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1 **Beef meat-promotion of dimethylhydrazine-induced colorectal**
2 **carcinogenesis biomarkers is suppressed by dietary calcium.**

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15

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19

20 **Abbreviations:** ACF: aberrant crypt foci, MDF: mucin-depleted foci, TBARS: thiobarbituric
21 acid reactive substances, DHN-MA: 1,4-dihydroxynonane mercapturic acid

22 **Abstract**

23

24 Red meat consumption is associated with increased risk of colorectal cancer. We have
25 previously shown that haemin, haemoglobin and red meat promotes carcinogen-induced
26 preneoplastic lesions: aberrant crypt foci (ACF) and mucin-depleted foci (MDF) in rats. We
27 have also shown that dietary calcium, antioxidant mix and olive oil, inhibit haemin-induced
28 ACF promotion, and normalize faecal lipoperoxides and cytotoxicity. Here we tested if these
29 strategies are effective also against red meat promotion in dimethylhydrazine-induced rats.
30 Three diets with 60% beef meat were supplemented with calcium phosphate (33 g/kg),
31 antioxidant agents (rutin and BHA, 0.05% each), and olive oil (5%). ACF, MDF, faecal water
32 cytotoxicity, thiobarbituric acid reactive substances (TBARS), and urinary 1,4-
33 dihydroxynonane mercapturic acid (DHN-MA) were measured. Beef-meat diet increased the
34 number of ACF (+30%) and MDF (+100%) ($P < 0.001$), which confirms our previous
35 findings. Promotion was associated with increased faecal water TBARS (x4) and cytotoxicity
36 (x2), and urinary DHN-MA excretion (x15). Calcium fully inhibited beef meat-induced ACF
37 and MDF promotion, and normalized faecal TBARS and cytotoxicity, but did not reduce
38 urinary DHN-MA. Unexpectedly, high-calcium control diet-fed rats had more MDF and ACF
39 in the colon than low-calcium control diet-fed rats. Antioxidant mix and olive oil did not
40 normalize beef-meat promotion nor biochemical factors. The results confirm that haem causes
41 promotion of colon carcinogenesis by red meat. They suggest that calcium can reduce
42 colorectal cancer risk in meat-eaters. They support the concept that toxicity associated with
43 the excess of a useful nutrient may be prevented by another nutrient.

44 **Introduction**

45 Red and processed meat consumption increases the risk of colorectal cancer, according
46 to meta-analyses of epidemiological studies^{1, 2}. Several explanations have been given for this
47 increase, involving fat, heterocyclic amines, N-nitrosated compounds, and haem iron. Intake
48 of dietary haem iron is associated with an increased risk of colon cancer among women of the
49 Iowa Women's Health Study³. Intake of black pudding, a blood sausage high in haem iron, is
50 associated with increased risk of colorectal cancer among women of the Swedish
51 Mammography Cohort⁴.

52 Experimental animal studies support the hypothesis that haem iron promotes colorectal
53 carcinogenesis⁵. We have shown that dietary haem, in the form of haemin, haemoglobin or
54 red meat, promotes putative precancerous lesions, aberrant crypt foci (ACF) and mucin-
55 depleted foci (MDF), in the colon of rats given a low-calcium diet^{6, 7}. Haemin is a free haem
56 ring stabilized by a chlorine atom, in contrast with chlorine-free protein-bound haem in meat
57 myoglobin. This haem-induced promotion is associated with increased lipoperoxidation and
58 cytotoxicity of faecal water, and linked to urinary DHN-MA excretion, a lipid peroxidation
59 biomarker⁸. The addition of calcium, antioxidant mix or olive oil to the diet inhibits haemin-
60 induced lipoperoxydation, cytotoxicity and promotion of carcinogenesis in rats⁶, but no
61 demonstration has already been given that these dietary factors can inhibit promotion by red
62 meat. We thus suggested, after van der Meer⁹, that diets high in calcium and oxidation-
63 resistant fat could prevent promotion by red meat.

64 This study was designed to test the hypothesis that addition of calcium, antioxidant
65 mix or olive oil to the diet can inhibit cancer-promoting effect of haem provided by beef
66 meat.

67 **Materials and Methods**

68 **Animals and Diets**

69 Eighty Fischer 344 female rats were purchased at four weeks of age from Iffa Credo
70 (St.Germain l'Arbresle, France). Animal care was in accordance with the guidelines of the
71 European Council on animals used in experimental studies. The animal colony and staff got
72 an official agreement #31-121 for in vivo rodents studies by French government. Rats were
73 housed by pairs into stainless steel wire bottomed cages. The room was kept at a steady
74 acclimatization to the animal colony and given control diet before being injected i.p. with the
75 carcinogen 1,2 dimethylhydrazine (Sigma chemical, St.Quentin, France; 190 mg/kg body wt)
76 in NaCl (9 g/L). Usually, several injections are given to rats. We reasoned that the first shot
77 initiates carcinogenesis, and the following shots promote it, blurring diet-induced promotion.
78 We thus chose a single-shot protocol, following Glauert¹⁰. Seven days later, rats were
79 randomly allocated to eight groups of ten, and allowed free access to their respective diet for
80 100 days. We chose to initiate all rats with the carcinogen, since the study was designed to
81 show dietary promotion, and because a 2.5% haemoglobin diet does not initiate ACF in rats
82 (Pierre and Corpet, unpublished results).

83 Eight experimental diets shown in Table 1 were based on the diet fed to control rats, a
84 modified AIN-76 powdered diet¹¹ prepared and formulated in a powdered form by UPAE
85 (INRA, Jouy-en-Josas, France). Dibasic calcium phosphate was included at a low
86 concentration of 2.7 g/kg. Four beef meat diets were formulated to contain 60% meat (freeze-
87 dried) w/w. Beef meat contained 0.6 µmol/g of haem. We chose this meat level, higher than
88 what most people eat, to be able to detect protection against promotion. The effect of calcium
89 and of an antioxidant mix was tested in two groups of rats given a beef meat diet
90 supplemented either with calcium phosphate (31 g/kg) or antioxidant mix (butylated
91 hydroxyanisole and rutin, 0.05% each). Last, the effect of oil was investigated by replacing
92 safflower oil by extra-virgin olive oil (5%, Puget, France) in a beef meat diet. Because
93 calcium, antioxidant mix and olive oil might be protective even in the absence of meat, three
94 other groups received beef-free control diet, supplemented with calcium phosphate,
95 antioxidant mix or olive oil. As shown on Table 1, all diets were balanced for protein (50%),
96 fat (20%) and iron (110 mg/kg) by addition of casein, lard, and ferric citrate. The diets were
97 made up every 14 days and maintained at -20°C to reduce lipoperoxidation.

98

99 **ACF Assay**

100 All 80 rats were killed by CO₂ asphyxiation in a random order at day 99 or 100. Colons were
101 excised from rats immediately post mortem, flushed with cold Krebs solution (Sigma
102 chemical, St.Quentin, France), opened longitudinally and fixed flat between two sheets of
103 filter paper in 10% formalin (Sigma chemical, St.Quentin, France). Eighty colons picked up
104 in random order were stained for 6 min in a 0.05% filtered solution of methylene blue¹².
105 Number of ACF per colon, and number of crypts in each ACF, were counted under light
106 microscope at x40 magnification in duplicate by two readers, blinded for the origin of the
107 colon. Data from the two readers were pooled.

108

109 **MDF Assay**

110 MDF may predict colon carcinogenesis better than ACF, since Apc mutations are present in
111 MDF with a frequency similar to that of tumours¹³. Colons, after being scored for ACF, were
112 stained with high iron diamine-Alcian blue procedure (HID-AB) to evaluate mucin
113 production¹⁴. Briefly, colons were rinsed in distilled water and left overnight in freshly
114 prepared HID solution (50 mL of distilled water with 120 mg N-N'-dimethyl-m-phenylene
115 diamine, 20 mg N-N'-dimethyl-p-phenylene diamine, and 1.4 mL of 60% ferric chloride).
116 After rinsing, colons were counterstained in 1% alcian blue solution for 30 min. MDF
117 number, and number of crypts per MDF, were scored blindly under light microscope at x40
118 magnification by a single reader.

119

120 **Preparation of Faecal Water**

121 Faecal pellets were collected under each cage of two rats for 24 h, thus leading to five
122 samples per group. Freeze-dried faeces were used to calculate dry faecal mass and to prepare
123 faecal water by adding 1 mL of sterilized water to 0.3 g of faeces. Samples were then
124 incubated at 37°C for one hour, stirring thoroughly every 20 min, followed by centrifugation
125 at 20 000g for 10 min. The aqueous phase was re-centrifuged at the same speed and duration
126 and the subsequent supernatant (faecal water) collected and conserved at -20°C until use.

127

128 **TBARS and Haem Assay**

129 Thiobarbituric acid reactive substances (TBARS) were measured in faecal water according to
130 Ohkawa et al.¹⁵, exactly as previously described⁷. Haem contents of freeze-dried faeces and
131 of faecal water were measured by fluorescence according to Van den Berg et al.¹⁶ and Sesink
132 et al.⁵, respectively, as already described⁷.

133

134 **Cytotoxicity Assay of Faecal Water**

135 Cytotoxicity of faecal water was quantified on a cell line according to Bonneson et al. ¹⁷, and
136 as previously described ⁷. Briefly, cancerous mouse colonic epithelial cell line, CMT93
137 (ECAC), was seeded in 96-well microtiter plates (1.6×10^4 cells per well in 200 μ L of
138 medium) and treated for 24 h with faecal water sample diluted at 10% (v/v) in the culture
139 medium. Cytotoxicity of each faecal water was quantified by the 3-(4,5-dimethylthiazol-2-yl)-
140 2,5 diphenyl tetrazolium bromide (MTT) test.

141

142 ***Urinary DHN-MA assay***

143 Each rat was placed alone in a metabolic cage, for two days during the fifth week of
144 experimental diet. The 24-hour urine was collected under each cage of one rat, thus leading to
145 ten samples per group. DHN-MA assay was done by competitive enzyme immunoassay (EIA)
146 as previously described ¹⁸, using DHN-MA-linked acetylcholinesterase enzyme. Each urine
147 sample was assayed in duplicate.

148

149 **Statistical Analysis**

150 Results were analyzed using Systat 10 software for Windows, and reported as mean \pm SD.
151 Values were considered firstly using one-way analysis of variance (ANOVA). If a significant
152 difference was found between groups ($p < 0.05$) then each experimental group was compared
153 to the control group using the Fishers's least-significant-difference test (ACF and MDF data),
154 and the Dunnett multiple comparison test (all other data).

155 **Results**

156 **Weight and food intake**

157 Final body weight of rats was 198 ± 3 g, without significant differences between groups at the
158 end of the experimentation. Food intake was the same in all groups of rats (data not shown).

159

160 **ACF and MDF data**

161 Beef meat diet doubled the number of MDF per colon compared to control rats, and increased
162 the number of ACF per colon (both $p<0.01$, Fig. 1). Number of crypts per lesions also was
163 enhanced by beef meat diet (Table 2).

164 Calcium fully suppressed beef meat-induced promotion of ACF and MDF (Fig. 1), but did not
165 reduce the mean number of crypts per lesions (Table 2). Antioxidant mix and olive oil
166 significantly reduced meat-induced promotion of MDF number, but did not normalize it to
167 control values (Table 2). In contrast, antioxidant mix and olive oil did not interfere
168 significantly with beef meat-induced promotion of ACF number (Table 2). Thus, only
169 calcium supplementation fully suppressed the beef-induced promotion of ACF and MDF.

170 Supplementation of no-meat control diet with antioxidant mix or olive oil did not modify
171 ACF or MDF incidence (Table 2), as previously observed ⁶. In contrast, surprisingly, high-
172 calcium control diet-fed rats had more MDF and ACF in the colon than low-calcium control
173 diet-fed rats, with more crypts per lesion ($p<0.01$, Table 2).

174

175 **Faecal haem, TBARS and Cytotoxicity**

176 Haem intake and faecal haem values matched study design: as expected, little haem was
177 detected in faeces of control rats, in contrast with beef meat-fed rats (Table 3). We also
178 measured haem concentrations in faecal water because, according to bile acids studies, the
179 soluble fraction of colonic contents would interact more strongly with the mucosa than the
180 insoluble fraction. As expected, haem concentration in faecal water depended directly on
181 haem level in beef-based diets (Table 3). However, rats fed the beef meat high-calcium diet
182 had little haem in faecal water, as previously observed ⁶.

183 Haem can induce the formation of peroxy radicals in fats, which may be cytotoxic and cleave
184 DNA *in vivo*. Lipid peroxidation was thus measured in faecal water by TBARS assay. Lipid
185 peroxidation correlated with haem concentration in faecal water (Table 3, $r=0.95$, $p=0.0002$).
186 Calcium almost normalized beef-induced lipid peroxidation to control level (66 and 33 μ M
187 MDA equivalent, respectively), but antioxidant mix or olive oil did not reduce peroxide

188 values (130 and 148 μM MDA equivalent, similar to 141 μM in beef meat-fed rats).
189 Furthermore, as already seen, faecal water of beef meat-fed rats was cytotoxic to CMT93
190 cells. Calcium fully inhibited beef meat-induced cytotoxicity of faecal water, but antioxidant
191 mix and olive oil did not.

192

193 **Urinary DHN-MA Excretion**

194 Table 3 shows that beef meat-based diet increased urinary DHN-MA excretion by 15-fold
195 compared with control diet ($P<0.001$). Calcium and olive oil did not reduce DHN-MA
196 excretion in beef meat-fed rats, while antioxidant mix gave a slight decrease, though
197 statistically significant.

198 **Discussion**

199 These data confirm that a red meat diet promotes colon carcinogenesis in rats. They
200 also establish that red meat promotion can be suppressed by dietary calcium. In addition
201 faecal water cytotoxicity and lipoperoxides level were linked with haem-induced promotion.

202 Red meat promoted ACF and MDF in the colon of carcinogen-induced rats, and meat
203 promotion was associated with faecal water haem, cytotoxicity and TBARS, in line with our
204 previous study ⁷. The mechanism of haem promotion is not known, and may be linked to the
205 stimulation of the endogenous production of N-nitroso compounds ^{19, 20}. Alternatively, we
206 suggest promotion is linked to peroxidation and cytotoxicity. We have explored the effect of
207 faecal water from beef-fed rats on normal (Apc +/+) and premalignant colonic cells (Apc
208 Min/+). Results show that Apc mutated cells survive haem-induced faecal lipoperoxides,
209 notably 4-hydroxynonenal (HNE) that is toxic to normal cells. Selection of mutated cells by
210 cytotoxic lipoperoxides may explain haem-promotion of colon carcinogenesis ²¹. Beef diet
211 reduces caspase-3 activity in the rat colonic mucosa, thus decreasing apoptosis induction ²². In
212 addition, loss of APC induces histone deacetylase 2: it is overexpressed in polyps of APC-
213 deficient mice, and it prevents apoptosis of colonic cells ^{23, 24}. Furthermore, HNE alters
214 histone acetylation ²⁵. Therefore, the modification of histone acetylation by meat-induced
215 HNE may reduce apoptosis induction and explain the selection of Apc-mutated cells. This
216 speculation on meat-promotion mechanism is supported by the present study: ACF and MDF
217 promotion in beef meat-fed rats was associated with high faecal lipoperoxides and
218 cytotoxicity, and, as discussed below, dietary changes that normalized faecal lipoperoxides
219 and cytotoxicity also suppressed beef meat-promotion.

220 Calcium added on top of beef-meat diet normalized number of ACF and MDF at the
221 same low level as control group, a protection already observed against haemin-induced
222 promotion⁶. In faeces from rats given high-calcium beef meat diet, haem concentration was
223 high (similar to beef meat-fed rats), but faecal water haem level was low (similar to no-meat
224 control rats) (Table 3). Calcium phosphate precipitates haem in the gut, and little haem
225 remains available to induce lipoperoxidation, as previously showed with haemin ^{6, 9}. Faecal
226 water thus contained little lipid peroxides and showed little cytotoxic activity (Table 3). The
227 trapping of haem by calcium abolished carcinogenesis promotion. This confirms that haem
228 is the cause of red meat promotion. The results also suggest that calcium can reduce colorectal
229 cancer risk in meat-eaters. It might explain discrepancies between clinical trials with calcium
230 supplements, since results were not analyzed based on meat consumption by volunteers. This

231 could be looked for in a prospective cohort study, to know if the protective effect of calcium
232 against red meat promotion can also be seen in human beings. Similarly, an epidemiological
233 study shows that chlorophyll from vegetables attenuates the elevated risk of colon cancer
234 associated with red meat intake ²⁶.

235 No protection against beef meat promotion was afforded by the antioxidant mix or by
236 olive oil (Table 2). These supplements did not normalize faecal values of haem lipoperoxides
237 and cytotoxicity either (Table 3). These results conflicts with a previous study in which the
238 antioxidant mix or olive oil had been effective against haemin-induced promotion⁶. This
239 conflict suggests that dietary haemin is not a suitable model for red meat to test preventive
240 strategies in rodents. We speculate that antioxidant molecules added to the diet can directly
241 prevent the effect of haemin powder on dietary oil⁶. Here, in contrast, protein-bound haem in
242 red meat might have been protected from the antioxidant effect. Furthermore, since faecal
243 water lipoperoxides and cytotoxicity are associated with haem-induced carcinogenesis, here
244 and in previous studies ^{6, 7}, we suggest they can be used as short term biomarkers to screen
245 preventive strategies against red meat-induced promotion of colon cancer.

246 An unexpected result here was that rats eating a high-calcium control diet had more
247 ACF and more MDF than low-calcium control diet-fed control rats. This promotion by
248 calcium phosphate in a high-fat context was not seen in a low-fat context, in our previous
249 haemin study ⁶. It is generally agreed that calcium reduces the risk of colorectal cancer ²⁷, and
250 a meta-analysis study shows that calcium modestly decreases tumour incidence in rats ²⁸.
251 However, in 14 studies out of 32, a non-significant tumour incidence increase was seen in
252 calcium-fed rats. The meta-analysis also shows that some calcium salts are more protective
253 than others, and that calcium phosphate affords no protection ²⁸. Calcium phosphate (which
254 we used here) sometimes promotes ACF or tumours ^{29, 30}. For instance Bull et al. showed that
255 calcium phosphate promotes colon tumourigenesis in two genetic contexts (Sprague-Dawley
256 and Fisher 344 rats). In both types of rat the promotion was more important in 30%-fat diet-
257 fed rats than in 3%-fat diet-fed rats ³⁰. Phosphate, not calcium, might be the promoting
258 nutrient, an issue discussed by Bruce³¹. To conclude, promotion by calcium phosphate in a
259 high-fat context was unexpected, but has already been reported.

260 Another surprise here is that all beef meat diets increased urinary DHN-MA excretion
261 more than ten-fold. We have recently proposed urinary DHN-MA as a noninvasive biomarker
262 of haem iron-induced promotion of carcinogenesis. Indeed, DHN-MA excretion increases
263 dramatically in rats given high-haem diets, and the excretion parallels ACF and MDF

264 numbers in azoxymethane initiated rats⁸. However, in the present study, the addition of
265 calcium to the meat diet did not reduce DHN-MA excretion while it normalized ACF and
266 MDF promotion. DHN-MA is the major urinary metabolite of HNE, a lipid peroxidation
267 product. DHN-MA excretion reflects endogenous HNE formation in the body, together with
268 formation in the diet⁸, the latter being probably quantitatively the most important³², while
269 preneoplastic lesions such as ACF and MDF may be due to lipid peroxidation occurring
270 locally in the colon lumen. One can hypothesize that calcium blocks haem in the intestine⁹ but
271 not in the diet, because of its powdered form, so the overall DHN-MA excretion is not
272 significantly reduced by the addition of calcium although HNE formation is reduced in the
273 colon lumen. Indeed, in a previous work, we have shown that HNE was found three times less
274 in the faeces of rats fed beef + calcium diet as compared to beef diet²¹. It thus seems that
275 DHN-MA is a biomarker of exposure to a promoting dose of haem in the diet, but DHN-MA
276 is not a risk factor. However, measurement of HNE in faeces, which can reflect HNE in colon
277 lumen, could be an indicator of the colon cancer risk associated with diets.

278 In conclusion, this study shows for the first time calcium prevention of red meat
279 promotion of colon carcinogenesis. This study supports the concept that toxicity associated
280 with the excess of a useful nutrient like haeminic iron may be prevented by another nutrient
281 like calcium. Yoghurt or cheese can be eaten after red meat, provided portions are small
282 enough to avoid fat overload. We found hardly any example of similar antidote effect, except
283 may be the lactulose prevention of protein-induced hepatic encephalopathy³³. This calcium
284 preventive effect should be looked for in a cohort study by crossing haem and calcium intake
285 with adenoma or cancer risk. Furthermore, different haem forms do not have the same
286 promoting potency and cannot be antagonized by identical agents, since haemin effect is not
287 identical to red meat effect. Last, faecal water lipoperoxidation and cytotoxicity may be
288 responsible, at least in part, of haem-induced promotion of colon carcinogenesis.

289

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Table 1: Composition of diets (g/kg)

| | Control (low calcium) | Beef (low calcium) | Control + Calcium | Beef + Calcium | Control + Olive Oil | Beef + Olive Oil | Control + Antiox. | Beef + Antiox. |
|--|---------------------------------|------------------------------|------------------------------------|---------------------------------|--------------------------------------|-----------------------------------|------------------------------------|---------------------------------|
| Beef | 0 | 600 | 0 | 600 | 0 | 600 | 0 | 600 |
| Lard | 160 | 0 | 160 | 0 | 160 | 0 | 160 | 0 |
| Safflower Oil | 50 | 50 | 50 | 50 | 0 | 0 | 50 | 50 |
| Olive Oil | 0 | 0 | 0 | 0 | 50 | 50 | 0 | 0 |
| Casein ^a | 500 | 59.7 | 500 | 59.7 | 500 | 59.7 | 500 | 59.7 |
| Corn Starch | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 |
| Sucrose | 127.5 | 128.6 | 96.5 | 97.5 | 127.5 | 128.6 | 126.5 | 127.6 |
| Cellulose | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 |
| Methionine | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Mineral mix ^b | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 |
| Vitamin mix ^b | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| Choline bitartrate | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| CaHPO₄·2H₂O | 2.7 | 2.1 | 33.8 | 33.1 | 2.7 | 2.1 | 2.7 | 2.1 |
| Rutin+BHA ^d | 0 | 0 | 0 | 0 | 0 | 0 | 0.5 + 0.5 | 0.5 + 0.5 |
| Ferric Citrate ^c | 0.27 | 0 | 0.27 | 0 | 0.27 | 0 | 0.27 | 0 |

a. Low-calcium casein

b. AIN76 mix, but 500g/kg of dibasic calcium phosphate replaced by sucrose in mineral mix.

c. All diets contained 110 mg/kg iron. Iron concentration was measured in freeze-dried beef before preparing the diets. Other nutrients were balanced: 50% protein, 21% fat, 20-24% carbohydrate, (based on added components, no analysis was done on whole diets).

d. BHA, butylated hydroxyanisole

Table 2: Effect of meat-based diets on aberrant crypt foci and mucin-depleted foci in the colon of rats 107 d after the injection of dimethylhydrazine¹.

| Diets ² | Haem | ACF | | | | | | MDF | | | | | |
|--------------------|-------------|------------------|----|------------------|----|------------------|-----|------------------|-----|-------------------|------|------------------|-----|
| | μmol/g diet | ACF/colon | | AC/colon | | Crypts/ACF | | MDF/colon | | MDC/colon | | Crypts/MDF | |
| | | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| Control | 0 | 105 ^a | 24 | 245 ^a | 52 | 2.3 ^a | 0.2 | 3.5 ^a | 2.0 | 18.2 ^a | 15.3 | 4.6 ^a | 1.7 |
| Beef | 0.4 | 137 ^b | 26 | 347 ^b | 55 | 2.6 ^b | 0.2 | 7.4 ^b | 2.0 | 40.7 ^b | 18.9 | 5.3 ^a | 1.6 |
| Beef + Calcium | 0.4 | 106 ^a | 24 | 265 ^a | 74 | 2.5 ^b | 0.2 | 3.4 ^a | 1.8 | 24.3 ^a | 12.6 | 7.8 ^b | 3.1 |
| Beef + Antiox. | 0.4 | 125 ^b | 20 | 299 ^c | 60 | 2.4 ^a | 0.2 | 5.3 ^c | 1.2 | 22.5 ^a | 5.3 | 4.3 ^a | 0.7 |
| Beef + Olive Oil | 0.4 | 127 ^b | 22 | 300 ^c | 40 | 2.4 ^a | 0.3 | 5.6 ^c | 1.1 | 22.4 ^a | 9.5 | 3.9 ^a | 1.4 |
| Con. + Calcium | 0 | 130 ^b | 22 | 365 ^b | 71 | 2.8 ^c | 0.2 | 7.6 ^b | 3.0 | 58.2 ^c | 27.5 | 7.6 ^b | 2.4 |
| Con. + Antiox. | 0 | 104 ^a | 25 | 258 ^a | 71 | 2.5 ^b | 0.2 | 3.8 ^a | 2.5 | 15.6 ^a | 13.0 | 4.0 ^a | 1.2 |
| Con. + Olive Oil | 0 | 107 ^a | 22 | 243 ^a | 48 | 2.3 ^a | 0.2 | 3.2 ^a | 1.3 | 14.7 ^a | 8.8 | 4.4 ^a | 1.4 |

¹ Values are means and SD, N = 10 rats /dietary group. Mean values within a column with unlike superscript letters were significantly different ($P < 0.05$)

² Diets were based on a low calcium formula, and were balanced for iron (110mg/kg). Each group had ten rats. See Table 1 for precise composition.

Table 3: Effect of meat-based diets on faecal values in rats, notably haem, lipoperoxides and cytotoxicity of faecal water¹.

| Diets ² | TBARS in faecal | | | | | | | | | | | | | |
|--------------------|------------------|-----|-------------------|------|-------------------|------|-----------------|----|----------------------|----|-------------------|----|----------------------|-------|
| | Haem | | Dry faecal | | Haem in | | Haem in | | water | | Cytotoxicity on | | Urinary | |
| | intake | SD | Mass | SD | faeces | SD | faecal water | SD | MDA | SD | CMT93 cells | SD | DHN-MA | SD |
| | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean % | SD | Mean | SD |
| | μmol/d | | g/d | | μmol/g | | μM | | μM | | cells lysed | | ng/d | |
| Control | 0 ^a | | 0.49 ^a | 0.12 | 0.56 ^a | 0.65 | 7 ^a | 6 | 33 ^a | 9 | 35 ^a | 8 | 58.2 ^a | 7.5 |
| Beef | 3.8 ^b | 0.3 | 0.68 ^b | 0.05 | 2.94 ^b | 1.01 | 49 ^b | 7 | 141 ^{b,c,d} | 16 | 63 ^b | 12 | 899.4 ^b | 244.7 |
| Beef + Calcium | 3.8 ^b | 0.3 | 0.99 ^c | 0.14 | 2.63 ^b | 1.28 | 9 ^a | 4 | 66 ^e | 7 | 26 ^{a,c} | 15 | 858.3 ^b | 262.3 |
| Beef + Antiox. | 3.6 ^b | 0.2 | 0.56 ^a | 0.07 | 3.20 ^b | 1.80 | 67 ^b | 17 | 130 ^d | 35 | 65 ^b | 10 | 630.5 ^c | 169.8 |
| Beef + Olive Oil | 3.6 ^b | 0.3 | 0.55 ^a | 0.11 | 3.11 ^b | 0.70 | 64 ^b | 21 | 148 ^c | 16 | 66 ^b | 9 | 747.1 ^{b,c} | 232.8 |
| Con. + Calcium | 0 ^a | | 0.79 ^b | 0.10 | 0.53 ^a | 0.51 | 6 ^a | 1 | 22 ^a | 8 | 16 ^c | 6 | 36.4 ^a | 6.5 |
| Con. + Antiox. | 0 ^a | | 0.58 ^a | 0.06 | 0.39 ^a | 0.35 | 9 ^a | 4 | 43 ^a | 21 | 32 ^a | 19 | 40.6 ^a | 2.4 |
| Con. + Olive Oil | 0 ^a | | 0.56 ^a | 0.07 | 0.52 ^a | 0.43 | 7 ^a | 5 | 39 ^a | 14 | 50 ^b | 12 | 55.6 ^a | 23.4 |

¹ Values are means and SD. Faecal values, N= 5 cages /group. Urine values, N=10 rats /group. Mean values within a column with unlike superscript letters were significantly different ($P<0.05$)

² Diets were based on a low calcium formula, and were balanced for iron (110mg/kg). Each group had ten rats. See Table 1 for precise composition.

Figure 1: Effect of beef meat, and high-calcium beef meat, diets on putative precancerous lesions per rat colon 100 d after the injection of dimethylhydrazine. Top panel, **A:** Number of aberrant crypt foci (ACF). Bottom panel, **B:** Number of mucin-depleted foci (MDF). Values are means \pm SD, N = 10. Means without a common letter differ, $P < 0.05$.

