Enteral Nutrition Prevents Bacterial Translocation but Does Not Improve Survival During Acute Pancreatitis

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Objective: To evaluate the effect of enteral nutrition (EN) in attenuating bacterial and/or endotoxin translocation, maintaining immune responsiveness, and improving outcome in early acute pancreatitis (AP) in Wistar male rats.

Design: Acute pancreatitis was induced in rats receiving total parenteral nutrition (TPN) (AP/TPN group) (n=34) and EN (AP/EN group) (n=35) by pressure injection of 1% deoxycholate into the biliopancreatic duct (0.6 mg/kg of body weight). Rats in the sham/TPN and sham/EN groups (n=10 each) underwent laparotomy without induction of AP. Catheters for TPN and EN were placed into the external jugular vein and jejunum, respectively. Rats were infused with Ringer lactate solution for 48 hours followed by TPN in the AP/TPN and sham/TPN groups, and EN in the AP/EN and sham/EN groups until day 7. The fluid volume and energy (calories) intake were similar in all groups.

Setting: Medical school research laboratory.

Main Outcome Measures: Survival, blood endotoxin level, villus height, 5-bromo-2'-deoxyuridine (BrdU) uptake in the jejunum and ileum, bacterial culture of mesenteric lymph nodes, and CD4/CD8 ratio of T cells in mesenteric lymph nodes, spleen, and peripheral blood.

Results: There was no difference in survival and pancreatic healing between the AP/TPN and AP/EN groups. Colony-forming units of the mesenteric lymph nodes and the endotoxin level were significantly lower in the AP/EN group than in the AP/TPN group (P<.05). Villus height and BrdU intake was significantly higher in the AP/EN group than in the AP/TPN group (P<.05). The CD4/CD8 ratio of T cells in spleen and peripheral blood was higher in the AP/EN group than in the AP/TPN group (P<.05), whereas there was no difference in mesenteric lymph nodes.

Conclusions: Jejunal administration of EN is well tolerated in early AP, maintains immune responsiveness and gut integrity, and reduces bacterial and/or endotoxin translocation. However, compared with TPN, EN does not improve outcome. These results suggest that factors other than bacterial and/or endotoxin translocation may be responsible for mortality in this rat model of early AP. However, additional studies of both early bacterial and/or endotoxin translocation and late assessment of outcome are indicated.


INFECTIOUS COMPLICATIONS account for more than 80% of mortality in human acute pancreatitis (AP).1,2 Although the pathogenesis of infection in AP is unclear, it is known that the microorganisms that cause pancreatic infection and sepsis in patients with AP are generally common enteric bacteria.2,3 This suggests that these bacteria may originate from the gastrointestinal tract. In fact, recent work on animals in AP has demonstrated that there is a loss of gut mucosal integrity with subsequent bacterial and/or endotoxin translocation (BET) from the gut lumen to other organs.3,4 However, few reports have demonstrated that BET per se has deleterious consequences for the host in experimental models of AP.

Extensive studies have demonstrated 3 major mechanisms that promote BET and secondary infections. These are disruption of the indigenous intestinal microflora, damage to the intestinal mucosa causing increased permeability, and impairment of host immunity.6-10 Further, compared with total parenteral nutrition (TPN), enteral nutrition (EN) attenuates cecal bacterial overgrowth,11 maintains gut mucosal integrity,12 and permeability,13 and maintains immune responsiveness of the host.8,14,15

Since BET is thought to be deleterious to the host and the route of nutrition can modulate BET, the purpose of this study was to compare the effect of TPN and EN on gut and immune system integrity and outcome in AP in Wistar male rats.
MATERIALS AND METHODS

ANIMALS

The experiments conducted were approved by the Kobe (Japan) University of Medicine Animal Care and Use Committee. All animals were maintained according to the recommendations of the National Institutes of Health Guide for Care and Use of Laboratory Animals and handled under the Guideline for Animal Experiments of the Kobe University School of Medicine. Animals were anesthetized with ether (Wako Pure Chemical Industries Ltd, Osaka, Japan). Laparotomy was performed though a midline incision, and the abdomen was closed in 2 layers. All procedures were performed using aseptic techniques.

EXPERIMENTAL GROUPS

Eighty-nine adult male Wistar rats weighing 230 to 250 g were studied in 4 groups: 34 rats underwent laparotomy with induction of AP and received TPN (AP/TPN group) and 35 rats underwent laparotomy with induction of AP and received EN (AP/EN group). The remaining 20 rats underwent laparotomy without induction of AP and received TPN (sham/TPN group; n=10) or EN (sham/EN group; n=10).

INDUCTION OF AP

Acute pancreatitis was induced in the AP/TPN and AP/EN groups as follows. A microaneurysm clip was placed on the biliary duct close to the liver. An incision was made, and a sterilized polyethylene catheter (inner diameter, 0.28 mm; outer diameter, 0.38 mm; Becton Dickinson and Co, Franklin Lakes, NJ) was inserted into the common biliopancreatic duct, introduced into the duodenum through the ampulla of Vater, and then the end of the catheter was taken out of a small antimesenteric duodenotomy on the opposite site of ampulla of Vater and attached to a 0.3-mL syringe (1/2 cc U-100 insulin syringe; Becton Dickinson and Co, Rutherford, NJ). The other end of the catheter was also introduced into the common biliopancreatic duct, and fixed above and below the incision by ligature with 3-0 silk sutures. Then, 0.6 mL/kg of 1% deoxycholate (Wako Pure Chemical Industries Ltd) was injected into the common biliopancreatic duct under steady manual pressure. Once the injection was finished, the microclip was removed.

PLACEMENT OF TPN AND EN CATHETER

In all animals, a silicon catheter (inner diameter, 0.6 mm; outer diameter, 1.0 mm; Imamura Co, Tokyo, Japan) was surgically inserted into the external jugular vein for TPN, and a silicon catheter (inner diameter, 1.0 mm; outer diameter, 2.0 mm; Imamura Co) was surgically placed into the jejunum via a gastrostomy for EN using standard techniques. The feeding catheters were tunneled subcutaneously and brought out in the suprascapular region. The catheters were passed through a stainless protective coil and attached to a swivel apparatus allowing mobility. Sterile polyethylene tubing was connected from the swivel apparatus through a microtube pump (Tokyo Rikakikai Co, Tokyo) to the sterile nutritional source.

NUTRITIONAL SUPPORT

All animals were placed in metabolic cages, and infused intravenously with Ringer lactate solution at the rate of 400 mL/kg per day for the first 24 hours, and then 300 mL/kg for the next 24 hours. Then, the intravenously fed animals (AP/TPN and sham/TPN groups) or intrajejunally fed animals (AP/EN and sham/EN groups) were infused with a commercially available TPN solution (TAB; Otsuka Pharmaceutical Co, Osaka, Japan) via the TPN tube or with a commercially available EN solution (Entered; Terumo Co, Tokyo) via the EN tube, respectively, at the rate of 264 mL/kg per day by day 7.

The TPN solution (glucose, 111.1 g/L; xylitol, 27.8 g/L; fructose, 55.6 g/L; amino acids, 33.3 g/L) was diluted to 1:2 on day 3 or 1:1.3 on day 4 with water. The EN solution (dextrin, 161.3 g/L; protein hydrolysate, 41.2 g/L; fat, 11.2 g/L; pH 6.5-7.5; osmolar pressure, 510-550 mOsm/kg) was diluted similarly with isotonic sodium chloride solution. On days 5 to 7, undiluted solutions were given for both TPN and EN. The administered energy intake per day was 502 kJ/kg (120 kcal/kg) on day 3, 753 kJ/kg (180 kcal/kg) on day 4, and 1004 kJ/kg (240 kcal/kg) on days 5 to 7 in all animals.

LABORATORY TESTS

All animals were reanesthetized with ether inhalation on day 7. After careful skin disinfection and draping, the abdominal cavity was opened through a wide midline and healing fibrosis with mononuclear leukocytic infiltration of the stroma in both the AP/TPN group and the AP/EN group (Figure 2). There was no difference in pancreatic healing between these 2 groups. No ascites were found at the time the rats were killed, and the pancreas was grossly and histologically normal in the 2 sham groups.

RESULTS

SURVIVAL

The survival rate was 85% (29/34) for the AP/TPN group and 74% (26/35) for the AP/EN group (Figure 1). There was no statistically significant difference in survival between these 2 groups. No rats died in the sham roups.

PANCREATIC PATHOLOGY

At the killing of the rats on day 7, the pancreas in the AP/TPN and AP/EN groups appeared slightly enlarged and swollen without visible areas of parenchymal or fat necrosis. No ascites were found in any rats in either group. Histological examination revealed a mixed finding of pancreatic collapse and healing fibrosis with mononuclear leukocytic infiltration of the stroma in both the AP/TPN group and the AP/EN group (Figure 2). There was no difference in pancreatic healing between these 2 groups. No ascites were found at the time the rats were killed, and the pancreas was grossly and histologically normal in the 2 sham groups.

TOTAL PROTEIN, ALBUMIN, AMYLASE, AND LIPASE LEVELS

Serum amylase and lipase levels were significantly lower in the AP/EN group than in the AP/TPN group (Table 1). There was no difference in serum total protein and albumin levels between the 2 AP groups, although they tended to be lower in the AP/EN group compared with the AP/TPN group.
laparotomy, and then blood was drawn from the aorta for determination of serum total protein, albumin, amylase, lipase, and plasma endotoxin levels. An Auto Analyzer 7170 (Hitachi Ltd, Tokyo) was used for the total protein, albumin, amylase, and lipase assays. Plasma endotoxin level was measured by means of an endotoxin-specific limulus ameboocyte lysate assay (Endospecy; Seikagaku, Tokyo) after pretreatment of the plasma with a conventional perchloric acid method.

TISSUE HISTOLOGY

The pancreas was excised, fixed in 10% formalin, and stained with hematoxylin-eosin for histological evaluation. A 5-cm segment of the ileum, beginning 5 cm before the ileocecal junction, was also harvested, fixed in 10% formalin, and stained with hematoxylin-eosin for histological measurement of villus height. The mucosal thickness from the top of the villus to the basal level of lamina muscularis was measured with an eyepiece micrometer for 200 villi per sample and the mean value was evaluated as ileum villus height in each animal.

BrdU UPTAKE BY EPITHELIUM IN JEJUNUM

A total of 20 mg/kg of 5-bromo-2′-deoxyuridine (BrdU) (Sigma Chemical Co, St Louis, Mo) was injected intraperitoneally 1 hour before the AP-induced rats were humanely killed. At the time the animals were killed, a 5-cm segment of jejunum, beginning 5 cm beyond the pyloroduodenal junction, was taken, fixed in 70% ethanol, stained with rabbit anti-BrdU antibody (Becton Dickinson and Co, Sandy, Utah) followed by peroxidase conjugate anti-rabbit IgG (Dako Co, Carpinteria, Calif). The number of BrdU-positive epithelial cells from the bottom of the crypt to the top of the villus was measured in 200 villi in each sample, and the mean value was evaluated as BrdU uptake per crypt in the jejunum of each animal.

LYMPHOCYTE ANALYSIS WITH MONOCLONAL ANTIBODIES AND FLOW CYTOMETRY

The spleen and mesenteric lymph nodes (MLN) were teased through fine stainless steel screens into 5 mL of RPMI 1640 (Gibco, Ground Island, NY), and the heparinized peripheral blood was incubated with 100 µL of lysing solution (Cyto-Lyse; Cytec, Fremont, Calif) for 10 minutes at room temperature followed by 1 mL of distilled water to lyse red blood cells. These cell suspensions were incubated with fluorescein isothiocyanate-conjugated anti-rat CD4 antibody (W3/25) (Serotec Ltd, Kidlington, England) and phycocerythrin-conjugated anti-rat CD8 antibody (OX8) (Serotec Ltd) for 30 minutes at room temperature and analyzed using a fluorescence-activated cell sorter (FACS 440; Becton Dickinson and Co, San Jose, Calif).

BACTERIAL TRANSLOCATION TO MLN

The MLN complex from the ileocecal area to the root of the mesentery were collected into a sterile plastic bag (Organon Co, Tokyo), weighed, and homogenized with a stomacher (Tekmar, Cincinnati, Ohio) in 1 mL of sterile phosphate-buffered saline. The homogenates were spread and incubated on blood agar (Becton Dickinson and Co, Cockeysville, Md) and cystin-lactose-electrolyte-deficient (CLED) agar plates (Nissui Pharmaceutical Co, Tokyo) under aerobic conditions, on Gifu anaerobic medium agar plates (Nissui Pharmaceutical Co) under anaerobic conditions at 35°C for 48 hours, and then examined for bacterial growth. The bacterial count was calculated as log number of colony-forming units per milligram of tissue.

BACTERIAL IDENTIFICATION

Gram-negative rods were identified using the Auto-scan 4 system (Dade Behring Co Ltd, Deerfield, Ill). Gram-positive cocci and rods were identified at the genus level using standard microbiologic methods.

STATISTICAL ANALYSIS

Probability of cumulative survival were assessed by the Kaplan-Meier method, and differences were compared using the log-rank test. All laboratory data were evaluated by analysis of variance and Fisher protected least significant difference method as post hoc test using a statistical software program (StatView-J 4.5; Abacus Concepts Inc, Berkeley, Calif) with a Macintosh computer 6500/250 (Apple Computer Inc, Cupertino, Calif). Probabilities less than .05 were considered significant.
significantly lower in the AP/EN group than in the AP/TPN group, indicating that enteral feeding prevented AP-induced bacterial translocation compared with intravenous feeding.

**BACTERIAL SPECIES ISOLATED FROM MLN**

Species of bacteria isolated from MLN were not different between the AP/TPN and AP/EN groups. Bacterial species were all common enteric bacteria and mostly gram-negative bacteria (Table 2).

**PLASMA ENDOTOXIN LEVEL**

The plasma endotoxin level was significantly higher in the AP/TPN group than in the AP/EN group, in which it was as low as both sham groups (Figure 3, bottom). In other words, EN prevented AP-induced endotoxin translocation from the gut to the systemic circulation.

**COMMENT**

Recent work in animal models has demonstrated that there is a loss of gut mucosal integrity with subsequent BET from the gut lumen to other organs in AP.\(^4,5\) Likewise, in this study, the overall incidence of AP-induced translocation of enteric bacteria to the MLN was 100% in both AP groups, and blood endotoxin levels were significantly higher in the AP/TPN group than in the control rats (sham groups). However, few reports have demonstrated the contribution of BET to deleterious consequences for the host in experimental AP. Isaji et al\(^18\) reported experimental data showing the effect of oral antibiotics on the prognosis and incidence of infections in diet-induced hemorrhagic AP of mice. The data suggested that reduction of the intestinal flora inhibits secondary infection caused by bacterial translocation and improves survival. However, as the authors pointed out, there is the pos-
possibility that oral antibiotics might improve the survival by diminishing the severity of injury to the pancreas as a result of decreased absorption of ethionine rather than reduced translocation of bacteria from the gut.

In the present study, all bacterial species isolated from MLN were common enteric bacteria, suggesting a process whereby intestinal microflora relocated to this site. In addition, the lower magnitude of recovery of bacteria from the MLN in the AP/EN group compared with the AP/TPN group on day 7 suggests that enteral feeding (1) induced more rapid clearance of bacteria in MLN, (2) prevented continuing translocation from the intestine to MLN, and/or (3) did not permit a persistent infection in MLN following temporary translocation from the intestine to MLN.10 Despite the significantly lower magnitude of bacterial translocation and significantly lower blood endotoxin levels on day 7 in the AP/EN group than in the AP/TPN group, the survival rate was not different between these 2 groups. These results suggest that the presence of live bacteria in MLN does not play a decisive role for a deleterious outcome at least up to day 7 in this AP rat model. However, it is still possible that BET early after onset of AP may be responsible for the similar mortality in both groups because it is assumed that BET occurred to the same extent in both groups before EN or TPN was initiated. Furthermore, it is also possible that BET may influence the subsequent outcome after day 7. In fact, in human AP, the development of a bacterial infection has emerged as a major determinant affecting survival in patients with necrotizing pancreatitis surviving longer than 1 week,3 although bacterial contamination in pancreatic necrosis could be detected as early as the first week.3

In humans, the most severe complication of AP is pancreatic infection.3 The finding that the microorganisms causing pancreatic infection are common enteric bacteria implies that the bacterial translocation from intestinal tract to pancreas may play a role in the pathogenesis of pancreatitis-induced sepsis. However, consistent pancreatic infection is rarely observed in experimental AP models in animals.4,5,18,20 This was confirmed in the pres-

### Table 1. Effect of Feeding Route and Acute Pancreatitis on Liver, Intestine, and Immune Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sham/TPN</th>
<th>Sham/EN</th>
<th>AP/TPN</th>
<th>AP/EN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amylase, IU/L</td>
<td>5125 ± 71</td>
<td>3688 ± 423†</td>
<td>4490 ± 148</td>
<td>3103 ± 162§</td>
</tr>
<tr>
<td>Lipase, IU/L</td>
<td>8.6 ± 0.5</td>
<td>9.7 ± 0.5</td>
<td>410.0 ± 9.5†</td>
<td>10.0 ± 4.1§</td>
</tr>
<tr>
<td>Total protein, g/L</td>
<td>54 ± 3.8</td>
<td>56 ± 0.3</td>
<td>53 ± 0.9</td>
<td>48 ± 2.4</td>
</tr>
<tr>
<td>Albumin, g/L</td>
<td>40 ± 0.1</td>
<td>46 ± 0.5†</td>
<td>39 ± 0.7</td>
<td>36 ± 0.1</td>
</tr>
<tr>
<td>Villus height of ileum, mm</td>
<td>0.342 ± 0.022</td>
<td>0.487 ± 0.024†</td>
<td>0.418 ± 0.022</td>
<td>0.531 ± 0.016§</td>
</tr>
<tr>
<td>Jejunum BrdU (per crypt)</td>
<td>No data</td>
<td>No data</td>
<td>16.4 ± 0.84</td>
<td>21.9 ± 0.71§</td>
</tr>
<tr>
<td>CD4/CD8 ratio</td>
<td>1.81 ± 0.023</td>
<td>2.62 ± 0.17†</td>
<td>1.42 ± 0.07†</td>
<td>2.31 ± 0.30§</td>
</tr>
<tr>
<td>Spleen†</td>
<td>2.94 ± 0.13</td>
<td>3.7 ± 0.12†</td>
<td>3.76 ± 0.13†</td>
<td>3.72 ± 0.31</td>
</tr>
<tr>
<td>Mesenteric lymph nodes†</td>
<td>2.47 ± 0.04</td>
<td>2.51 ± 0.09</td>
<td>1.77 ± 0.13†</td>
<td>2.81 ± 0.16§</td>
</tr>
<tr>
<td>Peripheral blood†</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Data are mean ± SEM. TPN indicates total parenteral nutrition; EN, enteral nutrition; AP, acute pancreatitis; and BrdU, 5-bromo-2'-deoxyuridine.
†T cells of spleen cells, T cells of mesenteric lymph node cells, and T cells of peripheral blood cells.
‡P < .05 vs sham/TPN group.
§P < .05 vs AP/TPN group.
||P < .05 vs sham/EN group.

### Table 2. Rats With Bacterial Translocation to Mesenteric Lymph Nodes According to Bacterial Species Isolated

<table>
<thead>
<tr>
<th>Bacteria</th>
<th>AP/TPN Group (N=29)</th>
<th>AP/EN Group (N=26)</th>
</tr>
</thead>
<tbody>
<tr>
<td>*Escherichia coli</td>
<td>29 (100)</td>
<td>18 (69)</td>
</tr>
<tr>
<td>*Enterococcus faecalis</td>
<td>21 (72)</td>
<td>26 (100)</td>
</tr>
<tr>
<td>*Klebsiella pneumonia</td>
<td>17 (59)</td>
<td>5 (19)</td>
</tr>
<tr>
<td>*Enterobacter aerogenes</td>
<td>17 (59)</td>
<td>5 (19)</td>
</tr>
<tr>
<td>*Morganella morganii</td>
<td>17 (59)</td>
<td>3 (12)</td>
</tr>
<tr>
<td>*Clostridium</td>
<td>4 (14)</td>
<td>5 (19)</td>
</tr>
</tbody>
</table>

*Data are number (percentage) of rats. AP/TPN indicates acute pancreatitis and total parenteral nutrition; AP/EN, acute pancreatitis and enteral nutrition.

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**Figure 3.** Magnitude of bacterial translocation to mesenteric lymph nodes (MLN) (top) and plasma endotoxin level (bottom) in rats induced with acute pancreatitis (AP) followed by total parenteral nutrition (TPN) and enteral nutrition (EN) and rats without AP induction receiving TPN (sham/TPN) and EN (sham/EN). Asterisk indicates P < .05 vs AP/TPN group; dagger, P < .05 vs sham/TPN group; and double dagger, P < .05 vs sham/TPN group. Data represent mean ± SEM. CFU indicates colony-forming unit.
ent study in that no organisms were found in the pancreas of rats in the AP/TPN or AP/EN groups on day 7 (data not shown). Because pancreatic infection is related to the extent of pancreatic necrosis in human and animal AP, one explanation for the lack of infection in this model of AP is that pancreatic necrosis was seen only after 24 hours (data not shown), but not seen on day 7 in either of the AP groups. One may thus expect pancreatitis with necrosis in a more severe and/or sustained model of pancreatitis.

Enteral feedings reportedly have several noteworthy advantages over TPN other than for the prevention of BET. In a number of disease states, such as AP, burns, trauma, and sepsis, EN decreases risk of nosocomial infection, multiple-organ failure, and length of hospitalization, and lowers cost and lowers cost when compared with TPN. These advantages of EN might be due to restoration of defensive mucosal function, attenuation of both the counterregulatory hormone and enhanced proinflammatory cytokine responses, down-regulation of coagulation, and normalization of the tumor necrosis factor receptor system.

Recent evidence in both animal and human studies suggests that elemental or semi-elemental peptide formulae are as well tolerated, and efficiently absorbed in the gut lumen with little or no pancreatic enzyme secretion. Preclinical studies have shown that jejunal feeding results in negligible increases in pancreatic enzyme, bicarbonate, and volume output from the pancreas. Simultaneous stimulation of small peptide formulas was well tolerated in AP-feeding animals, and efficiently absorbed in the gut lumen with little or no pancreatic enzyme secretion.

For example, the recent study showed that jejunal administration of small peptide formulae was well tolerated in AP-induced rats. Furthermore, compared with TPN, early EN not only maintained normal intestinal structure, which is probably implicated in increased enterocyte proliferation, but also restored the depressed CD4/CD8 ratio of T cells, suggesting that early EN can potentially maintain immune system integrity during AP. Further studies regarding the safety and efficacy of EN via jejunal feeding in AP are needed.

In summary, jejunal administration of EN was well tolerated in early AP, maintained immune responsiveness and gut integrity, and reduced BET. However, compared with TPN, EN did not improve outcome. These results suggest that BET to MLN is not associated with deleterious consequences for the host during the early period of experimental AP in rats. Finally, factors other than BET may be responsible for mortality in the rat AP model.

This study was supported by a research grant from Otsuka Pharmaceutical Factory Inc, Naruto, Tokushima, Japan, and Alpha Therapeutic Corporation, Los Angeles, Calif.


We thank Steve E. Calvano, PhD, and Edward Lin, DO, for help with preparation of the manuscript. We acknowledge the help of Syohiro Kinoshita, BS, Hiroomi Yokoya, PhD, Yoshiyuki Shinagawa, BS, Seicho Kano, BS, and Keiichi Okamoto, BS, in the development of this project.

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REFERENCES

Error in References. In the original article by Kotani et al titled “Enteral Nutrition Prevents Bacterial Translocation but Does Not Improve Survival During Acute Pancreatitis,” published in the March issue of the Archives of Surgery (1999;134:287-292), reference 30 was missing from the list of references on page 292. Reference 30 should have been listed as “Keith RG. Effect of a low fat elemental diet on pancreatic secretion during pancreatitis. Surg Gynecol Obstet. 1980;151:337-343.” The journal regrets the error.