Inhibition of peptic activity by carbenoxolone and glycyrrhetic acid

F. D. HENMAN

From the Research Laboratories, May & Baker Ltd, Dagenham, Essex

SUMMARY Carbenoxolone (Biogastrone, Berk) has been shown to reduce the peptic activity and total acidity of gastric juice obtained from anaesthetized pylorus-ligated rats without affecting significantly the volume of gastric juice secreted or the K+ concentration. Glycyrrhetic acid was less potent in reducing peptic activity and caused no reduction in total acidity.

Antipeptic activity of carbenoxolone has also been demonstrated in vitro using the pepsin plate technique and the haemoglobin pepsin assay.

It is suggested that these actions of carbenoxolone may contribute to the increased rate of healing of peptic ulcer in patients treated with the drug.

Liquorice extract has been used in the treatment of peptic ulcers for centuries without any particular rationale. Its activity is believed to be associated with the glycoside, glycyrrhizinic acid, hydrolysis of which yields glycyrrhetic acid (1) [3,hydroxy-11-oxo-18βolean-12-en-30-oic acid]. Carbenoxolone sodium (2) is the disodium salt of glycyrrhetic acid hemisuccinate, and is marketed as Biogastrone (Berk). It is claimed to be of value in the treatment of gastric ulcer but is of little value in the treatment of duodenal ulcer. Several clinical trials have been reported in recent years on the efficacy of carbenoxolone in gastric ulcer therapy. For instance Doll, Hill, Hutton, and Underwood (1962), Doll, Hill, and Hutton (1965), and Horwich and Galloway.
Previously shown to possess antipeptic activity
and to protect experimental animals against
peptic ulceration (Levey and Sheinfeld, 1954;
Anderson, 1961a and b; Anderson and Harthill,
1967).

Methods

1 PYLORUS-LIGATED RATS
Female Sprague-Dawley rats (180-220 g) were
deprived of food overnight but given free access
to 5% dextrose and 0.2% sodium chloride
in distilled water. Solutions were prepared so
that 2 ml of solution contained the weight of
compound required by 1 kg body weight.
Solutions were administered orally in a volume
of 2.0 ml/kg. Control animals received only
sodium bicarbonate solution at pH 7.0-8.0. The
pylorus was ligated while the animals were
anaesthetized with 40 mg/kg pentobarbitone
sodium given intraperitoneally. Four hours
later the rats’ stomachs were removed. The
contents were centrifuged at 3,000 rpm for 10
minutes and were assessed for volume, total
acid concentration, peptic activity, and K+ con-
centration (see method 2).
A chronic experiment was undertaken to
investigate the possibility that the antipeptic
activity of carbenoxolone could be cumulative
with prolonged dosage, and also the suggested
antagonism of carbenoxolone’s activity by
spironolactone. Three groups of 16 rats each
were treated daily with 2 ml/kg of the appro-
siate solutions. The first group received 10 mg/kg
carbenoxolone orally each day, the solution
being prepared as described below. A second
group received 10 mg/kg carbenoxolone + 2.5
mg/kg spironolactone orally each day, both
drugs being dissolved in the same solution. The
third control group received a solution of
sodium bicarbonate. The pH of all three solutions
was checked and when necessary adjusted to
7.0 with dilute hydrochloric acid. During treat-
ment the weight of food eaten and the volume
of water drunk by each cage of rats were recorded
for each 24-hour period and expressed as g/100g
body weight/day and ml/100 g body weight/day
respectively. After 17 days’ treatment eight of
each of the three groups of rats were subjected
to pyloric ligation as described above, and the
remaining 24 rats were similarly used after a
further six days’ treatment. In both cases the
final doses of the appropriate solutions were
administered before the administration of the
anaesthetic and pyloric ligation.

2 GASTRIC JUICE ANALYSIS METHODS

Pepsin
The method was essentially that of Anson (1938)
as modified by Aitken, Spray, and Walters (1954) except that dilutions were made by these authors with hydrochloric acid at pH 1.5.

One in 100 dilutions of the centrifuged gastric juice samples obtained from pylorus-ligated rats were prepared in dilute hydrochloric acid (pH 2.00). One ml of each dilution was incubated with 2% haemoglobin (5 ml) dissolved in the same hydrochloric acid at 37°C. After 10 minutes the reaction was stopped by the addition of 0.3 N trichloracetic acid (10 ml) and inverting the tube once. The solution was filtered through a Whatman no. 1 filter paper. A portion (5 ml) of the filtrate was made alkaline by adding 0.5 N NaOH (10 ml); 3 ml of a 1 in 3 dilution of Folin-Ciocalteu reagent was then added with care down the side of the test tube which was inverted once. The optical density was measured 10 to 20 minutes later on a Unicam SP 600 spectrophotometer at 660 m\mu. Blanks were prepared using 1 ml of dilute HCl instead of the gastric juice dilution and the mean value of the blanks was subtracted from the optical density readings to give a correct reading. Pepsin concentrations were calculated from a calibration curve previously prepared. All determinations were carried out in duplicate.

**Total acid**

Samples (0.1 ml) of gastric juice were titrated against 0.01 N sodium hydroxide with phenol red as indicator. All determinations were done at least twice. The results were expressed as m-equiv/ml.

**Potassium (K\textsuperscript{+})**

The 1 in 100 dilutions prepared for pepsin assay were submitted to flame photometry. The K\textsuperscript{+} concentration in parts per million was ascertained from a calibration curve.

3 A N T I P E P T I C A C T I V I T Y I N V I T R O

**Haemoglobin digestion**

Serial dilutions of carbenoxolone were made in hydrochloric acid at a pH of 2.0 when 75 \mu g/ml pepsin was present and at a pH of 3.6 with 2 mg/ml pepsin.

A Roter tablet (\equiv 350 mg bismuth subsalicylate) was ground in a mortar and the antacids were neutralized with hydrochloric acid. From the resulting suspension, serial dilutions were prepared similarly to those with carbenoxolone.

A suspension of Ebimar (1 tablet \equiv 0.5 g carrageenan substance) in distilled water was also serially diluted.

The procedure described above for pepsin was used to assay antipeptic activity in the samples. The haemoglobin substrate was made up in hydrochloric acid at pH 3.6 for use with dilutions in this medium. Optical density readings were compared with control readings. All determinations were carried out in quadruplicate.

**Pepsin plates**

Pepsin plates were prepared by the method of Carter and Sykes (1961). Plates were used in pairs, each pair having 32 cups. Pepsin solution, with or without carbenoxolone, Roter, or Ebimar, was made up in half-strength McIlwaine buffer (pH 3.5) such that the amount of pepsin in the 0.02 ml was either 1 or 10 \mu g. The concentration of the drug was varied, and five or six samples of each concentration were estimated in each assay, the solutions being distributed on the plates in a latin square design. After three hours, when the solutions had been absorbed into the agar, the plates were inverted and incubated at 37°C for 24 hours and then the zones of digestion were measured in two directions at right angles. After averaging the zones produced by each different solution and subtracting the cup diameter, the average zone sizes produced in the presence of the drug were compared with those produced by pepsin alone. Graphs were plotted of inhibition of peptic activity by the drugs at each concentration of pepsin.

**Materials Used**

**HAEMOGLOBIN**

Bovine, enzyme substrate powder, Piece Chemical Company, Illinois.

**PEPSIN**

Hog stomach 3 \times crystallized from diluted alcohol, Mann Research Laboratories, New York.

**CARBENOXOLONE**

The carbenoxolone used was prepared in the May & Baker Research Laboratories by Dr M. P. L. Caton by the reaction of glycyrrhetinic acid with succinic anhydride in boiling pyridine. The product was crystallized from aqueous methanol and had mp 317-320°C (decomp.). (Finney and Tarnoky (1960) give mp 315-7°C.)

(Found: C, 71.6; H, 8.8. Calc. for C\textsubscript{33}H\textsubscript{45}O\textsubscript{7}: C, 71.6; H, 8.8%). It was dissolved in aqueous sodium bicarbonate and the pH was adjusted to pH 7-0-8.0. One batch of material was used for the acute and in-vitro experiments whilst a second batch of carbenoxolone was employed in the chronic experiment. The glycyrrhetinic acid used was obtained from Fluka A.G. (Switzerland). This did not dissolve completely in bicarbonate, and was administered as a suspension in bicarbonate, again adjusted to pH 7.0-8.0. Suspensions of Roter (F.A.I.R.) and Ebimar (Evans Medical) were prepared as described in method 3.

Spironolactone, administered in chronic experiments, was obtained from Aldactone A
Inhibition of peptic activity by carbenoxolone and glycyrrhetinic acid

Table Ia Effect of carbenoxolone sodium and glycyrrhetinic acid on peptic activity of gastric juice obtained from anaesthetized pylorus-ligated rats

<table>
<thead>
<tr>
<th>Compound</th>
<th>Oral Dose (mg/kg)</th>
<th>Mean Pepsin Concentration (μg/ml × 10³) Mean</th>
<th>SE</th>
<th>Control</th>
<th>Mean Pepsin Concentration (μg/ml × 10³) Mean</th>
<th>SE</th>
<th>D</th>
<th>t</th>
<th>P</th>
<th>Percentage Inhibition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbenoxolone sodium</td>
<td>200 (6)</td>
<td>4-5</td>
<td>±3-36</td>
<td>5-05</td>
<td>14-72</td>
<td>&lt;0-0005</td>
<td>99-0</td>
<td>100 (6)</td>
<td>4-36</td>
<td>&lt;0-0005</td>
</tr>
<tr>
<td></td>
<td>100 (6)</td>
<td>5-25</td>
<td>±1-43</td>
<td>6-56</td>
<td>10-48</td>
<td>&lt;0-0005</td>
<td>53-4</td>
<td>25 (6)</td>
<td>2-55</td>
<td>&lt;0-0025</td>
</tr>
<tr>
<td></td>
<td>25 (6)</td>
<td>3-94</td>
<td>±1-09</td>
<td>5-97</td>
<td>5-35</td>
<td>&lt;0-0005</td>
<td>&gt;0-0005</td>
<td>12-5 (6)</td>
<td>3-90</td>
<td>&lt;0-35</td>
</tr>
<tr>
<td>Glycyrrhetinic acid</td>
<td>200 (6)</td>
<td>4-26</td>
<td>±1-94</td>
<td>8-98</td>
<td>2-73</td>
<td>&lt;0-030</td>
<td>5-6</td>
<td>100 (6)</td>
<td>4-24</td>
<td>&lt;0-030</td>
</tr>
</tbody>
</table>

Table Ib Total H⁺ Concentration in gastric juice obtained by four-hour pyloric ligation in anaesthetized rats determined by titration against \( \frac{N}{100} \) NaOH

<table>
<thead>
<tr>
<th>Compound</th>
<th>Oral Dose (mg/kg)</th>
<th>Mean Volume Juice Secreted (ml)</th>
<th>Mean K⁺ Concentration (ppm × 10³)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Experimental</td>
<td>Control</td>
</tr>
<tr>
<td>Carbenoxolone</td>
<td>200</td>
<td>3-70</td>
<td>4-20</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>3-73</td>
<td>2-83</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>4-92</td>
<td>4-98</td>
</tr>
<tr>
<td></td>
<td>12-5</td>
<td>2-90</td>
<td>1-86</td>
</tr>
<tr>
<td>Glycyrrhetinic acid</td>
<td>200</td>
<td>4-63</td>
<td>3-32</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>4-66</td>
<td>3-77</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>3-98</td>
<td>3-75</td>
</tr>
</tbody>
</table>

Table Ic Effect of carbenoxolone and glycyrrhetinic acid on volume of gastric juice and K⁺ concentration in anaesthetized pylorus-ligated rats
controls. There were no trends in the results for the volume of juice secreted, total acidity, or K+ concentration. These results are summarized in Table II. No consistent or significant differences were found in the average food and water intake per 100 g body weight per day or in the rate of increase of body weight.

**Antipeptic Activity in Vitro**

**Haemoglobin digestion**

Both carbenoxolone and Roter reduced peptic activity *in vitro*, the former being some 10 times more active than Roter when the latter’s activity was expressed as bismuth subnitrate (Table III). In this test Ebimar did not give reproducible results when amounts of carrageenan up to 18 mg were used. Glycyrrhetinic acid was not evaluated in this test.

![Graph showing percentage inhibition of peptic activity](image)

**Table II**  
Effect of chronic administration of carbenoxolone sodium (10 mg/kg p.o.) with or without spironolactone (2.5 mg/kg p.o.) on parameters of gastric secretion obtained from anaesthetized four-hour pylorus-ligated rats

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Duration of Treatment (days)</th>
<th>Mean Volume Juice Secreted (ml)</th>
<th>Mean Pepsin Concentration (ug/ml x 10^9)</th>
<th>Mean Total H+ Concentration (m-equiv/l x 10)</th>
<th>Mean K+ Concentration (ppm x 10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>17</td>
<td>4.25</td>
<td>1.96</td>
<td>1.35</td>
<td>1.08</td>
</tr>
<tr>
<td>Carbenoxolone sodium</td>
<td>3.89</td>
<td>18.0</td>
<td>1.46</td>
<td>&lt;0.05</td>
<td>&lt;0.0025</td>
</tr>
<tr>
<td>Carbenoxolone sodium + spironolactone</td>
<td>3.51</td>
<td>16.3</td>
<td>1.38</td>
<td>&lt;0.005</td>
<td>&gt;0.0125</td>
</tr>
<tr>
<td>Control</td>
<td>23</td>
<td>2.91</td>
<td>1.82</td>
<td>9.1</td>
<td>1.25</td>
</tr>
<tr>
<td>Carbenoxolone sodium</td>
<td>3.04</td>
<td>24.8</td>
<td>3.25</td>
<td>&lt;0.25</td>
<td>&lt;0.025</td>
</tr>
<tr>
<td>Carbenoxolone sodium + spironolactone</td>
<td>2.43</td>
<td>17.4</td>
<td>3.65</td>
<td>&lt;0.005</td>
<td>&gt;0.0025</td>
</tr>
</tbody>
</table>

1Figures refer to mean values determined in gastric juice obtained from the rat stomach removed four hours after the final administration of the drug and pyloric ligation.

2As compared with control group of animals in the same column and experiment.
Inhibition of peptic activity by carbenoxolone and glycyrrhetic acid

Fig. 2 Effect of carbenoxolone sodium, degraded carrageenan, and Roter on peptic activity in vitro as assessed by the pepsin plate technique.

--- --- * --- * --- Carbenoxolone against 1 µg pepsin
          Roter against 10 µg pepsin
--- * --- Carbenoxolone against 10 µg pepsin
          Ebimar against 10 µg pepsin

Each point represents the percentage reduction of the mean zone diameter produced by peptic digestion for 24 hours at 37°C when the inhibitor was present.

Discussion

The results reported here show a hitherto unpublished action of carbenoxolone, namely, its ability to inhibit pepsin both in vivo and in vitro. Carbenoxolone, which is the hemisuccinate of glycyrrhetic acid, was more potent than glycyrrhetic acid itself in inhibiting peptic activity and was also more active than both degraded carrageenan and Roter. Of those drugs currently used in the treatment of peptic ulcers, carbenoxolone represents the most potent inhibitor of pepsin.

Hausmann and Tárnozy (1966, and personal communication) were not able to see any significant trends in the gastric juice analyses which they carried out on 15 patients treated with
Carbenoxolone. However, these patients were suffering from a large variety of gastrointestinal disorders. In a single gastric ulcer patient treated with carbenoxolone for 20 days, as opposed to the 14-day treatment other patients received, they did show a reduction in both one hour basal gastric secretion volume and basal acid output. Bank et al (1967) observed a 34% reduction in the maximal acid output (MAO) on the augmented histamine test after two weeks' treatment with carbenoxolone (100 mg, tds) as compared with a 4% reduction in placebo-treated patients. However, after four weeks' treatment only a 24% reduction was seen in carbenoxolone-treated patients as opposed to a 13% reduction in placebo-treated patients. Apart from this, no authors seem to have considered effects on gastric secretion parameters, other than mucin secretion, when speculating on the mode of action of this drug.

Since the doses of carbenoxolone used clinically (a maximum of 100 mg orally tds, ie, 4.5 mg/kg) are considerably lower than those used in the present experiments, it might well be argued that the effects described here are irrelevant. However, comparative pharmacology is not sufficiently advanced to allow dogmatic prediction of results in one species purely on results from another species. Furthermore, we do not know what degree of inhibition of peptic activity is required for a beneficial effect to become apparent on peptic ulcer healing in man. The fact that carbenoxolone in these experiments is more effective than glycyrrhetinic acid, both in inhibiting pepsin and reducing total acid output, suggests that the effects observed with carbenoxolone may be relevant and that carbenoxolone might be expected to be more effective than glycyrrhetinic acid in the treatment of human gastric ulcers.

In the chronic experiment reported here carbenoxolone-treated animals did not show mineralocorticoid side effects despite the fact that the dose given was twice the maximal clinically used dose. It can, therefore, be argued that a larger dose and/or more prolonged administration should have been used. The effect of chronic carbenoxolone administration in the experimental situation must, therefore, still remain in doubt.

Peptic activity was reduced by carbenoxolone in vitro. Since pepsin is an albumin, the results of Whitehouse et al (1967), showing that carbenoxolone and glycyrrhetinic acid bind to bovine plasma albumin, support the idea that pepsin could be inactivated by a similar binding mechanism. They found that carbenoxolone bound more readily to bovine plasma albumin than did glycyrrhetinic acid. The effect they reported, however, was small. It is interesting that they found $\beta-[3-O(\beta$-carboxypropionyl)-18-$\beta$-glycyrrhetamido]benzoic acid was slightly more effective than carbenoxolone in its ability to bind with bovine plasma albumin. If protein-binding capacity is indeed the mechanism by which carbenoxolone inhibits pepsin, one might have expected that this compound would be more effective than carbenoxolone. The differences reported by Whitehouse et al, however, are small and might not be significant in an experiment in vivo.

In these experiments carbenoxolone was a far more potent antipeptic agent than 'Roterized' bismuth (Bateson, 1958; Matts, 1965) or the Ebimar carrageenan substance. The failure to show peptic inhibition with carrageenan may be explained by the hypothesis that carrageenan acts by forming a substrate-inhibitor complex (Anderson and Baillie, 1967). In the haemoglobin pepsin assay and, to a lesser extent, in the pepsin plate, excess substrate is present. This fact seems relevant when attempting an explanation as to why this compound had only a limited use clinically since stomach contents also contain an excess of substrate whenever food is present.

The mineralocorticoid activity of carbenoxolone has proved to limit the amounts of this drug that can be used clinically, and the limitation of dosage may well explain the variability in results of clinical trials. Doll, Langman, and Shawdon (1968) have shown that the administration of spironolactone in conjunction with carbenoxolone antagonizes both the beneficial effect on peptic ulceration as well as the effects on water retention. These results strengthened the hypothesis that the mineralocorticoid effects of carbenoxolone were essential for activity. Whilst there are some structural similarities between carbenoxolone and spironolactone it is difficult to understand how spironolactone could interfere with the mode of action of carbenoxolone if the latter is acting purely as a pepsin antagonist. To what extent the peptic inhibition contributes to the beneficial clinical results is unknown, but a more potent compound with this action and no mineralocorticoid activity could help to answer this question.

The activity of carbenoxolone in experimental ulceration has been studied in these laboratories using a variety of ulcer models. No significant and consistent effect of carbenoxolone on ulcer formation was found in any of these experimental situations (Ash and Edwards, personal communication). Whilst Dean (1968) did report some protection of Wistar rats against the ulcerogenic effects of the histamine liberator 48/80 by pretreatment with 10 mg/kg/day orally for two weeks, the protective effect he noted was small.

Khan and Sullivan (1968) were, however, able to show that carbenoxolone in an oral dose of 25 mg/kg/day increased the rate of healing of rat gastric ulcers produced by electrosurgery. Many workers feel that such studies of ulcer healing are of more value than studies of ulcer prophylaxis.

Whilst mucin stimulation has in the past been
Inhibition of peptic activity by carbenoxolone and glycyrrhetinic acid

considered as a possible mode of action of carbenoxolone the results in this paper suggest that peptic inhibition could also be considered. If these are the principal ways by which carbenoxolone helps to increase the rate of healing of gastric ulcers, one begins to understand why it is of value in treating gastric ulcers but of less value in duodenal ulcers. As gastric ulcers coexist with gastric hyposecretion, a given amount of peptic inhibition would be more significant than in duodenal ulcers where the levels of gastric secretion and peptic activity are much higher. Whilst presentation of the drug in capsules which burst in the pylorus could increase its activity in duodenal ulcers, one can speculate that a more potent peptic antagonist would be far more effective. The recent clinical trial of Duogastrone capsules by Montgomery, Lawrence, Manton, Mendl, and Rowe (1968) would seem to suggest that carbenoxolone preparations are of less value in duodenal ulcer cases.

Molecular models show very clearly that all the functional groups line along one side of the molecule and it might be suspected that only these groups would be involved in protein binding. The steroid-like backbone of the molecule probably only plays a non-specific role in peptic inhibition as a hydrophobic group. Schlamowitz, Shaw, and Jackson (1968) have shown, using a synthetic dipeptide substrate, that hydrophobicity greatly influences the binding energy of pepsin inhibitors.

If mineralocorticoid and peptic inhibitory effects can be dissociated then it should be possible to design compounds without the limitations of carbenoxolone.

The author wishes to thank Dr M. P. L. Caton for the preparation of carbenoxolone; Miss J. Mardell and her staff for the preparation of pepsin plates; and Miss S. Casey and Mr A. Jacobs for technical assistance.

References


