The 5-HT\textsubscript{3} receptor antagonist alosetron inhibits the colorectal distention induced depressor response and spinal c-fos expression in the anaesthetised rat

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Abstract

\textbf{Background—}Noxious intestinal distention elicits a reflex depressor response in the sodium pentobarbitone anaesthetised rat, which can be used as an index of visceral nociception. 5-HT\textsubscript{3} receptor antagonists inhibit this reflex. Repeated colorectal distention (CRD) induces Fos-like immunoreactivity (Fos-LI) in the rat spinal cord.

\textbf{Aims—}To examine the effect of the 5-HT\textsubscript{3} receptor antagonist alosetron on the depressor response to CRD, and on Fos expression in the lumbosacral spinal cord.

\textbf{Methods—}Male rats were anaesthetised with sodium pentobarbitone, and mean arterial blood pressure monitored during repeated colorectal balloon inflation before and after treatment with alosetron or saline. Rats anaesthetised with urethane and treated with alosetron or saline underwent a repeated CRD paradigm, after which the lumbosacral spinal cord was removed and processed for visualisation of Fos-LI.

\textbf{Results—}CRD elicited reproducible, volume dependent falls in arterial blood pressure, and repeated distension-effect curves were constructed. Alosetron (1–100 \textmu g/kg intravenously) inhibited the depressor response to CRD in a dose related manner, with an ID\textsubscript{50} value of 3.0 \textmu g/kg. Following repeated CRD, numbers of Fos-LI neurones were significantly increased to 1246 (total in 12 sections at 120 \textmu m intervals from L6 to S1) compared with 49 in sham distented animals. Pre-treatment with alosetron (100 \textmu g/kg) significantly reduced numbers of Fos-LI neurones to 479.8.

\textbf{Conclusion—}The 5-HT\textsubscript{3} receptor antagonist alosetron inhibits the depressor response to CRD in a potent and dose dependent manner. It also inhibits CRD induced Fos-LI in the spinal cord. These results suggest that 5-HT\textsubscript{3} receptors are involved in visceral nociceptive transmission, perhaps located on primary afferent or spinal neurones.

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Keywords: colorectal distention; alosetron; Fos; 5-HT\textsubscript{3}; spinal cord; pseudoaffective reflex

In man, distention of the gastrointestinal tract elicits visceral pain, as well as sensations including fullness and discomfort.\textsuperscript{1,2} In healthy subjects, visceral pain occurs in response to potentially tissue damaging distention pressure; however, the irritable bowel syndrome (IBS) has been described as a hypersensitivity of the gut, as many patients show reduced thresholds to pain and associated sensations in response to rectal balloon distention, which is not due to altered compliance.\textsuperscript{3,4} Recent studies have shown that 5-HT\textsubscript{3} receptor antagonists may modify gut sensation in patients with IBS. Alosetron has been reported to reduce pain scores significantly, and to increase rectal compliance in patients with IBS.\textsuperscript{5–8} Granisetron has also been reported to reduce rectal sensitivity in patients with IBS although ondansetron seems to be ineffective at reducing pain scores in similar studies.\textsuperscript{9,10}

In animals, noxious intestinal distention elicits a range of pseudoaffective responses including vasomotor, visceromotor, and respiratory responses,\textsuperscript{11,12} which can be used as an index of visceral nociception. The vasomotor response consists of a transient increase or decrease in arterial blood pressure, which is dependent on state and type of anaesthesia.\textsuperscript{13} This reflex is abolished by neonatal or perineural capsaicin,\textsuperscript{14,15} and is blocked by morphine in a naloxone reversible manner.\textsuperscript{16} Noxious intestinal distention also elicits an aversive response in conscious rats, as measured in a passive avoidance paradigm.\textsuperscript{14} Thus, intestinal distention can be considered to be an appropriate stimulus for studies of visceral nociception.

The immediate early gene c-fos is expressed in discrete areas of the central nervous system following chemical (cyclophosphamide, acetic acid, formalin, capsaicin) or mechanical (distention, ligation) visceral stimulation.\textsuperscript{17–23} Repetitive colorectal distention (CRD) induces c-fos expression in rat spinal cord, the number of Fos-like immunoreactive neurones increasing with stimulus intensity.\textsuperscript{24} Numbers of Fos-like immunoreactive nuclei are greatest in the lumbosacral spinal segments following CRD, which corresponds to afferent projection from the pelvic nerve.\textsuperscript{25} Systemic morphine has been shown to attenuate c-fos expression in the rat

\textbf{Abbreviations used in this paper:} CRD, colorectal distention; Fos-LI, Fos-like immunoreactive; IBS, irritable bowel syndrome.
spinal cord following noxious colorectal distention.\textsuperscript{20} In animal studies, a number of 5-HT\textsubscript{3} receptor antagonists have been reported to inhibit the vasomotor response to noxious intestinal distention.\textsuperscript{27} In the pentobarbitone anaesthetised rat, ondansetron, granisetron, and tropisetron have been shown to inhibit dose dependently volume related hypertensive responses that are also sensitive to inhibition by morphine, in a naloxone sensitive manner.\textsuperscript{29} In the present study, we have extended these studies to investigate the effect of the potent and selective 5-HT\textsubscript{3} receptor antagonist alosetron,\textsuperscript{30} and we also report the effect of alosetron on repetitive noxious CRD evoked spinal $c$-fos in the urethane anaesthetised rat. Thus we aim to establish a mechanism of action of 5-HT\textsubscript{3} receptors specific to visceral nociceptive neurotransmission. A preliminary account of this work has been presented in abstract form.\textsuperscript{30}

### Methods

All experiments were performed using male Wistar rats (220–340 g) with food and water ad libitum. All procedures were carried out in accordance with “Principles of laboratory animal care” (NIH publication No. 85-23) and Home Office guidelines (Animals (Scientific Procedures) Act 1986).

#### COLORECTAL DISTENTION—DEPRESSOR RESPONSE

Twenty nine rats were anaesthetised with sodium pentobarbitone (60 mg/kg intraperitoneally; 3–5 mg/kg intravenously). The trachea, right external jugular vein, and carotid artery were cannulated. The carotid cannula was connected to a chart recorder via a blood pressure transducer for continuous measurement of blood pressure. Body temperature was kept constant at 36–37°C using a homeothermic blanket. A 1 cm long latex balloon was inserted intrarectally so that the tip of the balloon was 2 cm from the anal verge. The balloon was connected via a double barreled cannula to a pressure transducer, and to a saline filled syringe for inflation/deflation of the balloon (the cannula was secured to the base of the tail with tape). The animals were left for 20 minutes, in order to obtain a stable recording baseline. The balloon was rapidly inflated with increasing volumes of saline (0.5–2.5 ml) for 30 seconds at five minute intervals and resultant blood pressure changes recorded. The value taken was the maximum decrease in mean arterial pressure obtained during the 30 second distention period. Three distention-response curves were constructed in this manner, allowing 10 minutes between successive curves. Alosetron (1–100 µg/kg) or saline was administered 10 minutes prior to commencement of the third curve. A single dose only was tested in each animal.

#### COLORECTAL DISTENTION—SPINAL $c$-FOS EXPRESSION

A total of 19 rats in four groups were included in this study: control CRD with intravenous saline (n=5), alosetron (30 µg/kg; n=5), alosetron (30 µg/kg; n=5), and sham distended (n=4). Rats were anaesthetised with urethane (1.5 g/kg intraperitoneally). The trachea was intubated and the right external jugular vein was cannulated for drug administration. A 4 cm long latex balloon was inserted intrarectally for until the tip of the balloon was 5 cm from the anal verge. The balloon was connected via a cannula to a barostat (Bioengineering, GlaxoWellcome Research and Development), and was inflated to 80 mm Hg for 30 seconds, every two minutes for a total of 120 minutes. In control (sham distended) animals, the balloon was not inflated. Within 30 minutes following the end of the distention period, the rats were perfused intracardially with 150 ml phosphate buffered saline followed by 300 ml neutral buffered formalin (Pioneer Research Chemicals Ltd).

The lumbosacral spinal cord (L4–S2) was removed and postfixed in fresh fixative for four hours at 4°C, then transferred to 30% sucrose in 0.1 M phosphate buffer overnight, again at 4°C for cryoprotection. Sections (40 µm) were cut on a freezing microtome; every fourth section was collected. Sections were stained for Fos-like immunoreactivity using the avidin-biotin technique, following a method similar to that described previously by Boissonade et al.\textsuperscript{31} Briefly, following preincubation with 10% normal rabbit serum (NRS) diluted in phosphate buffered saline (PBS) containing 0.2% Triton (PBST) for one hour, sections were incubated in an antibody raised in sheep against Fos (anti-Fos polyclonal antibody, 1/5000, Genosys Biotechnologies Inc., Cambridge, UK; diluted in PBST containing 5% NRS) for 44–48 hours at 4°C. The sections were rinsed, and incubated for 30 minutes in a solution containing biotinylated rabbit anti-sheep IgG (1/300, 30 minutes; Vector Laboratories Inc., Burlingame, California, USA), then incubated with the avidin-biotin complex (Vectastain Elite kit, Vector Laboratories Inc.). The reaction product was visualised using diaminobenzidine solution containing H\textsubscript{2}O\textsubscript{2} and nickel chloride (DAB substrate kit, Vector Laboratories Inc.); the sections were then mounted on gelatin coated glass slides, dehydrated, and coverslips applied. To assess antibody specificity, diluted Fos antibody was preincubated with Fos peptide (10 nmol/ml; Genosys; for 24 hours at 4°C) prior to the procedure above. In addition, incubation with the primary antibody was omitted for some sections. In either case, no significant staining was observed.

Numbers of Fos-like immunoreactive (Fos-LI) nuclei were counted 12 consecutive sections across the L6–S1 border as identified by morphology; the total number of Fos-LI nuclei in 12 sections was used for subsequent data analysis. The grey matter was divided into four regions, similar to those described previously\textsuperscript{32} for assessing regional distribution of Fos-LI nuclei (see fig 1). Images of the spinal sections were taken using an image analysis package (Leica Q600 running QWIN software; Leica UK Ltd, Milton Keynes, UK).
COMPOUNDS
Alosetron (2,3,4,5 tetrahydro-5-methyl-2-[5-
methyl-1-H-imidazol-4-yl-methyl]-1h-
pyrido[4,3-b]indol-1-one maleate; GlaxoWell-
come) was dissolved in saline (0.9%, wt/vol
sodium chloride) and was administered intra-
venously 10 minutes prior to the onset of the
test procedure in both experimental groups
(600 µl dose volume). Urethane was purchased
from Sigma and dissolved in saline (33%
wt/vol).

DATA AND STATISTICAL ANALYSIS
Results are given as mean (SEM) from n
observations. For the depressor response ex-
periments, the ID_{50} for alosetron was calculated
as the dose required to inhibit the response to
a 1.5 ml distention by 50% (geometric mean
with 95% confidence limits), and statistical
significance was determined using Student's
paired t test. In the immunocytochemistry
study, significance was determined using one
way analysis of variance (ANOVA) followed by
Dunnett's post hoc test for multiple compari-
sions. In both cases, p<0.05 was considered sig-
nificant.

Results
DEPRESSOR RESPONSE
The pentobarbitone anaesthetised rats dis-
played a mean arterial blood pressure of 108.3
(6.1) mm Hg (n=12). CRD (0.5–2.5 ml) elic-
ited volume dependent falls in mean arterial
blood pressure which were rapid in onset, and
persisted for the duration of the distention
period, despite some reduction (10–15%) in
intraballoon pressure, returning to control

Figure 1 (A) Bilateral Fos-like immunoreactivity
(Fos-LI) in a section of L6–S1 spinal cord following
repeated (2 h, 80 mm Hg for 30 s every 120 s) colorectal
distention. (B) Areas used to count regional Fos-LI: area 1,
superficial laminae I and II; area 2, laminae III and IV;
area 3, lateral laminae V–VII (intermediolateral horn) and
lateral ventral horn; area 4, medial laminae V–VII and X,
and medial ventral horn.

Figure 2 Colorectal distention (30 s every 5 min) evokes
volume related decreases in mean arterial pressure which
are highly reproducible (n=4).

Figure 3 Influence of alosetron (1–100 µg/kg) on the
hypotensive response to colorectal distention.
values within two minutes after the distention was stopped. Some animals (26% in this study) did not display a depressor response to CRD; these animals were excluded. Preliminary studies showed that sequential distention-effect curves could be constructed, the second and third of which were highly reproducible (fig 2). In all subsequent experiments, the first distention-effect curve acted as a primer, the second as control, and the third curve was constructed following drug administration.

The 5-HT3 receptor antagonist alosetron (1–100 µg/kg) inhibited the depressor response to colorectal distention in a dose related manner (fig 3). The response to 1.5 ml CRD was significantly inhibited at doses of 3–100 µg/kg (p<0.05), giving an ID50 of 3.0 µg/kg (0.4–9.3). At 10 µg/kg, alosetron reduced the response to 1.5 ml CRD to 3.3 (4.4) mm Hg compared with 21.8 (1.7) mm Hg control response (p<0.05, n=5). There was no further inhibition at doses up to 100 µg/kg (4.2 (2.4) mm Hg compared with 22.9 (2.3) mm Hg control response; p<0.05, n=6). Reduction of the response to 2.5 ml distention was greatest at 100 µg/kg (15.4 (6.1) mm Hg versus 27.1 (2.1) mm Hg control response; p<0.05, n=6). Alosetron had no effect on basal blood pressure (112.4 (6.8) mm Hg at 100 µg/kg versus 108.3 (6.1) mm Hg in control animals; n=6).

**FOS EXPRESSION**

Repetitive CRD significantly increased bilateral expression of Fos-LI compared with sham distended animals (from 49 (24) to 1246 (146); p<0.05, n=4–5). This expression was located in discrete areas of the spinal grey mat-

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**Figure 4** Alosetron reduces the number of Fos-like immunoreactive (Fos-LI) nuclei (in 12 sections across L6-S1) evoked following 2 h (80 mm Hg, for 30 s every 120 s) repeated colorectal distention. *p<0.05, **p<0.01, significant reduction of Fos-LI.

**Figure 5** Representative bitmap images illustrating distribution of Fos-like (Fos-LI) immunoreactivity in all treatment groups: (A) sham distended; (B) control colorectal distention (CRD); (C) CRD/alosetron, 30 µg/kg; (D) CRD/alosetron 100 µg/kg. Horizontal scale bar, 150 µm; arrows indicate examples of Fos-LI nuclei.
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Discussion

We have shown that responses to CRD using two experimental paradigms are blocked by the 5-HT3 receptor antagonist alosetron. In the pentobarbitone anaesthetised rat, noxious CRD elicits reproducible depressor responses, consistent with previous studies in both the small and large intestine.13,15 We have also shown that reproducible distention-effect curves obtained in this study can be used to assess drug effects. Of the animals tested, 74% displayed a vigorous depressor response to CRD, which is similar to previous findings.1,27 In the present study, the response parameters were somewhat dependent on the depth of anaesthesia. In urethane anaesthetised rats, however, where such reflexes are reported to be unaffected by anaesthetic levels, a similar proportion of animals do not display a depressor response to CRD, thus levels of anaesthetic probably do not account for the majority of non-responders in the present study.

Alosetron is a potent and selective 5-HT3 receptor antagonist, with a duration of action of several hours in the rat.24,31 It potently inhibited the depressor response to CRD, which is similar to previous findings.27,32 In the present study, the response parameters were significantly (p<0.05) reduced at 100 µg/kg alosetron. There was no significant difference in the area under the response curve at this dose between the drug treated and control groups.

Alosetron (100 µg/kg) significantly reduced the total numbers of Fos-LI nuclei in areas 1 and 3, and 68% in area 4 (100 µg/kg, p<0.05). There was no significant difference in the area under the response curve at this dose between the drug treated and control groups. At a lower dose (30 µg/kg), alosetron did not significantly reduce the total number of Fos-LI nuclei in any region, although there was a reduction of 35% in area 1. Figure 5 shows the distribution of Fos-LI nuclei in control and drug treated animals.

Dose-response relations obtained with certain 5-HT3 receptor antagonists may, however, result in underestimation of their potency.28 Alosetron did not display a bell shaped dose-response relation in this study, with stable inhibitory effects between 10 and 100 µg/kg. In other studies, systemic 5-HT3 receptor antagonists block the vasomotor response to distention of the duodenum and colorectum.27–32 These data are therefore consistent with previous findings. Continuous monitoring of intra-balloon pressure allowed the calculation of colorectal compliance from pressure-volume relations. Alosetron did not seem to affect colorectal compliance significantly in this study (unpublished observations), although this method may not be as sensitive as a barostat for detecting very small changes, as alosetron has been shown to increase compliance in studies in patients with IBS.29–31 Any such effects of alosetron on compliance in the present study would not be sufficient to account for its effect on the vasomotor response to CRD.

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Alosetron (100 µg/kg) significantly reduced the total numbers of Fos-LI nuclei in response to repetitive CRD, which is similar to previous findings.1,27 In the present study, the response parameters were somewhat dependent on the depth of anaesthesia. In urethane anaesthetised rats, however, where such reflexes are reported to be unaffected by anaesthetic levels, a similar proportion of animals do not display a depressor response to CRD, thus levels of anaesthetic probably do not account for the majority of non-responders in the present study.

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staining (amount of Fos-like protein) certainly do occur, but were not examined in the present study. This may also explain the steep dose-response curve obtained with alosetron, with a profound effect at 100 µg/kg, but no effect at 30 µg/kg. Different anaesthetics were used for the two experimental procedures, but it is unlikely that this had a major impact on the apparent efficacy of alosetron.

Induction of c-fos is thought to be largely indicative of c-fibre afferent activation, although Fos-LI occurs in response to both noxious and innocuous visceral and joint stimulation. The majority of afferents innervating the colon are c-fibres, most of which show a graded response to increasing stimulus intensity. Therefore, induction of Fos-LI in this model does not necessarily represent inhibition of nociceptive processing. Traub et al however, have reported that the opiate analgesics, morphine and tramadol, reduce CRD evoked spinal Fos-LI in both superficial and deep laminae. Their study provides some evidence that a significant proportion of the CRD evoked Fos-LI results from noxious stimulation of these dorsal horn neurones.

5-HT3 receptor protein and mRNA are widely distributed throughout the brain, spinal cord, and dorsal root ganglion neurones. A large proportion of these spinal receptors are located on the central terminals of afferent neurones, many of which are capsaicin sensitive. The present finding that deep as well as superficial laminar expression of c-fos was suppressed by alosetron, is not inconsistent with these data. Visceral afferent neurones have collaterals extending into deep as well as superficial laminae, although these neurones comprise a small proportion of the total number of afferents entering the spinal cord. Furthermore, many dorsal horn neurones in deeper laminae receive indirect input from superficial neurones; either these interneurones or the afferents terminating on them may express 5-HT3 receptors. Further evidence to support a role for 5-HT3 receptors in nociceptive processing includes the inhibition, by granisetron, of CRD induced c-fos immunoreactivity in the trigeminal nucleus by 5-HT3 receptor antagonists following noxious chemical stimulation of the rat nasal mucosa. 5-HT3 receptors are also found within the enteric nervous system of the gut, and are known to regulate gastrointestinal motility. Alosetron has been reported to normalise gut transit following sensitisation with egg albumin in rats, and to increase colonic compliance in patients with IBS. Alosetron receptors are associated with mucosal chemoceptors rather than mechanoreceptors responsive to distension. Alosetron has also been reported to inhibit the vasomotor response to CRD in dogs following intracerebroventricular injection, suggesting a central site of action.

In summary, these studies show that alosetron modulates visceral nociceptive neurotransmission in the rat, illustrated by a potent inhibition of the reflex depressor response to colorectal distention, and a reduction in numbers of Fos-LI nuclei in the spinal cord following repeated CRD. There is considerable anatomical and functional data to support a role for 5-HT3 receptors in visceral nociceptive processing. The site(s) of action of alosetron were not established in the present study; it could be at the level of the enteric or primary sensory neurone, or via spinal or supraspinal neuronal circuits concerned with the modulation of nociceptive transmission. Based on these data, in addition to recent studies indicating that alosetron decreases symptoms of abdominal pain in patients with irritable bowel syndrome, alosetron may be of potential use in the treatment of visceral pain conditions.

9 Cramer and Rademaker, however, have suggested that the site of action against distention evoked reflexes is not within the peripheral organ, as the 5-HT3 receptor antagonist ICS 205 930 inhibits the depressor response to ileal distention, but has no effect on the concurrent increased firing in afferent dorsal root fila. It is also worth noting that on vagal afferents innervating the stomach and small intestine, 5-HT3 receptors are associated with mucosal chemoceptors rather than visceral afferents.

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