Acute Effects of Selected Hepatocarcinogens on Polyribosomes and Protein Synthesis in the Livers of Rats Fed Purified Diets Containing Hepatocarcinogens

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ABSTRACT

This investigation was concerned with the acute effect of ethionine, thioacetamide, dimethylnitrosamine (DMN), or aflatoxin B1 on hepatic polyribosomes and protein synthesis of rats fed purified diets either ad libitum for 3 to 29 weeks containing 0.025% N-2-fluorenylacetamide (2-FAA) or 0.06% 3'-methyl-4-dimethylaminoazobenzene (3'-Me-DAB) or by force-feeding for 3 days of diets containing 2-FAA, 3'-Me-DAB, DMN, or aflatoxin B1. This study revealed that long-term feeding of 2-FAA or 3'-Me-DAB diminished the acute toxic effect of ethionine, disaggregation of polyribosomes, and inhibition of protein synthesis in liver. Likewise, short-term force-feeding (3 days) of hepatocarcinogens (2-FAA, 3'-Me-DAB, DMN, or ethionine) diminished the acute toxic effect of ethionine on hepatic polyribosomes and protein synthesis. Rats force-fed diets containing 2-FAA, 3'-Me-DAB, DMN, or ethionine for 3 days and then challenged acutely with thioacetamide, DMN, or aflatoxin B1 revealed variable responses of hepatic polyribosomes and protein synthesis. Thus, long- and short-term feeding of several hepatocarcinogens leads to a resistance in hepatic polyribosomes and protein synthesis in response to the acute administration of ethionine while rats force-fed for 3 days the same carcinogens and then challenged acutely with carcinogens (thioacetamide, DMN, or aflatoxin B1) other than ethionine develop variable effects.

INTRODUCTION

In an earlier study the response of hepatic polyribosomes and protein synthesis of rats that were fed a purified diet containing ethionine for days or months prior to the administration of ethionine 4 hr before being killed was investigated (21). The results revealed that rats fed a purified diet containing 0.25% ethionine ad libitum for up to 50 weeks failed to respond to the acute i.p. administration of ethionine with a change in hepatic polyribosomes (disaggregation) and protein synthesis (decrease) as did control rats fed the basal purified diet (21). As a follow-up to these earlier findings, we decided to study whether rats fed ad libitum a purified diet containing 0.025% 2-FAA or 0.06% 3'-Me-DAB for 3 to 29 weeks would show a response by hepatic polyribosomes and protein synthesis to the acute administration of ethionine. This would enable us to evaluate whether the altered effect in response to the acute administration of ethionine due to previous feeding of 1 hepatocarcinogen, ethionine, in the diet would or would not occur with the long-term feeding of other hepatocarcinogens.

Rats fed ad libitum diets containing carcinogens usually consume less diet and gain less body weight in comparison to control animals (19, 21, 24). It also has been demonstrated that an animal's prior state of nutrition greatly influences the hepatic response in regard to polyribosomes and protein synthesis to the acute administration of toxic agents, such as ethionine (10, 21, 23) or actinomycin D (27). Therefore, in order to overcome the effects of decreased diet intake and of the altered nutritional state in the experimental animals in comparison with control animals, groups of rats were force-fed in a number of experiments. Previously, it was demonstrated that rats force-fed a purified diet containing ethionine for 3 days responded to the acute administration of ethionine similarly to rats fed the same diet ad libitum for weeks or months (21). Thus, force-feeding of diets for 3 days controlled the amount of diet intake as well as possibly offered a short-term experimental model for evaluating the influence of previous feedings of different diets on the response to the acute administration of hepatocarcinogens. Rats were force-fed for 3 days a purified diet containing single chemical carcinogens, ethionine, 2-FAA, 3'-Me-DAB, thioacetamide, or DMN and were then studied for the determination of whether they would show an altered response by hepatic polyribosomes and protein synthesis to the acute administration of hepatotoxic and carcinogenic agents, such as ethionine, DMN, thioacetamide, or aflatoxin B1.

MATERIALS AND METHODS

Female Sprague-Dawley rats 8 to 10 weeks old and weighing 167 to 200 g were used in the long-term, ad libitum feeding experiments, and female Sprague-Dawley rats 5 to 7 weeks old and weighing 125 to 155 g were used in the short-term, force-feeding experiments. In these experiments the effect of an acute administration of single carcinogenic agents on animals fed a purified diet containing single carcinogenic agents was investigated. The basal diet was the purified diet used in earlier experiments (19, 21, 24) and was composed of 16% casein, 5% corn oil, 4% salts (Hegsted IV), 5% vitamin:sucrose mixture, and 70%...
sucrose. Rats were fed ad libitum or force-fed 3 times daily the basal diet alone or the basal diet containing 0.25% DL-ethionine, 0.025% 2-FAA, 0.06% 3’-Me-DAB, or 0.032% thioacetamide. In 2 experiments rats were force-fed for 3 days the basal diet containing 0.025% 4-FAA, a noncarcinogenic compound related to 2-FAA. When 3’-Me-DAB was added to the basal diet, the vitamin:sucrose mixture was changed so that it was low in riboflavin (33 μg/100 g diet) as was used earlier (24). Rats force-fed the DMN diet received DMN (0.8 mg/100 g of body weight) added to the third feeding each day but received the basal diet alone for the earlier 2 feedings each day. Animals were fed ad libitum the basal, 2-FAA, or 3’-Me-DAB diet for intervals of 3 to 29 weeks as indicated in Table 1. Before being killed, all animals were fasted overnight, and they received i.p. single injections of DL-ethionine (100 mg/100 g of body weight, 4 hr before being killed); DMN (10 mg/100 g of body weight, 14 hr before being killed); thioacetamide (5 mg/100 g of body weight, 4 hr before being killed); or aflatoxin B1 (0.6 mg/100 g of body weight, 12 hr before being killed). In the force-feeding experiments, all rats were tube fed the basal diet for 1 day, and then groups were tube fed for 3 days the basal, 2-FAA, 3’-Me-DAB, thioacetamide, or basal diet with supplementation of DMN. In these experiments, the diets were made up with distilled water into a 67% suspension that was administered by stomach tube 3 times daily. Each animal of the different groups received daily on the average 0.86 g diet per 10 g of initial body weight. Rats were killed on the fourth morning after beginning the experimental diets, approximately 16 hr after the last evening tube-feeding. Before being killed, they received i.p. single injections of carcinogens as described previously. Rats had free access to water. They were housed in individual wire cages with raised bottoms.

In vitro incorporation experiments, postmitochondrial supernatants or microsomes of homogenates of pooled livers were used. The postmitochondrial supernatants were prepared in 0.25 M sucrose containing 0.05 M Tris-HCl, pH 7.5, 0.025 M KCl, and 0.005 M MgCl2 and were used for protein synthesis in vitro or for size distribution analysis of polyribosomes after addition of deoxycholate (0.7%, final concentration) (25, 30). L-[U-14C]Leucine (10 μCi/mol), 0.5 μCi, was added to each incubation tube.

The degree of hepatic polyribosomal aggregation under

<table>
<thead>
<tr>
<th>Dietary group</th>
<th>Duration (wk)</th>
<th>No. of experiments</th>
<th>Protein synthesis</th>
<th>Disaggregation of polyribosomes</th>
</tr>
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<tr>
<td></td>
<td></td>
<td></td>
<td>(% inhibition)</td>
<td>Visual grading: ribosomes/total x 100</td>
</tr>
<tr>
<td>Basal</td>
<td>3-4</td>
<td>7</td>
<td>78.9 ± 4.06&lt;sup&gt;a, f&lt;/sup&gt;</td>
<td>3.6+ 73.0 ± 1.21&lt;sup&gt;a, f&lt;/sup&gt;</td>
</tr>
<tr>
<td>2-FAA</td>
<td>3-4</td>
<td>2</td>
<td>34.0 ± 14.00&lt;sup&gt;c&lt;/sup&gt;</td>
<td>1.0+ 56.4 ± 14.11&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>1</td>
<td>10</td>
<td>0 53.8</td>
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<td></td>
<td>12</td>
<td>1</td>
<td>11</td>
<td>0 45.2</td>
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<tr>
<td></td>
<td>16</td>
<td>1</td>
<td>8</td>
<td>0 48.6</td>
</tr>
<tr>
<td></td>
<td>19</td>
<td>1</td>
<td>3</td>
<td>0 42.6</td>
</tr>
<tr>
<td></td>
<td>25-29</td>
<td>3</td>
<td>9.3 ± 5.49&lt;sup&gt;e&lt;/sup&gt;</td>
<td>0.7+ 48.0 ± 0.95&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>2-FAA → basal</td>
<td>2</td>
<td>2</td>
<td>26.0 ± 9.00&lt;sup&gt;d&lt;/sup&gt;</td>
<td>1.5+ 58.8 ± 4.58&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>Basal</td>
<td>4</td>
<td>1</td>
<td>77.3 ± 2.25&lt;sup&gt;f&lt;/sup&gt;</td>
<td>3.6+ 73.3</td>
</tr>
<tr>
<td>3’-Me-DAB</td>
<td>3-4</td>
<td>2</td>
<td>20.0 ± 38.00&lt;sup&gt;g&lt;/sup&gt;</td>
<td>1.0+ 52.9 ± 9.95&lt;sup&gt;g&lt;/sup&gt;</td>
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<td></td>
<td>6</td>
<td>1</td>
<td>9</td>
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<td></td>
<td>14</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

<sup>a</sup> Rats were fed ad libitum the basal diet, the 2-FAA diet (basal diet containing 0.025% 2-FAA), or the 3’-Me-DAB diet (basal diet containing 0.06% 3’-Me-DAB).

<sup>b</sup> In each experiment, livers from 3 to 6 rats of each group were pooled.

<sup>c</sup> All rats were fasted overnight and DL-ethionine (100 mg/100 g of body weight) was administered i.p. 4 hr before killing.

<sup>d</sup> In vitro protein synthesis was assayed with [14C]leucine and postmitochondrial supernatants of pooled livers of each group.

<sup>e</sup> Sucrose density gradients of deoxycholate-treated postmitochondrial supernatants. All gradients were compared with comparable controls not treated with ethionine. On (monomer-dimer)/total ribosome analyses, the mean value for control groups was 42.4 ± 1.15.

<sup>f</sup> In each experiment, ethionine-treated rats were compared with control (basal, 2-FAA, or 3’-Me-DAB diet without ethionine treatment) rats.

<sup>g</sup> Disaggregation was graded in each experiment, ranging from marked (4+) to none (0); each value is the mean.

<sup>h</sup> Mean ± S.E.

<sup>i</sup> p < 0.01, compared with basal untreated group or comparable control group.

<sup>j</sup> 0.05 > p > 0.01, compared with basal, ethionine-treated group.

<sup>k</sup> p < 0.01, compared with basal, ethionine-treated group.

<sup>l</sup> Rats were fed the 2-FAA diet for 21 to 24 weeks and then switched to the basal diet for 5 weeks.
the different experimental conditions was evaluated from
the patterns obtained by sucrose density gradients in 2
ways: (a) by visual grading in which the shifts between
heavier and lighter aggregates were scored; and (b) by
calculating the relative distribution of monomer-dimers in
relation to total ribosomes. Visual scoring was conducted
in a manner similar to that described earlier (21, 27) and
consisted of rating each gradient pattern from 0 (control) to
4+ according to degree of disaggregation (shift from heav-
ier to lighter aggregates) or from 0 (control) to 4 accord-
ing to degree of aggregation (shift from lighter to heavier
aggregates). Relative distribution of monomer-dimers in
relation to total ribosomes was determined on each gra-
dient pattern by measuring the area under the monomer
and dimer peaks and the area under the entire pattern
(monomer-dimers plus the other polyribosome fractions).

In in vivo incorporation experiments, rats received i.p.
L-[14C]leucine (10 μCi/mol). In these experiments, the rats
received the acute administration of ethionine or 0.9% NaCl
solution by stomach tube rather than i.p. Each animal
received (2.5 μCi L-[14C]leucine per 100 g of body weight) 15
min before killing. The methods used for chemical analyses
of protein and radioactivity have been described in detail in
an earlier study (22). Radioactivity in protein was measured
with a liquid scintillation spectrometer.

For hepatic ATP determination, animals were anesthe-
tized with 2-bromo-2-chloro-1:1:1-trifluoroethane and then
exposed to 100% O2. A portion of liver was frozen between
the faces of metal tongs precooled in liquid N2 (2). The
frozen piece of liver was then weighed and extracted with
ice-cold 3.14% perchloric acid. The ATP in the neutralized
perchloric acid extract was determined by the luciferin-
luciferase reaction (31) with the use of desiccated firefly
lanterns.

All rats in the chronic feeding experiments were necrop-
sied. Tissues were fixed in Zenker-formol solution, and
sections were stained with haematoxylin and eosin.

RESULTS

The Protective Effect of Hepatocarcinogens in the Diet
against the Polyribosomal Disaggregation Caused by the
Acute Injection of Ethionine

Ad libitum Feeding Studies. Female rats were fed the
basal, the 2-FAA (basal plus 0.025% 2-FAA) or the 3'-Me-
DAB (basal plus 0.06% 3'-Me-DAB) diet for 3 to 29 weeks.
The animals were weighed at weekly intervals. The control
rats fed the basal diet gained weight throughout (more
during the first 10 weeks than later on) when compared with
rats fed the 2-FAA or the 3'-Me-DAB diet without ethionine
administration (8). The rats that had been fed the 2-FAA
diet lost weight (average, 19 g) during the first week
when compared with the findings in tumor tissue of
rats fed the 2-FAA or the 3'-Me-DAB diet without ethionine
administration (8). The rats that had been fed the 2-FAA
diet lost weight (average, 19 g) during the first week
when compared with the findings in tumor tissue of
rats fed the 2-FAA or the 3'-Me-DAB diet without ethionine
administration (8).

In 1 experiment in which rats had been fed the 2-FAA
diet for 27 weeks, primary hepatocellular carcinomas developed
and were used for analyses. Tumor tissues from rats with or
without ethionine treatment 4 hr before killing were ana-
lyzed for polyribosomes and in vitro protein synthesis. After
ethionine treatment there was no disaggregation of polyri-
bosomes and an 8% decrease in protein synthesis in tumor
tissue in comparison with the findings in tumor tissue of
untreated rats.

In 3 of the preceding experiments, hepatic ATP levels
were assayed. Rats fed diets for 3, 22, and 29 weeks were
used. Rats fed the 2-FAA diet had essentially the same
hepatic ATP levels (μmol/g of liver) as those fed the basal
diet. The values for the control (basal diet) and experimental
(2-FAA diet) rats at 3, 22, and 29 weeks, respectively, were:
2.62, 3.04; 2.32, 2.12; and 2.46, 2.13. Rats fed the 2-FAA
diet for 3, 22, and 29 weeks and then treated with ethionine
showed marked decreases in hepatic ATP levels similar to
those found in rats fed the basal diet throughout and then
treated with ethionine. Specifically, the results of hepatic
ATP levels in the control and experimental rats at 3, 22,
and 29 weeks and after ethionine treatment were, respectively:
0.53 (–80%), 0.45 (–85%); 0.51 (–78%), 1.03 (–51%); and
0.30 (–88%), 0.41 (–81%).

On histological examination, the livers appeared normal
in rats fed the basal diet. The livers of rats fed the 2-FAA or
the 3'-Me-DAB diet for varying periods appeared similar to
those reported in detail in earlier studies (19, 20, 24, 28).
Force-Feeding Studies. For the avoidance of the decreased diet intake due to carcinogens added to the basal diet in the ad libitum feeding experiments and for the determination of how early feedings with diets containing 2-FAA or 3'-Me-DAB would influence the subsequent response to the acute administration of ethionine, force-feeding experiments modeled after an earlier study (21) were undertaken. Rats were force-fed the basal diet for 1 day, and then they were divided into groups. One group (control group) was force-fed the basal diet, and the other groups were force-fed different experimental diets for 3 days. All rats received ethionine i.p. on the following (fourth) morning 4 hr before being killed. The results of these experiments are summarized in Table 2. While the rats force-fed the basal diet responded to the administration of ethionine with a moderate degree of inhibition in in vitro protein synthesis (46.5%) and of polyribosomal disaggregation, the rats force-fed the ethionine diet showed only a minimal response to the ethionine administration (Table 2). These results were similar to those reported earlier (21). Rats force-fed the 2-FAA, the 3'-Me-DAB, the thioacetamide, or the DMN diet and then treated acutely with ethionine showed only minimal inhibition of hepatic protein synthesis (11.4 to 23.5%) and minimal polyribosomal disaggregation in comparison to the rats fed the basal diet alone (Table 2). Thus the responses were very similar to those observed after feeding the ethionine diet in this (Table 2) and in an earlier study (21). Although the degree of hepatic polyribosomal disaggregation due to ethionine in the 2-FAA and 3'-Me-DAB groups was considered as minimal when compared to the basal untreated groups, the differences were somewhat more marked when each was compared to the comparable untreated 2-FAA or 3'-Me-DAB group, which had more aggregated patterns than did the untreated basal group (Table 2).

Since the administration of phenobarbital is known to lead to the induction of many liver microsomal enzyme systems (4) and since phenobarbital treatment has been demonstrated to influence the carcinogenicity of some chemical carcinogens (12, 14), several experiments were conducted in which phenobarbital was administered along with force-feeding of the basal or the ethionine diet. Sodium phenobarbital (3 mg/100 g body weight) was administered i.p. twice daily (10 a.m. and 3:30 p.m.) during the 3 days of

<table>
<thead>
<tr>
<th>Dietary group</th>
<th>Ethionine administration</th>
<th>No. of experiments</th>
<th>Protein synthesis (% inhibition)</th>
<th>Disaggregation of polyribosomes</th>
<th>Visual grading</th>
<th>Monomer-dimers/total ribosomes x 100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basal</td>
<td>–</td>
<td>16</td>
<td>46.5 ± 4.11 ^i, j</td>
<td>0</td>
<td>35.2 ± 1.77 ^h, i</td>
<td>0</td>
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<tr>
<td>Ethionine</td>
<td>+</td>
<td>16</td>
<td>57.9 ± 1.85 ^f</td>
<td>2.5+</td>
<td>35.3 ± 1.36 ^h, i</td>
<td>165</td>
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<td>2-FAA</td>
<td>–</td>
<td>12</td>
<td>17.4 ± 6.57 ^k, l</td>
<td>0.2-</td>
<td>41.4 ± 1.57 ^j</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>+</td>
<td>12</td>
<td>21.7 ± 8.39 ^l, i</td>
<td>0.6+</td>
<td>21.7 ± 2.20 ^h</td>
<td>77</td>
</tr>
<tr>
<td>3'-Me-DAB</td>
<td>–</td>
<td>7</td>
<td>41.5 ± 3.19 ^j</td>
<td>0.9+</td>
<td>26.6 ± 2.24 ^h</td>
<td>76</td>
</tr>
<tr>
<td></td>
<td>+</td>
<td>7</td>
<td>23.5 ± 7.06 ^m, n</td>
<td>1.3+</td>
<td>41.9 ± 4.72 ^k</td>
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<td>Thioacetamide</td>
<td>–</td>
<td>6</td>
<td>11.4 ± 3.85 ^r, s</td>
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<td>29.8 ± 2.77 ^h</td>
<td>85</td>
</tr>
<tr>
<td></td>
<td>+</td>
<td>6</td>
<td>36.7 ± 3.55 ^t</td>
<td>0.3-</td>
<td>37.1 ± 3.03 ^h</td>
<td>105</td>
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<tr>
<td>DMN</td>
<td>–</td>
<td>8</td>
<td>18.4 ± 3.44 ^u, v</td>
<td>0.7+</td>
<td>47.7 ± 1.55 ^k</td>
<td>138</td>
</tr>
</tbody>
</table>

a Rats were force fed the basal diet, the ethionine diet (basal diet containing 0.25% DL-ethionine), the 2-FAA diet (basal + 0.025% 2-FAA), the 3'-Me-DAB diet (basal + 0.06% 3'-Me-DAB), the thioacetamide diet (basal + 0.032% thioacetamide), or the DMN diet (basal + 0.8 mg DMN per 100 g of body weight added to the third feeding each day).
b Rats received DL-ethionine (100 mg/100 g of body weight i.p.) or 0.9% NaCl solution 4 hr before killing. All rats were killed 16 hr after the last evening feeding on the third day.
c In each experiment, livers from 2 to 6 rats of each group were pooled.
d In vitro protein synthesis was assayed with [14C]leucine and microsomes of pooled livers of each group. Supernatants of livers of rats fed the basal diet were used in all assays.
e Sucrose density gradients of deoxycholate-treated postmitochondrial supernatants were prepared.
f In each experiment, ethionine-treated rats were compared with control (basal, 2-FAA, or 3'-Me-DAB diet without ethionine treatment) rats.
g State of aggregation (+, lighter aggregates; –, heavier aggregates) was graded in each experiment ranging from marked (4) to control (basal) (0); values, mean.
h Mean ± S.E.
i p < 0.01, compared with basal (protein synthesis) or each control (polyribosomes), without ethionine treatment, group.
j p < 0.01, compared with basal, ethionine-treated group.
k 0.05 > p > 0.01, compared with basal (protein synthesis) or each control (polyribosomes), without ethionine treatment, group.
l 0.05 > p > 0.01, compared with basal, ethionine-treated group.
force-feeding of the diets. On the fourth morning the animals of each group were treated with ethionine 4 hr before being killed. The results of 3 experiments revealed that the phenobarbital treatment did not influence the responses to ethionine administration. Rats force-fed the basal diet with or without phenobarbital responded to the ethionine administration with a moderate degree of hepatic polyribosomal disaggregation and decreased in vitro protein synthesis while the rats force-fed the ethionine diet with or without phenobarbital responded to the ethionine administration with a minimal degree of hepatic polyribosomal disaggregation and decreased in vitro protein synthesis, similar to the results in Table 2.

**The Effect of Acute Injections of DMN, Thioacetamide, or Aflatoxin B, on the Livers of Rats Force-Fed a Purified Basal Diet Containing Selected Carcinogens**

On the basis of the preceding results, which indicated that the acute response of hepatic polyribosomes and protein synthesis to ethionine could be altered by each of a variety of hepatocarcinogens tested in long-term as well as in short-term experiments, it became of interest to determine whether rats force-fed a purified diet containing selected carcinogens (ethionine, 2-FAA, 3'-Me-DAB, thioacetamide, or DMN) for 3 days would respond in terms of differences in hepatic polyribosomes and protein synthesis to the acute administration of carcinogens other than ethionine, such as DMN, thioacetamide, or aflatoxin B1. Table 3 summarizes the results of such experiments. First, it is apparent that rats force-fed the carcinogen-containing diets for 3 days in comparison to rats force-fed the basal diet showed some differences in hepatic protein synthesis in vitro and in hepatic polyribosomal aggregation (Table 3). Hepatic protein synthesis in vitro was significantly increased in rats force-fed diets containing 2-FAA, thioacetamide, or DMN. Greater hepatic polyribosomal aggregation (less polyribosomal disaggregation) was present in rats force-fed diets containing 2-FAA, 3'-Me-DAB, thioacetamide, or 4-FAA.

Rats force-fed the carcinogen-containing diets all showed relatively similar decreases in hepatic protein synthesis in vitro and in hepatic polyribosomal disaggregation after the acute administration of DMN (Table 3). In general, hepatic protein synthesis in vitro was significantly diminished in the groups receiving acute injections of DMN in comparison to basal untreated controls or to carcinogen-containing diets but untreated controls (Table 3). Similarly, hepatic polyribosomal disaggregation was increased in experimental groups in comparison to control groups (Table 3).

The results following acute thioacetamide administration were different than after acute administration of ethionine, DMN, or aflatoxin B1 (Tables 2 and 3). Thioacetamide administration caused increased hepatic protein synthesis in all groups except the ethionine-fed group.

The results following the acute administration of aflatoxin B1 are summarized in Table 3. Rats force-fed the basal diet or the ethionine diet for 3 days responded to aflatoxin B1 with marked decreases in protein synthesis and in polyribosomal aggregation (more polyribosomal disaggregation) more marked in the latter group than in the former group. Rats of the 2-FAA or the 3'-Me-DAB group showed little or no response to aflatoxin B1.
insignificant changes in response to the administration of aflatoxin B1. In 2 experiments, 4-FAA was fed in the diet, and the results indicated that the response after aflatoxin B1 was similar to that of the control (basal diet) group rather than to that of the group fed the 2-FAA diet.

DISCUSSION

The results of this and an earlier study (21) reveal that the chronic feeding of selected hepatocarcinogens (2-FAA, 3'-Me-DAB, or ethionine) in purified diets prevents the acute toxic effect of ethionine on hepatic polyribosomes (disaggregation) and on hepatic protein synthesis (inhibition). A similar resistance to the acute toxic effect of ethionine has been described in intrahepatically transplanted hepatomas (26), in primary hepatocellular carcinomas induced by feeding ethionine or 2-FAA (21), and, based upon a few preliminary observations in our laboratory, in hyperplastic nodules induced by chronic ethionine feeding (5) (where the resistance is greater than in nonhyperplastic nodular areas of the same livers). Others have reported that livers of rats fed hepatocarcinogens showed different properties in response to a variety of agents or conditions (1, 8, 15, 16, 18) and that hepatomas often fail to respond by changes in enzyme activity due to dietary inducing substances or to hormones as occurs in normal liver, a manifestation speculated to represent altered genomic expression in malignant cells (17).

The resistance to the acute toxic effect of ethionine by the livers of rats receiving chronic feedings of selected hepatocarcinogens occurs within 3 to 4 weeks, persists for months (as long as the hepatocarcinogen is in the diet), and is at least partly reversible in that after lengthy exposure and then return to basal diet the liver again becomes vulnerable to the acute toxic response to ethionine (Table 1; Ref. 21). The latter finding must be interpreted with caution since the total livers were studied and since even although the majority of hepatocytes may respond in this manner, the hyperplastic nodules, possible premalignant precursors (5, 6, 7, 33), could probably behave quite differently, as suggested by earlier mentioned preliminary observations. Studies by others (9, 29) also have reported that hyperplastic nodules induced by a variety of hepatocarcinogens become resistant to hepatotoxins or hepatocarcinogens.

The results of this study reveal 2 additional observations that are interesting. First, the acute toxic response to ethionine administration is different in rats fed the basal diet ad libitum than in those force-fed the basal diet. The ad libitum-fed rats showed a more marked disaggregation of polyribosomes and a greater inhibition of in vitro protein synthesis than did the force-fed rats (Tables 1 and 2). This difference may be due to the longer fast (overnight) in the ad libitum-fed rats that normally eat mainly at night than in the force-fed rats that were fed at 6 p.m. and killed the following morning. Indeed, prior nutritional state (fasted versus nonfasted) of rats prior to the administration of a hepatotoxin such as ethionine (21) or actinomycin D (27) has been reported to influence the degree of response of hepatic polyribosomes and protein synthesis. Second, hepatic protein synthesis appears to become enhanced in rats that have been force-fed for 3 days a hepatocarcinogen (ethionine, 2-FAA, 3'-Me-DAB, thioacetamide, or DMN)-containing diet (Table 3). Since these are hepatotoxic agents as well as hepatocarcinogenic agents, it is possible that the early response to low levels of the compounds in the diet is due to minimal cellular injury. Histologically, the livers did not show significant morphological alterations during the 3-day feedings, and there were no evident changes in cell populations. It is possible that the enhanced protein synthesis in the livers may reflect a reactive metabolic response similar to that that occurs with microsomal enzyme induction that acts to metabolize or detoxify low levels of carcinogens. Such effects have been demonstrated with compounds such as methylcholanthrene and others (4).

The acute feeding (3 days force-feeding) of selected hepatocarcinogens (ethionine, 2-FAA, 3'-Me-DAB, thioacetamide, or DMN) diminished the acute toxic effect of ethionine (Table 2; Ref. 21). This suggests that the use of a 3-day force-feeding protocol for acute toxicity studies may provide useful information. The results with this model, measuring the acute toxic effect of ethionine, suggest that a variety of hepatocarcinogens in the diet may cause or induce resistance to develop to acute ethionine toxicity. However, other studies with this model and measuring the acute toxic effects of different agents, DMN, thioacetamide, or aflatoxin B1, produced variable results (Table 3). First, we observed that the acute administration of some hepatocarcinogens, DMN and aflatoxin B1, to rats force-fed the basal diet produced hepatic polyribosomal disaggregation and inhibition of hepatic protein synthesis similar to that seen with ethionine while acute doses of one, thioacetamide, did not. Second, we found that force-feeding the basal diet containing some hepatocarcinogens protected against the hepatic polyribosomal disaggregation and the inhibition of hepatic protein synthesis seen with some acute toxic hepatocarcinogens, while force-feeding the basal diet containing other hepatocarcinogens did not. It is possible that the diversity of responses may be related to the overall metabolism of each carcinogen, which are known to be quite different (34), and to the means by which each agent produces acute toxic injury, which are again considered to be quite different (32). The nature of the resistance developed under certain conditions to the acute toxic action of selected hepatocarcinogens is not known, but it may be related to possibilities such as a reduced capacity for uptake of the toxic agent or from deficiencies in enzyme systems needed for metabolic activation of the toxin (3, 9, 11, 13). Further studies are necessary to elucidate the mechanisms responsible for the differences in responses. Recently, a number of reports (9, 29) have dealt with the resistance of putative premalignant liver cell populations to acute cytotoxic effects. On the basis of these findings, Solt et al. (29) have postulated sequential steps in the development of liver cancer in experimental animals. Our own studies in which rats were force-fed purified diets containing hepatocarcinogens for 3 days reveal that in response to some carcinogens the liver becomes resistant to certain acute toxic responses relating to hepatic protein synthesis. Whether these responses are due to alterations in selected liver cells or in the total population is not known.
These changes occur very early, possibly before significant morphological alterations develop. Further studies are needed for the determination of whether the effects obtained by this acute experimental approach are in any way related to the subsequent course in carcinogenesis.

REFERENCES

Acute Effects of Selected Hepatocarcinogens on Polyribosomes and Protein Synthesis in the Livers of Rats Fed Purified Diets Containing Hepatocarcinogens

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