 10^{-4}$ bacteria per 2 ml of colonocyte suspension and was decreased (less than $1 \times 10^{-4}$ per 2 ml cell suspension) by antibiotics.

Discussion

Based on the criteria of cell permeability, oxygen consumption, and lactate formation, it seems that viable suspensions of colonocytes can be obtained from the lining epithelium of the rat colon. Such cell suspensions are free from muscle and connective tissue which may be present in mucosal scrapings of the colonic mucosa. Methods to prepare surface epithelial cells by scraping have been reported by Rosenthal and Lasnitzki (1928) and Perret et al. (1977) but have not been used extensively for metabolic studies.

The oxygen consumption is higher with isolated cell suspensions than with mucosal scrapings. Rosenthal and Lasnitzki (1928) report a consumption of 10-9 μmol/min/g (dry weight) from scrapings of the rat colon incubated with glucose, while Perret et al. (1977) report virtually no oxygen consumption from the rat mucosa in the absence of any substrates. The high value presently obtained in the absence of substrates must reflect the utilisation of endogenous substrates which are not removed during cell preparation. An oxygen consumption of 8-41 μmol/min/g (dry weight) is reported for scrapings of the human rectal mucosa (Rosenthal and Lasnitzki, 1928). This value is similar to that obtained with the present method for cells of the descending colon.

Oxygen consumption is enhanced in rat and man by glucose and n-sodium-butyrate, both of which are available to the colonic epithelium in vivo. Anaerobic fermentation is known to occur in the rat colon (Lasnitzki, 1928). The results of Table 1 show that the rate of oxygen consumption is increased by addition of n-butyrate to the incubation medium for both normal and quiescent colonocytes from the rat descending colon. The results of Table 2 show that the rate of oxygen consumption is increased for colonocytes from the rat ascending colon by addition of n-butyrate to the incubation medium.

Table 1. Oxygen consumption (μmol/min/g (dry weight)) of isolated rat colonocytes incubated for 60 min with mucolytic agents

<table>
<thead>
<tr>
<th>Substrate</th>
<th>No mucolytes</th>
<th>5 mM DTT</th>
<th>5 mM n-acetylcysteine</th>
</tr>
</thead>
<tbody>
<tr>
<td>No substrate</td>
<td>7.29 ± 0.12(3)</td>
<td>12.96 ± 1.14(8)</td>
<td>—</td>
</tr>
<tr>
<td>10 mM glucose</td>
<td>10.27 ± 0.05(3)</td>
<td>15.30 ± 0.08(10)*</td>
<td>13.39(2)</td>
</tr>
<tr>
<td>10 mM n-sodium</td>
<td>10.81 ± 0.30(3)</td>
<td>16.88 ± 1.18(4)*</td>
<td>—</td>
</tr>
</tbody>
</table>

Mean and SEM of the number of experiments in parentheses. Compared against endogenous oxygen consumption; paired t test (n = 4); *p<0.001.

Table 2. Oxygen consumption of human colonocytes (μmol/min/g (dry weight)) incubated for 60 min with 10 mM DTT and substrates as indicated

<table>
<thead>
<tr>
<th>Substrate</th>
<th>Ascending colon (normal)</th>
<th>Descending colon (normal)</th>
<th>Descending colon (quiescent colitis + corticosteroids)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No substrate</td>
<td>8.29 ± 0.57(7)</td>
<td>7.47 ± 0.60(7)</td>
<td>8.43 ± 0.53(5)</td>
</tr>
<tr>
<td>10 mM glucose</td>
<td>8.92 ± 0.60(7)†</td>
<td>7.88 ± 0.83(7)*</td>
<td>9.44 ± 0.48(5)*</td>
</tr>
<tr>
<td>10 mM glucose + 10 mM sodium n-butyrate</td>
<td>10.97 ± 0.64(7)‡</td>
<td>9.31 ± 0.58(7)‡</td>
<td>11.13 ± 0.38(5)‡</td>
</tr>
<tr>
<td>10 mM n-butyrate</td>
<td>10.41 ± 0.56(7)†</td>
<td>9.30 ± 0.83(7)‡</td>
<td>—</td>
</tr>
</tbody>
</table>

Mean and SEM of the number of colectomy specimens in parentheses. Compared against endogenous oxygen consumptions; paired t test; *NS, †p < 0.025, ‡p < 0.005, §p < 0.001.
robic bacteria in the colon produce n-butyrate, of which considerable amounts are absorbed (Dawson et al., 1964). The increase of oxygen consumption by n-butyrate suggests that this fatty acid is metabolised by the colonic epithelium, an observation which has been reported in the rabbit colon (Henning and Hird, 1972).

From a theoretical point of view the colonic epithelial cells in ulcerative colitis might be expected to tolerate the stress of cell isolation less well than the epithelial cells of normal mucosa. However, the present method produces coloocytes from colitic mucosa which have oxygen consumptions like that of normal cells. They thus seem metabolically active and could be useful for investigating ulcerative colitis.

In conclusion, isolated cell suspensions are a convenient way of studying mucosal epithelial cells in health and in disease. The oxygen consumption of cell suspensions is higher than that obtained with mucosal scrapings and cell suspensions have the further advantage that they are homogeneous and therefore permit parallel experiments to be carried out on the same tissue.

We are indebted to Dr Patricia Lund and Dr John Porteous, FRSE, for helpful discussions and encouragement during the course of this work.

References


