Simultaneous measurement of intestinal crypt cell production rate and water absorption

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SUMMARY Intestinal cell proliferation and cell production is best quantified by measuring the rate of accumulation of vincristine arrested metaphases in microdissected intestinal crypts to determine the crypt cell production rate (CCPR). Studies of intestinal adaptation could be much more informative if a valid measure of intestinal function could also be included. One such method is the water absorption capacity. The CCPR of the jejunum and intestinal water absorption were measured in 19 groups of hypo and hyperproliferative rats which were in a 'steady state' of cell production and turnover. The minimum values were obtained after hypophysectomy and the maximum values were observed in lactation. Crypt cell production rate and absorption were significantly correlated (p<0.001) to each other. There was a significant (p<0.001) correlation between both CCPR and absorption and dry weight of the intestinal segment studies and food intake. Body weight was a poor predictor of either CCPR or absorption. The combined study of CCPR and water absorption is thus a practical and convenient approach to the study of intestinal cell proliferation and intestinal adaptation.

The relationship between cell production and intestinal function is of great interest in studies of intestinal adaptation. Intestinal cell production can be measured in several ways, some of which have been extensively criticised. One method which is robust enough to withstand criticism and account for the many changes which can occur in an adapting intestine is the crypt cell production rate (CCPR) method.

Warm ischaemia and the presence of unstirred layers can confound absorption measures; however, these can be avoided if a single pass segmented flow technique is used. A preliminary investigation showed that vincristine had no significant effect on intestinal water absorption within the time course of a crypt cell production rate assay. The two techniques were thus applied to the following group of rats: starved hypophysectomy, intestinal bypass in self-emptying blind loops, hypothermic hyperphagia, lactation and experimentally induced diabetes. Several groups with normal proliferative rates (the control groups for the various treatments) were also included.

Methods

ANIMALS
Male Wistar rats were used (Olac Ltd, Blackthorn, Oxon, UK). They were kept in wire bottomed cages and fed a standard laboratory diet (Labshure PRD, Christopher Hill, Poole, Dorset). Nineteen groups of rats containing eight animals were chosen to represent the range of proliferative rates found in models of intestinal adaptation. The hypoproliferative models were starvation, hypophysectomy, and intestinal bypass. Hyperproliferative models included hypothermic induced hyperphagia, streptozotocin induced diabetes and lactation. The various control groups for these models were also included. Preliminary results showed that there were no significant sex differences in CCPR and absorptive rate thus female rats were included (pregnant and lactating).

CRYPT CELL PRODUCTION RATE
Rats were injected with 1 mg/kg vincristine sulphate at 900 am, killed at timed intervals. One centimetre lengths of intestine were fixed in Carnoy's fluid and the tissue samples were stored in 70% v/v ethanol. They were later hydrolysed in 1 M HCl for six minutes and stained with Schiff's reagent. The intestinal crypts
were microdissected; the number of arrested metaphases in 10 crypts was counted and the mean values plotted against time after injection. The slope of the line, fitted by least squares linear regression, gave the crypt cell production rate (CCPR).  

**Intestinal Perfusion**

The 'segmented-flow' technique for single pass luminal perfusion of Fisher and Gardener\(^4\) was used. The perfusion apparatus consisted of two water jacketed gut baths mounted on a frame. Each gut bath had a flexible water jacketed tube to supply the perfusate and warm moist gas. A peristaltic pump generated the segmented flow by pumping gas and fluid into a glass Y connector. Rats were anaesthetised with ether, the abdomen opened. A glass catheter was tied into the jejunum and the intestine was perfused with gassed 0.12 M NaCl/NaHCO\(_3\) 'saline' solution at 38 °C. When the solution started to inflate the caecum, a cannula was tied into the distal ileum. The gut was then rinsed through with alternate pulses of perfusion medium and warm saline moistened CO\(_2/\)O\(_2\) (95:5). The mesenteric arteries were then clamped and the mesentery was gently stripped away. The gut was then suspended in a gassed bath. The perfusion medium was a modified Krebs-Henseleit bicarbonate solution (pH 7.4) equilibrated with the gas mix.\(^4\) It contained 28 mmol/l glucose and 141 nmol/ml phenol red. The water absorption rates were determined directly from the weight of fluid secreted during the three consecutive five minute periods after the first and second five minute collections.

**Results**

The rats in the five control groups had a mean weight of 288.6±29.8 g, ate 25.9±2.2 g and the length of the segments of intestine perfused (from ligament of Trietz to 5 cm above the ileocaecal valve) was 78.3±9.3 cm and the dry weight of this segment was 1.41±0.18 g. The absorption rate was 13.4±10.3 µl/cm/h (10.828±2120 µl/gut/h) and the CCPR was 25.0±1.5 cells/crypt/h.

The correlations between the various groups are shown in the Table. While most factors were significantly correlated (by both the Pearson product moment method and by Spearman's Rank correlation) body weight and length of small intestine were poor predictors of CCPR (and absorption). Absorption and CCPR were significantly correlated (Figure) and it made little difference whether absorption per cm or per gut was considered. The highest correlation coefficients were seen between food intake gut dry weight, absorption and CCPR (Figure).

**Discussion**

Vincristine did not affect our measure of absorption over the time scale of the CCPR method (CCPR studies in the gut should be completed within three hours or the arrested metaphases may start to decay.\(^1\)

The mean values for the control groups in this study were very similar to previously published values using similar techniques\(^5\) which confirms that the combination of these techniques did not alter the measured values. The combination of the two techniques should prove to be very useful as the determination of intestinal cell proliferation by the quantification of vincristine arrested metaphases in microdissected crypts has several advantages over other proliferative measures. It is a rate measure and can detect changes in cell production irrespective of whether they are the result of alterations in the cell cycle time, crypt size or growth fraction and the technique also avoids the problems associated with the quantification of cell types in sectioned material and with the use of tritiated thymidine.\(^1\) Intestinal water absorption measurement also has several advantages over other absorption methods; it gives a holistic measure of gut function and is not distorted by the presence of unstirred layers of fluid next to the absorptive cells or by the rapid loss of absorptive

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### Table: Correlation between various groups

<table>
<thead>
<tr>
<th></th>
<th>Rat weight</th>
<th>Small intestine (length)</th>
<th>Gut weight</th>
<th>Absorption per cm</th>
<th>Absorption per gut</th>
<th>CCPR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length SI</td>
<td>0.40</td>
<td>0.691</td>
<td>0.825</td>
<td>0.839</td>
<td>0.865</td>
<td>0.74</td>
</tr>
<tr>
<td>Dry weight gut</td>
<td>0.691</td>
<td>0.825</td>
<td>0.839</td>
<td>0.865</td>
<td>0.74</td>
<td>0.78</td>
</tr>
<tr>
<td>Absorption per cm</td>
<td>0.57*</td>
<td>0.72*</td>
<td>0.71*</td>
<td>0.74*</td>
<td>0.74</td>
<td></td>
</tr>
<tr>
<td>Total absorption</td>
<td>0.51*</td>
<td>0.88*</td>
<td>0.87*</td>
<td>0.96*</td>
<td>0.78</td>
<td></td>
</tr>
<tr>
<td>CCPR</td>
<td>0.42</td>
<td>0.55*</td>
<td>0.71*</td>
<td>0.74*</td>
<td>0.78</td>
<td></td>
</tr>
<tr>
<td>Food intake</td>
<td>0.68†</td>
<td>0.58†</td>
<td>0.78†</td>
<td>0.82†</td>
<td>0.78</td>
<td></td>
</tr>
</tbody>
</table>

* = Significantly correlated (Pearsons method) p < 0.05; † = Significantly correlated (Pearsons method) p < 0.01; ‡ = Significantly correlated (Pearsons method) p < 0.001
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function associated with warm ischaemia. When the dynamic renewal system of the mouse gut is in a state of equilibrium there is an almost direct equivalence between crypt cell number and villus cell number and the results of the present study suggest that the same applies to the rat gut. This may not be the case when the system is perturbed. Wright et al determined cell population directly in micro-dissected mouse crypts and villi, which is the method of choice for the determination of crypt or villus cell populations as simple estimates of crypt or villus height can be very misleading. Rat villi are considerably larger than mouse villi and their convoluted shape makes their microdissection almost impossible. There is thus a great need for another method for assessing villus cell population and the results of the present study suggest that the measure of the in vitro water absorptive capacity may be of use.

This study also suggests that in the adapted small bowel the rate of cell proliferation in the jejunum generally reflects the state of the rest of the small intestine, thus the quantification of CCPR in one site may be valid in these models.

When the bowel is in a relatively ‘steady state’ of cell production the migration water absorption gives a more precise measure than the CCPR because it is a holistic method. It is also less labour intensive; and with a two bath system eight to 10 animals can be measured in a morning. The CCPR method must still remain as the method of choice for measuring intestinal proliferative status.

The food intake immediately before the measurement of proliferation and absorption was highly correlated with these measures. Although systemic and other factors have an important role to play in the control of intestinal epithelial cell proliferation they are also very dependent on food intake. Humoral factors are clearly involved in the massive proliferative response of the gut in lactation but this response can be abolished if hyperphagia is prevented. The effects of food intake on intestinal epithelial cell is perhaps best shown by the profound intestinal atrophy seen in intravenously fed animals. The mechanisms involved in the trophic response to ‘luminal nutrition’ may involve the direct action of nutrients on enterocytes, their stimulation of the requirements of ‘intestinal workload’, the actions of endogenous secretions and the effects of hormones.

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References

3 Lerner JA, Miller DS. Techniques in intestinal absorption studies. In: Titchen TA, ed. Techniques in the life