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Complete List of Authors:	Eyers, Sally; Medical Research Institute of New Zealand, Williams, Mathew; Medical Research Institute of New Zealand, Jefferies, Sarah; Medical Research Institute of New Zealand, Perrin, Kyle; Medical Research Institute of New Zealand, Weatherall, Mark; University of Otago Wellington, Medicine Siebers, Robert; University of Otago Wellington, Medicine Crane, Julian; University of Otago Wellington, Medicine Patel, Mitesh; Medical Research Institute of New Zealand, Travers, Justin; Medical Research Institute of New Zealand, Shirtcliffe, Philippa; Medical Research Institute of New Zealand, Beasley, Richard; Medical Research Institute of NZ,
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RANDOMISED PLACEBO CONTROLLED STUDY OF THE EFFECT OF PARACETAMOL ON ASTHMA SEVERITY IN ADULTS

[1,2,3]Sally Eyers, [1]Mathew Williams, [1,2] Sarah Jefferies, [1,2] Kyle Perrin

[2,3]Mark Weatherall [3]Robert Siebers, [3]Julian Crane, [1,2] Mitesh Patel

[1]Justin Travers, [1,2] Philippa Shirtcliffe, [1,2]Richard Beasley

[1]Medical Research Institute of New Zealand, Wellington, New Zealand

[2]Capital & Coast District Health Board, Wellington, New Zealand

[3]University of Otago Wellington, Wellington, New Zealand

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Correspondence:

Prof Richard Beasley
Medical Research Institute of New Zealand
Private Bag 7902, Wellington 6242
New Zealand
Telephone: 64-4-805 0230
Fax: 64-4-389 5707
Email: richard.beasley@mrinz.ac.nz

ABSTRACT (word count 250)

Background: Epidemiological evidence suggests that paracetamol may be a risk factor in the development of asthma and its severity. This is the first randomised placebo-controlled trial of the effect of regular paracetamol on bronchial responsiveness and asthma control in adult asthma.

Methods: In a 12-week randomised, double-blind, placebo-controlled, parallel-group study, 94 adults with mild to moderate asthma received 12 weeks of 1g paracetamol twice daily or placebo twice daily. The primary outcome variable was bronchial hyperresponsiveness, measured as the provocation concentration of methacholine causing a 20% fall in FEV_1 (PC_{20} MCh), at week 12. Secondary outcome variables included FEV_1, FeNO and ACQ score.

Results: 94 participants received randomised treatment (36 and 58 in the paracetamol and placebo groups respectively); 85 participants completed the study. At 12 weeks the mean (SD) logarithm base two PC_{20} was 1.07 (2.36) in the control group (N=54) and 0.62 (2.09) in the paracetamol group (N=31). After controlling for baseline $PC_{20,}$ the difference (paracetamol minus placebo) was -0.48 doubling dose (95% CI -1.28 to 0.32), P=0.24. There were no statistically significant differences (paracetamol minus placebo) in log FeNO 0.09 (95% CI -0.097 to 0.27)), FEV_1 (-0.07 L (95% CI -0.15 to 0.01)), or ACQ score (-0.04 (95% CI -0.27 to 0.18)).

Conclusions: There was no significant effect of paracetamol on bronchial responsiveness and asthma control in adults with mild to moderate asthma. However, the study findings are limited by low power and the upper confidence interval limits did not rule out a clinically relevant adverse effect.

STRENGTHS AND WEAKNESSES

- Randomised placebo-controlled trial
- Physiological, clinical and immunological outcome measures
- Powered to detect a marked effect on BHR

KEY MESSAGES

What is the key question?

Does regular paracetamol use result in worsening asthma severity?

What is the bottom line?

Paracetamol use did not cause a marked increase in bronchial hyperresponsiveness or asthma control in adult asthma, although it was not possible to rule out a clinically relevant effect.

Why read on?

This is the first randomised placebo-controlled trial to measure the effects of paracetamol in stable adult asthma. The study findings provide information on which the design of further studies can be based.

INTRODUCTION

There is a growing body of evidence to suggest that paracetamol may play an important role as a risk factor for the development of asthma, and that increasing world-wide use may have contributed to the increasing global prevalence of asthma seen over the last 40 years.[1,2] Childhood asthma risk increases in the offspring of women who consume paracetamol during pregnancy,[3] and paracetamol use in the first 12 months of life is associated with an increased risk of wheezing at 3 years [4,5] and 6-7 years.[6] Cross-sectional surveys in children,[6] adolescents [7] and adults [8-11] consistently demonstrate an association between current paracetamol use and asthma in populations with widely differing lifestyles, standards of living, medical practice and availability of paracetamol. However, there is also evidence that these associations may, in part, be due to confounding by indication in some,[12-14] but not all cohort studies in childhood.[15] Cohort studies in adults have demonstrated that increasing frequency of paracetamol use is positively associated with newly-diagnosed (adult-onset) asthma.[16,17]

There is also evidence that paracetamol may increase the severity of asthma in those with the disease. This primarily comes from the only randomised controlled trial of the effect of paracetamol use for fever and asthma outcomes, in which asthmatic children experiencing a current febrile illness were randomised to receive either paracetamol or ibuprofen.[18] The children who received paracetamol were more likely to require an outpatient visit for asthma compared to children in the ibuprofen group. The increased risk with paracetamol was dose dependent and related to respiratory febrile illnesses rather than other causes of fever. In a case-control study which reported a dose-dependent association between paracetamol use and asthma, a progressively greater risk in those with more severe disease was noted, suggesting an effect on both causation and severity of the disease.[10]

The mounting epidemiological evidence, supported by several biologically plausible mechanisms [19-28] has led to repeated calls [2,5-7,13,29-32] for randomised controlled trials to be undertaken

to explore the relationship between paracetamol and asthma. This study is the first randomised controlled trial undertaken to investigate the effect of regular daily paracetamol on asthma severity in adult patients with asthma. It was powered to detect a one doubling dose change in PC_{20} methacholine bronchial hyperresponsiveness (BHR). Markers of airways inflammation and systemic immunological responses were monitored to provide insight into possible mechanisms of action. The hypothesis was that regular paracetamol use would result in a worsening in BHR and asthma control.

METHODS

The study design was a double-blind, randomised, placebo-controlled, parallel group trial based in Wellington, New Zealand. The study methods are summarised with additional details provided in the supplementary appendix. The study was approved by the Central Regional Ethics Committee (CEN/08/12/070) and all participants gave written informed consent. The trial was registered on the Australian New Zealand Clinical Trials Registry (ACTRN12609000551291).

Participants

Participants were identified from the Medical Research Institute of New Zealand (MRINZ) asthma register, general practitioner patient databases, and the general public through advertising. Inclusion criteria included age between 18 and 65 years, wheeze in the previous 12 months and a doctor's diagnosis of asthma, forced expiratory volume in 1 second (FEV_1) $\geq$70% predicted at screening and baseline and a PC_{20} MCh (the provocation concentration of methacholine causing a 20% reduction in FEV_1) of between 0.125 and 16 mg/ml at baseline. Exclusion criteria included regular use of theophylline, ipratropium bromide, tiotropium or leukotriene receptor antagonists in the previous 3 months, alanine aminotransferase (ALT) levels greater than 1.5 times the upper limit of normal at baseline, a history of liver disease or the current use of hepatotoxic drugs, an exacerbation of asthma within the previous two months requiring prednisone or nebulised bronchodilator, current or past cigarette smoking >10 pack years, history of sensitivity or allergy to paracetamol or current regular use of paracetamol, use of high-dose aspirin or non-steroidal anti-inflammatory drugs, history of alcoholism or current excessive alcohol intake, history of previous intentional overdose of paracetamol, previous suicide attempt or current unstable depression, body mass index <16 kg/m^2, pregnant or breast-feeding women or women not using adequate contraception and participants unsuitable for BHR challenge testing in accordance with American Thoracic Society (ATS) criteria.[33]

Interventions

Participants were randomised to receive one of two treatment regimens for 12 weeks. The treatments were paracetamol 1g, administered as two 500mg tablets, or placebo administered as two identically appearing tablets, taken twice daily. The paracetamol and placebo tablets were supplied by Aspen Asia Pacific Ltd, Sydney, Australia.

Randomisation

A computer-generated randomisation schedule was generated by the study statistician and was administered by the study pharmacists. It was necessary to randomise the participants prior to their final eligibility screening visit (visit 2) to enable the study pharmacists adequate time to prepare the study medication for dispensing at visit 2 following final determination of eligibility. If a participant failed one of the eligibility criteria at visit 2, the randomised medication was not dispensed and the participant was withdrawn from the study. The randomisation code was not re-used.

Blinding

Study investigators, participants, and participant health care providers were blinded through provision of medication as identically appearing tablets in bottles, with neither the investigator dispensing the medication or the participants aware of the allocated treatment.

Design

The trial involved four study clinic visits and between two and four additional blood tests over 13 weeks (Figure 1). A screening visit (visit 1) was held approximately one week prior to baseline and consisted of a medical history and brief physical examination, pregnancy test where applicable, bronchodilator reversibility testing, liver function screen and allergy skin prick tests (see online supplement for details). A diary was used to record morning and evening peak expiratory flow (PEF) values (prior to asthma medication use) for one week prior to the second visit. Participants who met initial eligibility criteria were randomised at this stage, prior to final eligibility assessment at visit 2.

At visit 2, designated the baseline visit, the Qoltech asthma control questionnaire (ACQ)[34] was administered and PEF_{var} (PEF variability measured as the amplitude as a percentage of the mean) calculated. Baseline assessments of FEV_1 were undertaken using a Micro Medical Microlab spirometer (Micro Medical, Kent, UK) and Fractional exhaled Nitric Oxide (FeNO) was assessed using a NiOX Flex chemiluminescence analyser (Aerocrine AB, Stockholm, Sweden). Methacholine (Methapharm, Ontario, Canada) challenge testing was undertaken via the two-minute tidal breathing dosing protocol recommended by the ATS,[33] as outlined in the online supplement. Participants who met all the eligibility criteria were then dispensed a six-week supply of randomised medication, a medication diary to record administered doses and a prescription for codeine phosphate for emergency pain relief during the trial period. These participants then underwent blood tests including full blood count (eosinophils), total serum immunoglobulin E (IgE), and serum cytokine levels (interferon (IFN)-γ, interleukin (IL)-4, IL-5, IL-13) (see online supplement for details).

At visits 3 and 4, six and 12 weeks after baseline, FEV_1, ACQ, FeNO and blood tests were repeated and medication compliance checked via pill count and medication diary check (see online supplement for details). At the third visit, participants were given a further six-week supply of study medication, a second medication diary, and a diary to record morning and evening PEF values in the final intervention week. At the fourth and final visit, BHR testing was repeated. Liver function tests were monitored throughout the study (see online supplement for details).

Outcomes

The primary outcome variable was PC_{20} MCh at 12 weeks, adjusted for baseline. Secondary outcome measures were FEV_1, FEV_1 % predicted, ACQ score and FeNO at six and 12 weeks, and the mean morning peak flow, PEF_{var}, and exacerbations of asthma (requiring a doctor's visit and need for prednisone or nebulised bronchodilator) at 12 weeks. Blood eosinophil, serum IgE, and serum cytokine (IFN-γ, IL-4, IL-5 and IL-13) levels were measured at six and 12 weeks.

Statistical Methods

The primary analysis method was ANCOVA. The logarithm base two PC_{20} for methacholine at 12 weeks was the primary response variable, with the baseline logarithm base two PC_{20} as a covariate, and a categorical variable for the paracetamol group. The difference in logarithm base two PC_{20} was the doubling dose difference between the two randomised groups. Secondary outcome variables, including FEV_1, FEV_1 % predicted, ACQ score, FeNO, mean morning peak flow and PEF_{var} were also analyzed by ANCOVA. The distribution of FeNO, serum IgE and eosinophil count was skewed and normality assumptions for these variables were best met on the natural logarithm scale.

A risk difference and appropriate confidence intervals were calculated for the categorical variable, the number of participants with at least one asthma exacerbation. Simple t-tests were used to compare mean values for ALT, the logarithm transformed FeNO, eosinophil count and IgE by paracetamol or placebo group, as the latter three had skewed distributions. For those variables with a logarithm transformation, the exponent of the difference in logarithms was interpreted as the ratio of mean values.

The analysis was by intention to treat of randomised participants who passed the final eligibility screening and as a result received randomised treatment. No randomised participants who failed the final eligibility screen received randomised treatment or underwent any outcome assessments. For each individual analysis, a two-sided P value of 0.05 was used, with 95% confidence intervals for each estimate. We have not adjusted for multiple statistical testing.

Sample Size

A sample size of 60 in each group has 80% power at the 5% level of significance to detect a difference of one doubling dose in PC_{20} MCh between the groups, based on a standard deviation of 1.9.[35] To allow for the possibility of up to 10% of study participants withdrawing early from the study, a recruitment target of 66 participants was set for each group.

RESULTS

Recruitment commenced in June 2009 and ended in September 2011. The planned study period of two years was extended by three months due to difficulties in recruitment. Figure 2 shows the flow of participants. There were 724 patients assessed for eligibility at phone screening and/or visit 1; of these, 338 failed to meet the inclusion criteria and 205 declined to participate (see online supplement). There were 181 participants randomised prior to visit 2 based on initial eligibility at visit 1; 91 to the paracetamol group and 92 to the placebo group. 53/91 participants allocated to the paracetamol group and 34/92 allocated to the placebo group were withdrawn at visit 2 as they either did not meet the inclusion/exclusion criteria (PC_{20} >16mg/ml, n=68; PC_{20} <0.125mg/ml, n=3; FEV_1 <70% predicted, n=6; unable to perform spirometry, n=1) or were lost to follow-up or withdrew consent (n=9). No study medication was dispensed to the participants who were withdrawn at visit 2 (see online supplement).

Medication was dispensed to 94 participants who commenced the intervention phase following visit 2: 36 randomised to paracetamol and 58 to placebo. The characteristics of the subjects are shown in Table 1. The mean age of participants was 40 years and there were 59 female participants. Approximately 30% of study participants were prescribed inhaled corticosteroids and 18% prescribed long-acting beta agonist drugs. Around 90% of participants had positive skin prick tests to either cat, mixed grass or house dust mite. Participants had mild to moderate asthma, with a baseline ACQ score of 0.86 (SD 0.59). The baseline mean FeNO was 48.9 ppb (SD 41.3) and the mean FEV_1 was 94% of predicted (SD 12.0). The baseline mean PC_{20} was 4.29 mg/ml (SD 4.54).

There were 85/94 participants who completed the study. Five participants were withdrawn from the paracetamol group; two withdrew at the participant's own discretion, one was excluded due to a raised ALT (119 IU/L), one was lost to follow-up and one was excluded due to intercurrent illness. Four participants were withdrawn from the placebo group; two were excluded due to a raised ALT

(207 and 227 IU/L respectively), one withdrew at the participant's own discretion and one was lost to follow-up.

Primary Outcome Variable

At 12 weeks the mean (SD) logarithm base two PC_{20} was 1.07 (2.36) in the control group (N=54) and 0.62 (2.09) in the paracetamol group (N=31). After controlling for baseline PC_{20}, the difference (expressed as a doubling dose difference, paracetamol minus placebo) was not statistically significant: -0.48 (95% CI -1.28 to 0.32), P=0.24 (Table 2).

Secondary Outcome Variables

There were no statistically significant differences in FEV_1, FEV_1 % predicted, ACQ score, mean morning peak flow or PEF_{var} between the control and paracetamol groups at Week 12 (Table 2) or in FEV_1 or ACQ score at Week 6 (Online Supplement). There were three asthma exacerbations in the placebo group and none in the paracetamol group, an absolute difference of 5.6% (95% CI -0.5 to 11.7%). There was 93.2% compliance in the control group and 90.8% compliance in the paracetamol group when assessed by pill count and medication diaries, a difference of 2.4%, (95% CI -1.0 to 5.8). Serum paracetamol levels (greater than the 30 µmol/L threshold) were detectable in between 31.3 to 38.7% of participants in the paracetamol group and were undetectable in all participants in the placebo group between week 2 and week 12 of the study.

There were no statistically significant differences observed in log FeNO at Week 6 (see Online Supplement), or at Week 12, or in log eosinophil or log IgE levels between the two groups at week 12 (Table 3). Only a proportion of participants had measurable levels of IFN-γ, IL-4, IL-5 and IL-13 at baseline or at other times throughout the trial, precluding meaningful analysis (see online supplement). ALT levels were significantly higher in the paracetamol group, with a mean ALT of 25.4 (SD 9.7) and 19.0 (SD 6.0) in the paracetamol and placebo groups respectively at visit 4, difference 6.3 (95% CI 2.9 to 9.7, p <0.001).

DISCUSSION

This double-blind, randomised, placebo-controlled, parallel group study found no statistically significant reduction in PC_{20} with 12-weeks paracetamol treatment. However, the results did not rule out a clinically significant effect, with the 95% confidence interval containing the pre-specified difference of one doubling dose reduction in PC_{20}. There were no significant differences observed in any of the pre-specified secondary outcome variables of asthma control, inflammatory or immunological markers.

This is the first reported randomised placebo-controlled trial of the effects of daily paracetamol in stable adult asthma. The only other published randomised controlled trial of paracetamol and asthma was the Boston University Fever Study.[18] Children randomised to the ibuprofen group had a reduced risk of having an outpatient visit for asthma during the 4 week study period (OR 0.56, 95% CI 0.34 to 0.95) compared with children in the paracetamol group. Because the study did not include a placebo treatment, it was not possible to determine whether the observed difference in morbidity according to treatment group was attributable to an increased risk with paracetamol or a decreased risk with ibuprofen.

There are several methodological issues relevant to the interpretation of our study findings. First, as enshrined in the Declaration of Helsinki [36] there is a requirement to study the least vulnerable populations wherever applicable. Most, but not all, of the putative adverse effects of paracetamol on asthma have been shown in observational studies of children and suggest that paracetamol may increase the risk of developing asthma.[1,2] However, as there is some data to suggest that regular paracetamol use may lead to a deterioration in asthma control in adults,[1,10] we opted to firstly examine the effects of paracetamol in adults with stable asthma.

Second, this trial was powered to determine whether there was an effect on BHR of at least one-doubling dose reduction in PC_{20} MCh. Our ability to achieve the designated sample size completing

the study was affected by several factors. First, despite a rigorous recruitment campaign during which over 700 patients were screened, due to the inclusion and exclusion criteria employed to ensure participant safety, only 94 screened participants were dispensed randomised medication. Secondly, variability in PC_{20} from baseline to week 12 was larger than anticipated, with a pooled SD of 2.27 doubling doses compared to that used in the sample size calculation based on a SD of 1.9, derived from previous studies.[35] Another factor which affected the study power was the requirement to randomise subjects prior to their final screening visit in order to allow the pharmacy adequate time for dispensing at visit 2, following final determination of eligibility. If the participant failed this final eligibility, the randomised medication was not dispensed, the participant was withdrawn from the study, and the randomisation code was not reused. By chance this resulted in a disparity between the proportion of participants receiving active or placebo study medication.

Compliance was high when measured via pill count, and although less than half of participants in the paracetamol group had measurable levels of paracetamol in the blood at the times tested throughout the study, this is likely to be due to the laboratory cut-off for a detectable paracetamol level (30 µmol/L). Following a 1g dose, participant blood levels may fall below this laboratory cut-off level in as little as 3 hours (given an paracetamol half-life of 2 hours and a peak plasma concentration 1 hour after administration of 80 µmol/L [37]).

Our 12-week dosing period was chosen based on evidence that regular, long-term use of paracetamol is associated with an increased risk of asthma in adults [9-11,16,17] and that chronic ingestion of therapeutic doses can reduce serum antioxidant capacity in as little as two weeks.[38] We had originally intended to use the maximum daily dose of 4g paracetamol, however chose to administer half this dose due to concerns of liver toxicity. These concerns were based on a previous clinical trial of paracetamol in which the incidence of ALT elevations more than three times the upper limit of normal in healthy participants taking 4g/day for 14 days was 31 to 44%.[39] Our results showed no clinically significant liver function derangement with paracetamol administered at a dose of 2g/day for 12 weeks.

Whilst the study did not demonstrate a statistically significant effect of paracetamol on BHR to MCh, the results do not rule out a clinically significant effect, with the upper 95% confidence interval of a 1.28 doubling-dose worsening in BHR containing the pre-specified difference of one doubling-dose. Furthermore, our point estimate of a reduction in PC_{20} of 0.48 of a doubling-dose could potentially be of major public health significance. As proposed by Mitchell,[40] a small shift to the left of the BHR curve in a population could lead to a relatively large increase in the prevalence of severe asthma. Relevant to the interpretation of our findings it has recently been calculated that a one half doubling dose increase in BHR increases the prevalence of moderate and severe BHR by about 30%.[41] Likewise, although the 9% increase in FeNO with paracetamol was not statistically significant, a change of this magnitude is considered clinically significant.[42] For FEV_1, the point estimate was consistent with a lower value in the paracetamol group, however the difference was of uncertain clinical significance and was associated with wide confidence intervals.

No significant effect was seen on serum IgE or peripheral blood eosinophil levels. It was not possible to undertake any meaningful analysis of the cytokine measurements, due to the low numbers of participants with detectable levels, and as a result we were unable to determine if paracetamol influenced the Th1/Th2 balance. Another less recognised potential mechanism of action, which was not directly assessed in this study, relates to neurogenic inflammation of the airways through the stimulation of the transient receptor potential ankyrin-1 (TRPA-1) cation channel by NAPQI, the metabolite of paracetamol.[26] This pathway, which is activated following therapeutic doses of paracetamol, mediates a non-eosinophilic inflammatory response and has been implicated in the pathogenesis or provocation of asthma by isocyanates, aldehydes, cigarette smoke and chlorine.[43,44]

Our findings provide information on which the design of further studies could be based. A trial of similar design, utilising the same duration and dose of paracetamol and with BHR testing to MCh as the primary outcome variable, based on the standard deviation derived from this study, would

require a sample size of approximately 650 to attain adequate power to detect a difference of 0.5 doubling-doses. Alternatively, a study of short-term use of paracetamol at higher doses could be undertaken, to more closely replicate the common use of paracetamol for relief of fever or pain in self-limited illnesses. Based on our findings, a sample size of 140 would be adequate to determine a 0.5 doubling-dose difference in MCh BHR, and a 10% increase in FeNO, in a short-term study of cross-over design. Finally, our study investigated the effect of paracetamol on asthma severity and not whether paracetamol has a role in the pathogenesis of asthma. Testing this hypothesis would require a clinical trial in infants, which would raise ethical and practical issues regarding consent and the use of placebo for the management of pain or fever in young children. However given the common usage of paracetamol in all age groups including pregnancy and the global burden of asthma, we propose that randomised controlled trials are required to determine the effect of paracetamol use on the development of asthma in infancy and early childhood.

In conclusion, this study has shown no significant effect of 12 weeks of treatment with paracetamol at half the maximum therapeutic daily dose on BHR and asthma control in adults with well controlled asthma. Whilst this outcome provides some reassurance that regular paracetamol use has no marked deleterious effect in adult asthma, further adequately powered studies are needed before the safety of paracetamol for patients with asthma is assured. Furthermore, the study findings do not preclude an effect of paracetamol on the development of asthma in infancy, childhood or adult life.

COMPETING INTERESTS

R Beasley has been a member of the GlaxoSmithKline (NZ) Advisory Board, and received research grants, payment for lectures or support to attend meetings from GlaxoSmithKline, a manufacturer of paracetamol.

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ADDITIONAL DATA

There are no additional data available.

CONTRIBUTORSHIP STATEMENT:

S Eyers was principal investigator and contributed to study planning, study conduct, data analysis and manuscript preparation. K Perrin contributed to study planning, study conduct and manuscript preparation, M Williams, S Jefferies and M Patel contributed to study conduct, M Weatherall contributed to randomisation, statistical analysis and preparation of manuscript, R Siebers contributed to blood analysis and preparation of manuscript, J Crane contributed to study planning and manuscript preparation, J Travers and P Shirtcliffe were safety investigators and R Beasley contributed to study planning, study conduct, data analysis and manuscript preparation.

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Table 1: Characteristics of participants who received randomised treatment

	Paracetamol Group	Placebo Group
Number	36	58
Demographic		
Mean age, y ±SD	41.5 ±13.9	38.3 ± 12.5
Male sex, No. (%)	15 (41.7)	20 (34.5)
Weight, Kg ±SD	75.1 ± 16.7	77.4 ± 17.8
Height, m ±SD	1.7 ± 0.1	1.69 ± 0.11
BMI, Kg/m^2 ±SD	25.9 ± 4.2	27.1 ± 5.8
Medication Use		
ICS, No. (%)	9 (25%)	20 (34%)
SABA, No. (%)	33 (92%)	55 (95%)
LABA, No. (%)	9 (25%)	8 (14%)
Defining Study Population		
FEV_1, L ±SD	3.09 ± 0.78	3.12 ± 0.87
FEV_1 % Predicted ±SD	94.1 ± 11.3	94.0 ± 12.4
Bronchodilator Reversibility (%)	9.1 ± 6.0	7.8 ± 5.5
SPT Cat pelt, No. (% +ve)	20 (55.6)	33 (57.9)
SPT D. pteronyssinus No. (% +ve)	30 (83.3)	52 (91.2)
SPT Mixed grass, No. (% +ve)	25 (69.4)	38 (66.7)
SPT at least one positive, No. (% +ve)	33 (91.7)	55 (96.5)
Clinical and Physiological Measurements		
PC_{20} MCh, mg/ml ±SD	4.14 ± 4.42	4.39 ± 4.66
Mean morning peak flow, L/min ±SD	424.0 ± 83.8	419.5 ± 92.3
$PEF_{var,}$ %, ±SD	19.0 ± 9.3	22.2 ± 10.5
ACQ Score ±SD	0.93 ± 0.63	0.82 ± 0.56
Inflammation and Immunology		
FeNO, ppb ±SD	44.9 ± 39.2	51.3 ± 42.6
Eosinophils, x 10^9/L, ±SD	0.26 ± 0.12	0.32 ± 0.17
IgE, kU/L, ±SD	518.4 ± 705.7	480.4 ± 914.0

Abbreviations: BMI = Body mass index; ICS = Inhaled corticosteroid; SABA = Short-acting beta agonist; LABA = Long-acting beta agonist; FEV_1 = Forced expiratory volume in 1 second; SPT = Skin prick test; PC_{20} MCh = Provocation concentration of methacholine causing a 20% fall in FEV_1; PEF_{var} = Peak flow variability; ACQ = Asthma Control Questionnaire; FeNO = Fractional exhaled nitric oxide; IgE = Immunoglobulin E

Table 2: Effect of paracetamol use on BHR, lung function and asthma control

	BASELINE		WEEK 12		Difference
	Paracetamol N=36	Placebo N=58	Paracetamol N=31	Placebo N=54	(adjusted for baseline)
Log 2 PC_{20} (mg/ml)	1.30 (1.50)	1.09 (1.96)	0.62 (2.09)	1.07 (2.36)	-0.48 (-1.28 to 0.32) P=0.24†
FEV_1 (L)	3.06 (0.73)	3.05 (0.83)	3.01 (0.74)	3.07 (0.86)	-0.07 (-0.15 to 0.01) P=0.08
ACQ score	0.81 (0.47)	0.93 (0.59)	0.88 (0.56)	1.03 (0.71)	-0.04 (-0.27 to 0.18) P=0.71
Mean morning peak flow (L/min)	424.0 (83.8)	419.5 (92.3)	417.1 (82.3)	417.5 (85.9)	-8.6 (-26.7 to 9.5) P=0.35
PEF_{var} (%)	19.0 (9.3)	22.2 (10.5)	20.4 (10.3)	21.7 (11.7)	0.21 (-4.3 to 4.8) P=0.93

Numbers are mean (SD)

Abbreviations:

PC_{20} = Provocation concentration of methacholine causing a 20% fall in FEV_1; FEV_1 = Forced expiratory volume in one second;

PEF_{var} = PEF variability (measured as amplitude as a percentage of the mean); ACQ = Asthma Control Questionnaire;

† = Difference in doubling doses

Table 3: Effect of paracetamol use on FeNO, blood eosinophil count and serum IgE

	BASELINE		WEEK 12		Difference (adjusted for baseline)
	Paracetamol N=36	Placebo N=58	Paracetamol N=31	Placebo N=54	
Log FeNO (ppb)	3.53 (0.71)	3.66 (0.78)	3.69 (0.70)	3.65 (0.76)	0.09 (-0.097 to 0.27) P=0.36
Log eosinophils ($x10^9$/L)	-1.41 (0.47)	-1.27 (0.53)	-1.33 (0.54)	-1.32 (0.58)	-0.056 (-0.25 to 0.14) P=0.57
Log IgE (kU/L)	5.28 (1.52)	5.29 (1.30)	5.02 (1.56)	5.20 (1.37)	0.098 (0.009 to 0.21) P=0.073

Abbreviations:

FeNO = Fractional exhaled nitric oxide; IgE = Immunoglobulin E

FIGURE LEGENDS

Figure 1:

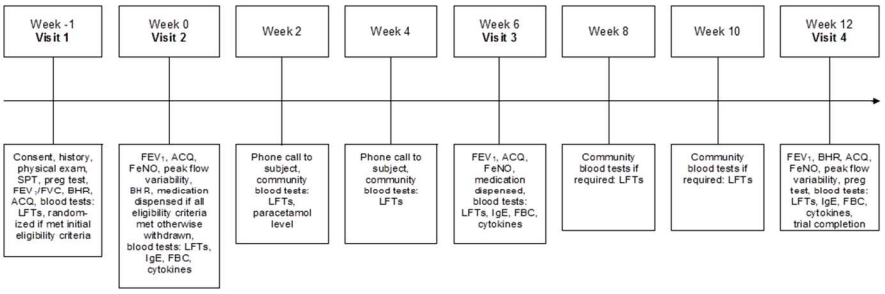
Study design flow chart

Abbreviations: SPT = Skin prick test; Preg test = pregnancy test; FEV_1/FVC = Forced expiratory volume in 1 second/forced vital capacity; BHR = bronchial hyperresponsiveness testing; ACQ = Asthma Control Questionnaire; LFT = liver function test; FeNO = Fractional exhaled nitric oxide; IgE = Immunoglobulin E; FBC = full blood count

Figure 2:

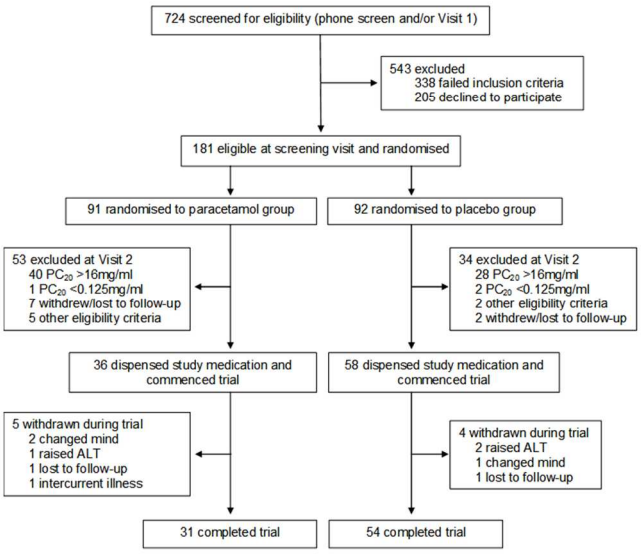
CONSORT participant flow diagram

Figure 1:



296x209mm (300 x 300 DPI)

Figure 2:



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ONLINE SUPPLEMENT

RANDOMISED PLACEBO CONTROLLED STUDY OF THE EFFECT OF PARACETAMOL ON ASTHMA SEVERITY

[1,2,3]Sally Eyers, [1]Mathew Williams, [1,2]Sarah Jefferies, [1,2]Kyle Perrin

[2,3]Mark Weatherall, [3]Rob Siebers, [3]Julian Crane, [1,2]Mitesh Patel,

[1]Justin Travers, [1,2]Philippa Shirtcliffe, [1,2]Richard Beasley

[1]Medical Research Institute of New Zealand, Wellington, New Zealand

[2]Capital & Coast District Health Board, Wellington, New Zealand

[3]University of Otago Wellington, Wellington, New Zealand

METHODOLOGY

Randomisation

A computer-generated randomisation schedule was generated by the study statistician and was administered by the study pharmacists. It was necessary to randomise the subjects prior to their final eligibility screening visit (visit 2) to enable the study pharmacists adequate time to prepare the study medication for dispensing at visit 2 following final determination of eligibility. Pharmacists received notification from the study investigators that a participant was due to attend visit 2, and assigned the appropriate treatment group to the participant based on the randomisation schedule. Allocated medication was then delivered to the MRINZ research offices in labelled medication bottles, ready for dispensing to study participants at the end of visit 2 if they were eligible for the study. If a participant failed one of the eligibility criteria at visit 2, the randomised medication was not dispensed and the participant was withdrawn from the study. The randomisation code was not re-used.

Skin Prick Testing

Skin prick testing was undertaken to grass (grass mix #7, Hollister Stier Laboratories, USA), house dust mite (Dermatophagoides pteronyssinus, Hollister Stier Laboratories, USA), cat pelt (Stallergenes Laboratories, France), and positive (histamine) and negative controls (Hollister Stier Laboratories, USA), performed in accordance with Australasian Society of Clinical Immunology and Allergy (ASCIA) guidelines (Australasian Society of Clinical Immunology and Allergy 2006 (Revised March 2009)).

Methacholine Challenge Testing

Participants were asked to withhold long-acting beta-agonists (LABAs) for 48 hours and short-acting beta-agonists (SABAs) and food or drink containing caffeine for eight hours prior to BHR testing. Methacholine (provocholine) was sourced from Methapharm Inc

(Ontario, Canada) as 1280mg vials, and was diluted with normal saline in a sterile manner, and refrigerated at a concentration of 128mg/ml for a period of up to three months. Methacholine was further diluted for each individual challenge test into doubling concentrations of 0.0125, 0.03, 0.06, 0.125, 0.05, 1,2, 4, 8, 16, and 32mg/ml and left to warm to room temperature for at least 30 minutes prior to each test. An English Wright nebuliser (Roxon Meditec, Montreal, Canada) was used to deliver the methacholine dose. Basic spirometry was performed prior to challenge testing, and a saline (diluent) dose was given prior to the first methacholine dose. At each inhaled dose, the subject was asked to breath normally though the mouthpiece (with nose clip in place) for two minutes, after which time FEV_1 was measured at 30s and 90s. The next concentration of methacholine was then administered within 5 minutes of the original dose commencement. If FEV_1 fell by $\geq$ 20% from baseline (or if subject finished all concentrations without a drop in FEV_1), no further medication was given and nebulised salbutamol (5mg/2.5ml) was administered immediately, followed by a 10-minute rest period. The subject was monitored and salbutamol nebuliser repeated if necessary until FEV_1 was within 10% of post-saline baseline. PC20, defined as the provocation concentration of inhaled methacholine required to produce a 20% reduction in FEV_1 was calculated via the formula:

Logarithmic PC20 = Antilog [(20-R1)(logC2-logC1)/(R2-R1) + logC1]

where C1 is the methacholine concentration producing less than a 20% Fall in FEV_1 and C2 is that producing a greater than 20% fall in FEV_1. R1 and R2 are the percent FEV_1 reductions produced by C1 and C2 respectively (Cockcroft, Murdock et al. 1983).

Liver Function Tests

Liver function tests included alanine aminotransferase (ALT), alkaline phosphatase (ALP), bilirubin, albumin, total protein and gamma-glutamyl transferase (GGT). Any

participant who developed an elevation in ALT of greater than three times the upper limit of normal during the study period was withdrawn from the trial. Blood tests to monitor liver function were undertaken at two and four weeks after randomisation and were accompanied by a phone call to the participant to monitor adverse events. Participants who experienced a rise in ALT two to three times the upper limit of normal during the first six weeks of the study were required to have additional blood tests to monitor liver function eight and 10 weeks after randomisation. In order to maintain investigator blinding, results of liver function tests were kept from the study investigators and viewed only by the allocated safety data reviewers (JT and PS). If further blood tests were required at weeks eight and 10, contact was made with the participant by the safety reviewer directly so as to maintain investigator blinding. If, during the course of the study, any participant was found to have abnormal liver function which required their withdrawal from the study, the safety investigator unblinded the participant in order to inform their ongoing management and notified their health care provider.

Cytokine Measurement

Concentrations of IFN- γ, IL-4, IL-5 and IL-13 were measured by ELISA (Quantikine, R&D Systems, Minneapolis, MN), according to the manufacturer's protocols. The ELISA minimum detectable level for IFN- γ was 12.5 pg/ml, for IL-4 was 27.7 pg/ml, for IL-5 was 3.5 pg/ml and for IL-13 was 55.3 pg/ml.

Medication Compliance Monitoring

Compliance with study medication was determined by a review of the medication diary, a count of the units of medication returned at the end of the first and second 6-week study period, and blood paracetamol levels taken at weeks 2, 6 and 12.

At visit 3 and 4, participants returned their medication diary and any remaining study medication from the first or second 6-week period of the study. All participants were given

188 tablets of study medication at visit 2 and visit 3, which equated to 6 weeks of fully compliant medication dosing and one extra week in case of a delay in follow-up. The number of days that the participant had been randomised, and therefore the number of doses of study medication expected to have been consumed over that time period were calculated based on the entries in the medication diary. The remaining tablets of study medication were then counted and were compared with the number of tablets expected to be returned.

References

Australasian Society of Clinical Immunology and Allergy. Skin Prick Testing for the Diagnosis of Allergic Disease, A Manual for Practitioners. 2006 (Revised March 2009).

Cockcroft DW, Murdock KY, et al. Determination of histamine PC20. Comparison of linear and logarithmic interpolation. *Chest* 1983;**84**:505-6

Table E1: Participant recruitment failures

Excluded at Phone Screen (n=486)	
200	Declined to participate
56	Smoker/Ex-smoker
39	Contraindication to trial/paracetamol (incl: planned surgery, use of contraindicated meds, chronic pain conditions, allergy to NSAIDS/paracetamol)
37	Asthma too severe
35	Currently using regular paracetamol
35	Asthma too mild/no asthma
34	Unable to travel to study site
18	History suicide attempt/current depression
10	Breastfeeding, pregnant, no contraception
8	Trial period ended
7	History of liver disease
6	Age outside range
1	High weekly alcohol intake
Excluded at Visit 1 (n=57)	
19	FEV_1<70% predicted
11	Raised ALT
10	History suicide attempt/current depression
5	Lost to follow up/withdrew consent
4	Smoker/ex-smoker>10py
3	Contraindication to trial/paracetamol (incl: planned surgery, use of contraindicated meds, chronic pain conditions, allergy to NSAIDS/paracetamol)
2	High weekly alcohol intake
1	No contraception
1	High blood pressure
1	Age outside range
Excluded at Visit 2 (n=87)	
68	PC_{20} > 16 mg/ml
9	Lost to follow up/withdrew consent
7	FEV_1 < 70% predicted
3	PC_{20} < 0.0125 mg/ml

Table E2: Participants with detectable levels of cytokines

Variable (detectable level)	N/N (%)	
	Paracetamol	Placebo
IFN-γ (12.5 pg/ml)		
Visit 2	21/36 (58.3)	33/58 (56.9)
Visit 3	25/29 (86.2)	40/55 (72.7)
Visit 4	26/31 (83.9)	44/53 (83.0)
IL-4 (27.7 pg/ml)		
Visit 2	1/36 (2.8)	3/58 (5.2)
Visit 3	4/29 (13.8)	1/55 (1.8)
Visit 4	2/31 (6.5)	2/53 (3.8)
IL-5 (3.5 pg/ml)		
Visit 2	1/36 (2.8)	2/58 (3.5)
Visit 3	3/29 (10.3)	4/55 (7.8)
Visit 4	3/31 (9.7)	0/53 (0)
IL-13 (55.3 pg/ml)		
Visit 2	0/36 (0)	4/58 (6.9)
Visit 3	1/29 (3.5)	3/55 (5.5)
Visit 4	1/31 (3.2)	7/53 (13.2)

Abbreviations: IFN-γ = Interferon gamma; IL-4/5/13 = Interleukin 4/5/13

Table E3: Effect of paracetamol use on BHR, lung function and asthma control

	BASELINE		WEEK 6		Difference
	Paracetamol N=36	Placebo N=58	Paracetamol N=32	Placebo N=55	(adjusted for baseline)
FEV_1 (L)	3.06 (0.73)	3.05 (0.83)	3.08 (0.78)	3.13 (0.83)	-0.03 (-0.14 to 0.08) P=0.54
ACQ score	0.81 (0.47)	0.93 (0.59)	0.74 (0.49)	0.78 (0.50)	0.04 (-0.13 to 0.22) P=0.62
Log FeNO (ppb)	3.53 (0.71)	3.66 (0.78)	3.59 (0.68)	3.67 (0.71)	0.001 (-0.15 to 0.16) P=0.99

Numbers are mean (SD)

Abbreviations:

FEV_1 = Forced expiratory volume in one second; ACQ = Asthma Control Questionnaire;

FeNO = Fractional exhaled nitric oxide

CONSORT 2010 checklist of information

Page numbers refer to the page in the manuscript [top right of document]. OS: Online supplement. P: Protocol, N/A: Not applicable

Section/Topic	Item No	Checklist item	Reported on page No
Title and abstract			
	1a	Identification as a randomised trial in the title	1
	1b	Structured summary of trial design, methods, results, and conclusions (for specific guidance see CONSORT for abstracts)	2-3
Introduction			
Background and objectives	2a	Scientific background and explanation of rationale	4
	2b	Specific objectives or hypotheses	5
Methods			
Trial design	3a	Description of trial design (such as parallel, factorial) including allocation ratio	6-8, Fig 1
	3b	Important changes to methods after trial commencement (such as eligibility criteria), with reasons	N/A
Participants	4a	Eligibility criteria for participants	6
	4b	Settings and locations where the data were collected	6-8
Interventions	5	The interventions for each group with sufficient details to allow replication, including how and when they were actually administered	7-8
Outcomes	6a	Completely defined pre-specified primary and secondary outcome measures, including how and when they were assessed	8, OS
	6b	Any changes to trial outcomes after the trial commenced, with reasons	None
Sample size	7a	How sample size was determined	10
	7b	When applicable, explanation of any interim analyses and stopping guidelines	None
Randomisation:			
Sequence generation	8a	Method used to generate the random allocation sequence	7
	8b	Type of randomisation; details of any restriction (such as blocking and block size)	7
Allocation concealment mechanism	9	Mechanism used to implement the random allocation sequence (such as sequentially numbered containers), describing any steps taken to conceal the sequence until interventions were assigned	7
Implementation	10	Who generated the random allocation sequence, who enrolled participants, and who assigned participants to interventions	7, OS

Blinding	11a	If done, who was blinded after assignment to interventions (for example, participants, care providers, those assessing outcomes) and how	7
	11b	If relevant, description of the similarity of interventions	7
Statistical methods	12a	Statistical methods used to compare groups for primary and secondary outcomes	9
	12b	Methods for additional analyses, such as subgroup analyses and adjusted analyses	9
Results			
Participant flow (a diagram is strongly recommended)	13a	For each group, the numbers of participants who were randomly assigned, received intended treatment, and were analysed for the primary outcome	11, Fig 2
	13b	For each group, losses and exclusions after randomisation, together with reasons	11, Fig 2, OS Table 1
Recruitment	14a	Dates defining the periods of recruitment and follow-up	11
	14b	Why the trial ended or was stopped	11
Baseline data	15	A table showing baseline demographic and clinical characteristics for each group	Table 1
Numbers analysed	16	For each group, number of participants (denominator) included in each analysis and whether the analysis was by original assigned groups	11,12
Outcomes and estimation	17a	For each primary and secondary outcome, results for each group, and the estimated effect size and its precision (such as 95% confidence interval)	11,12, Tables 2 and 3
	17b	For binary outcomes, presentation of both absolute and relative effect sizes is recommended	11,12
Ancillary analyses	18	Results of any other analyses performed, including subgroup analyses and adjusted analyses, distinguishing pre-specified from exploratory	OS Tables 2 and 3
Harms	19	All important harms or unintended effects in each group (for specific guidance see CONSORT for harms)	11,12
Discussion			
Limitations	20	Trial limitations, addressing sources of potential bias, imprecision, and, if relevant, multiplicity of analyses	13-15
Generalisability	21	Generalisability (external validity, applicability) of the trial findings	13
Interpretation	22	Interpretation consistent with results, balancing benefits and harms, and considering other relevant evidence	15,16
Other information			
Registration	23	Registration number and name of trial registry	3
Protocol	24	Where the full trial protocol can be accessed, if available	3
Funding	25	Sources of funding and other support (such as supply of drugs), role of funders	17

RANDOMISED PLACEBO CONTROLLED STUDY OF THE EFFECT OF PARACETAMOL ON ASTHMA SEVERITY IN ADULTS

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Primary Subject Heading:	Respiratory medicine
Secondary Subject Heading:	Pharmacology and therapeutics
Keywords:	Asthma < THORACIC MEDICINE, Allergy < THORACIC MEDICINE, Respiratory physiology < THORACIC MEDICINE

RANDOMISED PLACEBO CONTROLLED STUDY OF THE EFFECT OF PARACETAMOL ON ASTHMA SEVERITY IN ADULTS

[1,2,3]Sally J Ioannides, [1]Mathew Williams, [1,2] Sarah Jefferies, [1,2] Kyle Perrin

[2,3]Mark Weatherall [3]Robert Siebers, [3]Julian Crane, [1,2] Mitesh Patel

[1]Justin Travers, [1,2] Philippa Shirtcliffe, [1,2]Richard Beasley

[1]Medical Research Institute of New Zealand, Wellington, New Zealand

[2]Capital & Coast District Health Board, Wellington, New Zealand

[3]University of Otago Wellington, Wellington, New Zealand

Key words: Asthma, paracetamol, randomised controlled trial, bronchial hyperresponsiveness

Word count: 3,859

Running Title: Effect of paracetamol on adult asthma

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Correspondence:

Prof Richard Beasley
Medical Research Institute of New Zealand
Private Bag 7902, Wellington 6242
New Zealand
Telephone: 64-4-805 0230
Fax: 64-4-389 5707
Email: richard.beasley@mrinz.ac.nz

ABSTRACT (word count 249)

Background: Epidemiological evidence suggests that paracetamol may be a risk factor in the development of asthma and its severity. This is the first randomised placebo-controlled trial of the effect of regular paracetamol on bronchial hyperresponsiveness (BHR) and asthma control in adult asthma.

Methods: In a 12-week randomised, double-blind, placebo-controlled, parallel-group study, 94 adults with mild to moderate asthma received 12 weeks of 1g paracetamol twice daily or placebo twice daily. The primary outcome variable was BHR, measured as provocation concentration of methacholine causing a 20% fall in FEV_1 (PC_{20}), at week 12. Secondary outcome variables included FEV_1, FeNO and ACQ score.

Results: 94 participants received randomised treatment (36 and 58 in paracetamol and placebo groups respectively); 85 participants completed the study. At 12 weeks the mean (SD) logarithm base two PC_{20} was 1.07 (2.36) in the control group (N=54) and 0.62 (2.09) in the paracetamol group (N=31). After controlling for baseline PC_{20}, the mean difference (paracetamol minus placebo) was -0.48 doubling dose worsening in BHR in the paracetamol group (95% CI -1.28 to 0.32), P=0.24. There were no statistically significant differences (paracetamol minus placebo) in log FeNO 0.09 (95% CI -0.097 to 0.27)), FEV_1 (-0.07 L (95% CI -0.15 to 0.01)), or ACQ score (-0.04 (95% CI -0.27 to 0.18)).

Conclusions: There was no significant effect of paracetamol on BHR and asthma control in adults with asthma. However, the study findings are limited by low power and the upper confidence limits did not rule out clinically relevant adverse effects.

STRENGTHS AND WEAKNESSES

- Randomised placebo-controlled trial
- Physiological, clinical and immunological outcome measures
- Powered to detect a marked effect on BHR

KEY MESSAGES

What is the key question?

Does regular paracetamol use result in worsening asthma severity?

What is the bottom line?

Paracetamol use did not cause a marked increase in bronchial hyperresponsiveness or deterioration in asthma control in adults with asthma, although it was not possible to rule out a clinically relevant effect.

Why read on?

This is the first randomised placebo-controlled trial to measure the effects of paracetamol in stable adult asthma. The study findings provide information on which the design of further studies can be based.

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INTRODUCTION

There is a growing body of evidence to suggest that paracetamol may play an important role as a risk factor for the development of asthma, and that increasing world-wide use may have contributed to the increasing global prevalence of asthma seen over the last 40 years.[1,2] Childhood asthma risk increases in the offspring of women who consume paracetamol during pregnancy,[3] and paracetamol use in the first 12 months of life is associated with an increased risk of wheezing at 3 years [4,5] and 6-7 years.[6] Cross-sectional surveys in children,[6] adolescents [7] and adults [8-11] consistently demonstrate an association between current paracetamol use and asthma in populations with widely differing lifestyles, standards of living, medical practice and availability of paracetamol. However, there is also evidence that these associations may, in part, be due to confounding by indication in some,[12-14] but not all cohort studies in childhood.[15] Cohort studies in adults have demonstrated that increasing frequency of paracetamol use is positively associated with newly-diagnosed (adult-onset) asthma.[16,17]

There is also evidence that paracetamol may increase the severity of asthma in those with the disease. This primarily comes from the only randomised controlled trial of the effect of paracetamol use for fever and asthma outcomes, in which asthmatic children experiencing a current febrile illness were randomised to receive either paracetamol or ibuprofen.[18] The children who received paracetamol were more likely to require an outpatient visit for asthma compared to children in the ibuprofen group. The increased risk with paracetamol was dose dependent and related to respiratory febrile illnesses rather than other causes of fever. In a case-control study which reported a dose-dependent association between paracetamol use and asthma, a progressively greater risk in those with more severe disease was noted, suggesting an effect on both causation and severity of the disease.[10]

The mounting epidemiological evidence, supported by several biologically plausible mechanisms [19-28] has led to repeated calls [2,5-7,13,29-32] for randomised controlled trials to be undertaken

to explore the relationship between paracetamol and asthma. This study is the first randomised controlled trial undertaken to investigate the effect of regular daily paracetamol on asthma severity in adult patients with asthma. It was powered to detect a one doubling dose change in PC_{20} methacholine bronchial hyperresponsiveness (BHR). Markers of airways inflammation and systemic immunological responses were monitored to provide insight into possible mechanisms of action. The hypothesis was that regular paracetamol use would result in a worsening in BHR and asthma control.

METHODS

The study design was a double-blind, randomised, placebo-controlled, parallel group trial based in Wellington, New Zealand. The study methods are summarised with additional details provided in the supplementary appendix. The study was approved by the Central Regional Ethics Committee (CEN/08/12/070) and all participants gave written informed consent. The trial was registered on the Australian New Zealand Clinical Trials Registry (ACTRN12609000551291).

Participants

Participants were identified from the Medical Research Institute of New Zealand (MRINZ) asthma register, general practitioner patient databases, and the general public through advertising. Inclusion criteria included age between 18 and 65 years, wheeze in the previous 12 months and a doctor's diagnosis of asthma, forced expiratory volume in 1 second (FEV_1) $\geq$70% predicted at screening and baseline and a PC_{20} MCh (the provocation concentration of methacholine causing a 20% reduction in FEV_1) of between 0.125 and 16 mg/ml at baseline. Exclusion criteria included regular use of theophylline, ipratropium bromide, tiotropium or leukotriene receptor antagonists in the previous 3 months, alanine aminotransferase (ALT) levels greater than 1.5 times the upper limit of normal at baseline, a history of liver disease or the current use of hepatotoxic drugs, an exacerbation of asthma within the previous two months requiring prednisone or nebulised bronchodilator, current or past cigarette smoking >10 pack years, history of sensitivity or allergy to paracetamol or current regular use of paracetamol, use of high-dose aspirin or non-steroidal anti-inflammatory drugs, history of alcoholism or current excessive alcohol intake, history of previous intentional overdose of paracetamol, previous suicide attempt or current unstable depression, body mass index <16 kg/m^2, pregnant or breast-feeding women or women not using adequate contraception and participants unsuitable for BHR challenge testing in accordance with American Thoracic Society (ATS) criteria.[33]

Interventions

Participants were randomised to receive one of two treatment regimens for 12 weeks. The treatments were paracetamol 1g, administered as two 500mg tablets, or placebo administered as two identically appearing tablets, taken twice daily. The paracetamol and placebo tablets were supplied by Aspen Asia Pacific Ltd, Sydney, Australia. All participants were instructed to avoid taking other forms of paracetamol (including over-the-counter remedies containing paracetamol) or non-steroidal anti-inflammatory drugs (NSAIDs) for the duration of the study. All participants were provided with a prescription for codeine to use as an analgesic during the study.

Randomisation

A computer-generated randomisation schedule was generated by the study statistician and was administered by the study pharmacists. It was necessary to randomise the participants prior to their final eligibility screening visit (visit 2) to enable the study pharmacists adequate time to prepare the study medication for dispensing at visit 2 following final determination of eligibility. If a participant failed one of the eligibility criteria at visit 2, the randomised medication was not dispensed and the participant was withdrawn from the study. The randomisation code was not re-used.

Blinding

Study investigators, participants, and participant health care providers were blinded through provision of medication as identically appearing tablets in bottles, with neither the investigator dispensing the medication or the participants aware of the allocated treatment.

Design

The trial involved four study clinic visits and between two and four additional blood tests over 13 weeks (Figure 1). A screening visit (visit 1) was held approximately one week prior to baseline and consisted of a medical history and brief physical examination, pregnancy test where applicable, bronchodilator reversibility testing, liver function screen and allergy skin prick tests (see online

supplement for details). A diary was used to record morning and evening peak expiratory flow (PEF) values (prior to asthma medication use) for one week prior to the second visit. Participants who met initial eligibility criteria were randomised at this stage, prior to final eligibility assessment at visit 2.

At visit 2, designated the baseline visit, the Qoltech asthma control questionnaire (ACQ)[34] was administered and PEF_{var} (PEF variability measured as the amplitude as a percentage of the mean) calculated. Baseline assessments of FEV_1 were undertaken using a Micro Medical Microlab spirometer (Micro Medical, Kent, UK) and Fractional exhaled Nitric Oxide (FeNO) was assessed using a NiOX Flex chemiluminescence analyser (Aerocrine AB, Stockholm, Sweden). Methacholine (Methapharm, Ontario, Canada) challenge testing was undertaken via the two-minute tidal breathing dosing protocol recommended by the ATS,[33] as outlined in the online supplement. Participants who met all the eligibility criteria were then dispensed a six-week supply of randomised medication, a medication diary to record administered doses and a prescription for codeine phosphate for emergency pain relief during the trial period. These participants then underwent blood tests including full blood count (eosinophils), total serum immunoglobulin E (IgE), and serum cytokine levels (interferon (IFN)-γ, interleukin (IL)-4, IL-5, IL-13) (see online supplement for details).

At visits 3 and 4, six and 12 weeks after baseline, FEV_1, ACQ, FeNO and blood tests were repeated and medication compliance checked via pill count and medication diary check (see online supplement for details). At the third visit, participants were given a further six-week supply of study medication, a second medication diary, and a diary to record morning and evening PEF values in the final intervention week. At the fourth and final visit, BHR testing was repeated. Liver function tests were monitored throughout the study (see online supplement for details).

Outcomes

The primary outcome variable was PC_{20} MCh at 12 weeks, adjusted for baseline. This direct measure of BHR was chosen as an objective well standardised physiological measure of asthma severity, recommended for monitoring the effects of therapy which may modify asthma severity.[33,35] Secondary outcome measures were FEV_1, FEV_1 % predicted, ACQ score and FeNO at six and 12 weeks, and the mean morning peak flow, PEF_{var}, and exacerbations of asthma (requiring a doctor's visit and need for prednisone or nebulised bronchodilator) at 12 weeks. Blood eosinophil, serum IgE, and serum cytokine (IFN-γ, IL-4, IL-5 and IL-13) levels were measured at six and 12 weeks.

Statistical Methods

The primary analysis method was ANCOVA. The logarithm base two PC_{20} for methacholine at 12 weeks was the primary response variable, with the baseline logarithm base two PC_{20} as a covariate, and a categorical variable for the paracetamol group. The difference in logarithm base two PC_{20} was the doubling dose difference between the two randomised groups. Secondary outcome variables, including FEV_1, FEV_1 % predicted, ACQ score, FeNO, mean morning peak flow and PEF_{var} were also analyzed by ANCOVA. The distribution of FeNO, serum IgE and eosinophil count was skewed and normality assumptions for these variables were best met on the natural logarithm scale.

The proportion of participants with at least one asthma exacerbation was compared as an absolute risk difference, with an appropriate confidence interval, because in the event there were no asthma exacerbations in one of the randomised groups so that a relative risk could not be calculated. Simple t-tests were used to compare mean values for ALT by randomised group. FeNO, eosinophil count and IgE were logarithm transformed because of skewed distributions, and the difference in logarithms was compared by a t-test. For those three variables with a logarithm transformation, the exponent of the difference in logarithms is interpreted as the ratio of mean values.

The analysis was by intention to treat of randomised participants who passed the final eligibility screening and as a result received randomised treatment. No randomised participants who failed the final eligibility screen received randomised treatment or underwent any outcome assessments. For each individual analysis, a two-sided P value of 0.05 was used, with 95% confidence intervals for each estimate. We have not adjusted for multiple statistical testing.

Sample Size

A sample size of 60 in each group has 80% power at the 5% level of significance to detect a difference of one doubling dose in PC_{20} MCh between the groups, based on a standard deviation of 1.9.[36] To allow for the possibility of up to 10% of study participants withdrawing early from the study, a recruitment target of 66 participants was set for each group.

RESULTS

Recruitment commenced in June 2009 and ended in September 2011. The planned study period of two years was extended by three months due to difficulties in recruitment. Figure 2 shows the flow of participants. There were 724 patients assessed for eligibility at phone screening and/or visit 1; of these, 338 failed to meet the inclusion criteria and 205 declined to participate (see online supplement). There were 181 participants randomised prior to visit 2 based on initial eligibility at visit 1; 91 to the paracetamol group and 92 to the placebo group. 53/91 participants allocated to the paracetamol group and 34/92 allocated to the placebo group were withdrawn at visit 2 as they either did not meet the inclusion/exclusion criteria (PC_{20} >16mg/ml, n=68; PC_{20} <0.125mg/ml, n=3; FEV_1 <70% predicted, n=6; unable to perform spirometry, n=1) or were lost to follow-up or withdrew consent (n=9). No study medication was dispensed to the participants who were withdrawn at visit 2 (see online supplement).

Medication was dispensed to 94 participants who commenced the intervention phase following visit 2: 36 randomised to paracetamol and 58 to placebo. The characteristics of the subjects are shown in Table 1. The mean age of participants was 40 years and there were 59 female participants. Approximately 30% of study participants were prescribed inhaled corticosteroids and 18% prescribed long-acting beta agonist drugs. Around 90% of participants had positive skin prick tests to either cat, mixed grass or house dust mite. Participants had mild to moderate asthma, with a baseline ACQ score of 0.86 (SD 0.59). The baseline mean FeNO was 48.9 ppb (SD 41.3) and the mean FEV_1 was 94% of predicted (SD 12.0). The baseline mean PC_{20} was 4.29 mg/ml (SD 4.54).

There were 85/94 participants who completed the study. Five participants were withdrawn from the paracetamol group; two withdrew at the participant's own discretion, one was excluded due to a raised ALT (119 IU/L), one was lost to follow-up and one was excluded due to intercurrent illness. Four participants were withdrawn from the placebo group; two were excluded due to a raised ALT

(207 and 227 IU/L respectively), one withdrew at the participant's own discretion and one was lost to follow-up.

Primary Outcome Variable

At 12 weeks the mean (SD) logarithm base two PC_{20} was 1.07 (2.36) in the control group (N=54) and 0.62 (2.09) in the paracetamol group (N=31). After controlling for baseline PC_{20}, the difference (expressed as a doubling dose difference, paracetamol minus placebo) was not statistically significant: -0.48 (95% CI -1.28 to 0.32), P=0.24 (Table 2).

Secondary Outcome Variables

There were no statistically significant differences in FEV_1, FEV_1 % predicted, ACQ score, mean morning peak flow or PEF_{var} between the control and paracetamol groups at Week 12 (Table 2) or in FEV_1 or ACQ score at Week 6 (Online Supplement). There were three asthma exacerbations in the placebo group and none in the paracetamol group, an absolute difference of 5.6% (95% CI -0.5 to 11.7%). There was 93.2% compliance in the control group and 90.8% compliance in the paracetamol group when assessed by pill count and medication diaries, a difference of 2.4%, (95% CI -1.0 to 5.8). Serum paracetamol levels (greater than the 30 µmol/L threshold) were detectable in between 31.3 to 38.7% of participants in the paracetamol group and were undetectable in all participants in the placebo group between week 2 and week 12 of the study.

There were no statistically significant differences observed in log FeNO at Week 6 (see Online Supplement), or at Week 12, or in log eosinophil or log IgE levels between the two groups at week 12 (Table 3). Only a proportion of participants had measurable levels of IFN-γ, IL-4, IL-5 and IL-13 at baseline or at other times throughout the trial, precluding meaningful analysis (see online supplement). ALT levels were significantly higher in the paracetamol group, with a mean ALT of 25.4 (SD 9.7) and 19.0 (SD 6.0) in the paracetamol and placebo groups respectively at visit 4, difference 6.3 (95% CI 2.9 to 9.7, p <0.001).

DISCUSSION

This double-blind, randomised, placebo-controlled, parallel group study found no statistically significant increase in BHR with 12-weeks paracetamol treatment. However, the results did not rule out a clinically significant effect, with the 95% confidence interval containing the pre-specified difference of one doubling dose reduction in PC_{20}. There were no significant differences observed in any of the pre-specified secondary outcome variables of asthma control, inflammatory or immunological markers.

This is the first reported randomised placebo-controlled trial of the effects of daily paracetamol in stable adult asthma. The only other published randomised controlled trial of paracetamol and asthma was the Boston University Fever Study.[18] Children randomised to the ibuprofen group had a reduced risk of having an outpatient visit for asthma during the 4 week study period (OR 0.56, 95% CI 0.34 to 0.95) compared with children in the paracetamol group. Because the study did not include a placebo treatment, it was not possible to determine whether the observed difference in morbidity according to treatment group was attributable to an increased risk with paracetamol or a decreased risk with ibuprofen.

There are several methodological issues relevant to the interpretation of our study findings. First, as enshrined in the Declaration of Helsinki [37] there is a requirement to study the least vulnerable populations wherever applicable. Most, but not all, of the putative adverse effects of paracetamol on asthma have been shown in observational studies of children and suggest that paracetamol may increase the risk of developing asthma.[1,2] However, as there is some data to suggest that regular paracetamol use may lead to a deterioration in asthma control in adults,[1,10] we opted to firstly examine the effects of paracetamol in adults with stable asthma.

Second, this trial was powered to determine whether there was an effect on BHR of at least one-doubling dose reduction in PC_{20} MCh. Our ability to achieve the designated sample size completing

the study was affected by several factors. First, despite a rigorous recruitment campaign during which over 700 patients were screened, due to the inclusion and exclusion criteria employed to ensure participant safety, only 94 screened participants were dispensed randomised medication. Secondly, variability in PC_{20} from baseline to week 12 was larger than anticipated, with a pooled SD of 2.27 doubling doses compared to that used in the sample size calculation based on a SD of 1.9, derived from previous studies.[36] Another factor which affected the study power was the requirement to randomise subjects prior to their final screening visit in order to allow the pharmacy adequate time for dispensing at visit 2, following final determination of eligibility. If the participant failed this final eligibility, the randomised medication was not dispensed, the participant was withdrawn from the study, and the randomisation code was not reused. By chance this resulted in a disparity between the proportion of participants receiving active or placebo study medication. The power was reduced further due to the withdrawal of 10% of participants following randomisation. As there is an uncertain association between observed variables and missing BHR data in these participants, it was not possible to perform a robust imputation.

Compliance was high when measured via pill count, and although less than half of participants in the paracetamol group had measurable levels of paracetamol in the blood at the times tested throughout the study, this is likely to be due to the laboratory cut-off for a detectable paracetamol level (30 µmol/L). Following a 1g dose, participant blood levels may fall below this laboratory cut-off level in as little as 3 hours (given an paracetamol half-life of 2 hours and a peak plasma concentration 1 hour after administration of 80 µmol/L [38]). The use of this laboratory cut-off for paracetamol levels meant that it was not possible to investigate medication compliance through this method.

Our 12-week dosing period was chosen based on evidence that regular, long-term use of paracetamol is associated with an increased risk of asthma in adults [9-11,16,17] and that chronic ingestion of therapeutic doses can reduce serum antioxidant capacity in as little as two weeks.[39] We had originally intended to use the maximum daily dose of 4g paracetamol, however chose to

administer half this dose due to concerns of liver toxicity. These concerns were based on a previous clinical trial of paracetamol in which the incidence of ALT elevations more than three times the upper limit of normal in healthy participants taking 4g/day for 14 days was 31 to 44%.[40] Our results showed no clinically significant liver function derangement with paracetamol administered at a dose of 2g/day for 12 weeks.

Whilst the study did not demonstrate a statistically significant effect of paracetamol on BHR to MCh, the results do not rule out a clinically significant effect, with the upper 95% confidence interval of a 1.28 doubling-dose worsening in BHR containing the pre-specified difference of one doubling-dose. Furthermore, our point estimate of a reduction in PC_{20} of 0.48 of a doubling-dose could potentially be of major public health significance. As proposed by Mitchell,[41] a small shift to the left of the BHR curve in a population could lead to a relatively large increase in the prevalence of severe asthma. Relevant to the interpretation of our findings it has recently been calculated that a one half doubling dose increase in BHR increases the prevalence of moderate and severe BHR by about 30%.[42] Likewise, although the 9% increase in FeNO with paracetamol was not statistically significant, a change of this magnitude is considered clinically significant.[43] For FEV_1, the point estimate was consistent with a lower value in the paracetamol group, however the difference was of uncertain clinical significance and was associated with wide confidence intervals.

No significant effect was seen on serum IgE or peripheral blood eosinophil levels. It was not possible to undertake any meaningful analysis of the cytokine measurements, due to the low numbers of participants with detectable levels, and as a result we were unable to determine if paracetamol influenced the Th1/Th2 balance. Another less recognised potential mechanism of action, which was not directly assessed in this study, relates to neurogenic inflammation of the airways through the stimulation of the transient receptor potential ankyrin-1 (TRPA-1) cation channel by NAPQI, the metabolite of paracetamol.[26] This pathway, which is activated following therapeutic doses of paracetamol, mediates a non-eosinophilic inflammatory response and has

been implicated in the pathogenesis or provocation of asthma by isocyanates, aldehydes, cigarette smoke and chlorine.[44,45]

Our findings provide information on which the design of further studies could be based. A trial of similar design, utilising the same duration and dose of paracetamol and with BHR testing to MCh as the primary outcome variable, based on the standard deviation derived from this study, would require a sample size of approximately 650 to attain adequate power to detect a difference of 0.5 doubling-doses. Alternatively, a study of short-term use of paracetamol at higher doses could be undertaken, to more closely replicate the common use of paracetamol for relief of fever or pain in self-limited illnesses. Based on our findings, a sample size of 140 would be adequate to determine a 0.5 doubling-dose difference in MCh BHR, and a 10% increase in FeNO, in a short-term study of cross-over design. Important issues with the design of such a study are the duration of both the treatment periods and the crossover period. It would be important if possible to include a placebo rather than ibuprofen arm, as NSAIDs may have the potential to both cause NSAID-induced bronchospasm, as well as reducing asthma severity with long term use.[29]

Finally, our study investigated the effect of paracetamol on asthma severity and not whether paracetamol has a role in the pathogenesis of asthma. Testing this hypothesis would require clinical trials both of the effect of paracetamol use in pregnancy on the development of asthma in childhood, and the effect of paracetamol use in infants and older children and subsequent asthma risk. Such studies would raise ethical and practical issues regarding consent and the use of placebo for the management of pain or fever during pregnancy and in young children. However given the common usage of paracetamol in all age groups including pregnancy and the global burden of asthma, we propose that randomised controlled trials are required to determine the effect of paracetamol use on the development of asthma in infancy and early childhood.

In conclusion, this study has shown no significant effect of 12 weeks of treatment with paracetamol at half the maximum therapeutic daily dose on BHR and asthma control in adults with well

controlled asthma. Whilst this outcome provides some reassurance that regular paracetamol use has no marked deleterious effect in adult asthma, further adequately powered studies are needed before the safety of paracetamol for patients with asthma is assured. Furthermore, the study findings do not preclude an effect of paracetamol on the development of asthma in infancy, childhood or adult life.

COMPETING INTERESTS

R Beasley has been a member of the GlaxoSmithKline (NZ) Advisory Board, and received research grants, payment for lectures or support to attend meetings from GlaxoSmithKline, a manufacturer of paracetamol.

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CONTRIBUTORSHIP STATEMENT:

SJ Ioannides was principal investigator and contributed to study planning, study conduct, data analysis and manuscript preparation. K Perrin contributed to study planning, study conduct and manuscript preparation, M Williams, S Jefferies and M Patel contributed to study conduct, M Weatherall contributed to randomisation, statistical analysis and preparation of manuscript, R Siebers contributed to blood analysis and preparation of manuscript, J Crane contributed to study planning and manuscript preparation, J Travers and P Shirtcliffe were safety investigators and R Beasley contributed to study planning, study conduct, data analysis and manuscript preparation

DATA SHARING STATEMENT

No additional data

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Table 1: Characteristics of participants who received randomised treatment

	Paracetamol Group	Placebo Group
Number	36	58
Demographic		
Mean age, y ±SD	41.5 ±13.9	38.3 ± 12.5
Male sex, No. (%)	15 (41.7)	20 (34.5)
Weight, Kg ±SD	75.1 ± 16.7	77.4 ± 17.8
Height, m ±SD	1.7 ± 0.1	1.69 ± 0.11
BMI, Kg/m^2 ±SD	25.9 ± 4.2	27.1 ± 5.8
Medication Use		
ICS, No. (%)	9 (25%)	20 (34%)
SABA, No. (%)	33 (92%)	55 (95%)
LABA, No. (%)	9 (25%)	8 (14%)
Defining Study Population		
FEV_1, L ±SD	3.09 ± 0.78	3.12 ± 0.87
FEV_1 % Predicted ±SD	94.1 ± 11.3	94.0 ± 12.4
Bronchodilator Reversibility (%)	9.1 ± 6.0	7.8 ± 5.5
SPT Cat pelt, No. (% +ve)	20 (55.6)	33 (57.9)
SPT D. pteronyssinus No. (% +ve)	30 (83.3)	52 (91.2)
SPT Mixed grass, No. (% +ve)	25 (69.4)	38 (66.7)
SPT at least one positive, No. (% +ve)	33 (91.7)	55 (96.5)
Clinical and Physiological Measurements		
PC_{20} MCh, mg/ml ±SD	4.14 ± 4.42	4.39 ± 4.66
Mean morning peak flow, L/min ±SD	424.0 ± 83.8	419.5 ± 92.3
$PEF_{var,}$ %, ±SD	19.0 ± 9.3	22.2 ± 10.5
ACQ Score ±SD	0.93 ± 0.63	0.82 ± 0.56
Inflammation and Immunology		
FeNO, ppb ±SD	44.9 ± 39.2	51.3 ± 42.6
Eosinophils, x 10^9/L, ±SD	0.26 ± 0.12	0.32 ± 0.17
IgE, kU/L, ±SD	518.4 ± 705.7	480.4 ± 914.0

Abbreviations: BMI = Body mass index; ICS = Inhaled corticosteroid; SABA = Short-acting beta agonist; LABA = Long-acting beta agonist; FEV_1 = Forced expiratory volume in 1 second; SPT = Skin prick test; PC_{20} MCh = Provocation concentration of methacholine causing a 20% fall in FEV_1; PEF_{var} = Peak flow variability; ACQ = Asthma Control Questionnaire; FeNO = Fractional exhaled nitric oxide; IgE = Immunoglobulin E

Table 2: Effect of paracetamol use on BHR, lung function and asthma control

	BASELINE		WEEK 12		Difference
	Paracetamol N=36	Placebo N=58	Paracetamol N=31	Placebo N=54	(adjusted for baseline)
Log 2 PC_{20} (mg/ml)	1.30 (1.50)	1.09 (1.96)	0.62 (2.09)	1.07 (2.36)	-0.48 (-1.28 to 0.32) P=0.24†
FEV_1 (L)	3.06 (0.73)	3.05 (0.83)	3.01 (0.74)	3.07 (0.86)	-0.07 (-0.15 to 0.01) P=0.08
ACQ score	0.81 (0.47)	0.93 (0.59)	0.88 (0.56)	1.03 (0.71)	-0.04 (-0.27 to 0.18) P=0.71
Mean morning peak flow (L/min)	424.0 (83.8)	419.5 (92.3)	417.1 (82.3)	417.5 (85.9)	-8.6 (-26.7 to 9.5) P=0.35
PEF_{var} (%)	19.0 (9.3)	22.2 (10.5)	20.4 (10.3)	21.7 (11.7)	0.21 (-4.3 to 4.8) P=0.93

Numbers are mean (SD)

Abbreviations:

PC_{20} = Provocation concentration of methacholine causing a 20% fall in FEV_1; FEV_1 = Forced expiratory volume in one second;

PEF_{var} = PEF variability (measured as amplitude as a percentage of the mean); ACQ = Asthma Control Questionnaire;

† = Difference in doubling doses

Table 3: Effect of paracetamol use on FeNO, blood eosinophil count and serum IgE

	BASELINE		WEEK 12		Difference (adjusted for baseline)
	Paracetamol N=36	Placebo N=58	Paracetamol N=31	Placebo N=54	
Log FeNO (ppb)	3.53 (0.71)	3.66 (0.78)	3.69 (0.70)	3.65 (0.76)	0.09 (-0.097 to 0.27) P=0.36
Log eosinophils ($x10^9$/L)	-1.41 (0.47)	-1.27 (0.53)	-1.33 (0.54)	-1.32 (0.58)	-0.056 (-0.25 to 0.14) P=0.57
Log IgE (kU/L)	5.28 (1.52)	5.29 (1.30)	5.02 (1.56)	5.20 (1.37)	0.098 (0.009 to 0.21) P=0.073

Abbreviations:

FeNO = Fractional exhaled nitric oxide; IgE = Immunoglobulin E

FIGURE LEGENDS

Figure 1:

Study design flow chart

Abbreviations: SPT = Skin prick test; Preg test = pregnancy test; FEV_1/FVC = Forced expiratory volume in 1 second/forced vital capacity; BHR = bronchial hyperresponsiveness testing; ACQ = Asthma Control Questionnaire; LFT = liver function test; FeNO = Fractional exhaled nitric oxide; IgE = Immunoglobulin E; FBC = full blood count

Figure 2:

CONSORT participant flow diagram

RANDOMISED PLACEBO CONTROLLED STUDY OF THE EFFECT OF PARACETAMOL ON ASTHMA SEVERITY IN ADULTS

[1,2,3]Sally ~~Eyers~~J Ioannides, [1]Mathew Williams, [1,2] Sarah Jefferies, [1,2] Kyle Perrin

[2,3]Mark Weatherall [3]Robert Siebers, [3]Julian Crane, [1,2] Mitesh Patel

[1]Justin Travers, [1,2] Philippa Shirtcliffe, [1,2]Richard Beasley

[1]Medical Research Institute of New Zealand, Wellington, New Zealand

[2]Capital & Coast District Health Board, Wellington, New Zealand

[3]University of Otago Wellington, Wellington, New Zealand

Key words: Asthma, paracetamol, randomised controlled trial, bronchial hyperresponsiveness

Word count: ~~3,607~~3,813

Running Title: Effect of paracetamol on adult asthma

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Central Regional Ethics Committee Number: CEN/08/12/070

Correspondence:

Prof Richard Beasley
Medical Research Institute of New Zealand
Private Bag 7902, Wellington 6242
New Zealand
Telephone: 64-4-805 0230
Fax: 64-4-389 5707
Email: richard.beasley@mrinz.ac.nz

ABSTRACT (word count ~~250~~249)

Background: Epidemiological evidence suggests that paracetamol may be a risk factor in the development of asthma and its severity. This is the first randomised placebo-controlled trial of the effect of regular paracetamol on bronchial hyperresponsiveness (BHR) and asthma control in adult asthma.

Methods: In a 12-week randomised, double-blind, placebo-controlled, parallel-group study, 94 adults with mild to moderate asthma received 12 weeks of 1g paracetamol twice daily or placebo twice daily. The primary outcome variable was ~~bronchial hyperresponsiveness~~BHR, measured as ~~the~~ provocation concentration of methacholine causing a 20% fall in FEV_1 (PC_{20} ~~MCh~~), at week 12. Secondary outcome variables included FEV_1, FeNO and ACQ score.

Results: 94 participants received randomised treatment (36 and 58 in ~~the~~ paracetamol and placebo groups respectively); 85 participants completed the study. At 12 weeks the mean (SD) logarithm base two PC_{20} was 1.07 (2.36) in the control group (N=54) and 0.62 (2.09) in the paracetamol group (N=31). After controlling for baseline PC_{20}, the mean difference (paracetamol minus placebo) was -0.48 doubling dose worsening in BHR in the paracetamol group (95% CI -1.28 to 0.32), P=0.24. There were no statistically significant differences (paracetamol minus placebo) in log FeNO 0.09 (95% CI -0.097 to 0.27)), FEV_1 (-0.07 L (95% CI -0.15 to 0.01)), or ACQ score (-0.04 (95% CI -0.27 to 0.18)).

Conclusions: There was no significant effect of paracetamol on ~~bronchial responsiveness~~BHR and asthma control in adults with ~~mild to moderate~~ asthma. However, the study findings are limited by low power and the upper confidence ~~interval~~ limits did not rule out ~~a~~ clinically relevant adverse effects.

STRENGTHS AND WEAKNESSES

- Randomised placebo-controlled trial
- Physiological, clinical and immunological outcome measures
- Powered to detect a marked effect on BHR

KEY MESSAGES

What is the key question?

Does regular paracetamol use result in worsening asthma severity?

What is the bottom line?

Paracetamol use did not cause a marked increase in bronchial hyperresponsiveness or deterioration in asthma control in adults with asthma, although it was not possible to rule out a clinically relevant effect.

Why read on?

This is the first randomised placebo-controlled trial to measure the effects of paracetamol in stable adult asthma. The study findings provide information on which the design of further studies can be based.

ADDITIONAL DATA

There are no additional data available.

CONTRIBUTORSHIP STATEMENT:

S ~~Eyers~~J Ioannides was principal investigator and contributed to study planning, study conduct, data analysis and manuscript preparation. K Perrin contributed to study planning, study conduct and manuscript preparation, M Williams, S Jefferies and M Patel contributed to study conduct, M Weatherall contributed to randomisation, statistical analysis and preparation of manuscript, R Siebers contributed to blood analysis and preparation of manuscript, J Crane contributed to study planning and manuscript preparation, J Travers and P Shirtcliffe were safety investigators and R Beasley contributed to study planning, study conduct, data analysis and manuscript preparation.

INTRODUCTION

There is a growing body of evidence to suggest that paracetamol may play an important role as a risk factor for the development of asthma, and that increasing world-wide use may have contributed to the increasing global prevalence of asthma seen over the last 40 years.[1,2] Childhood asthma risk increases in the offspring of women who consume paracetamol during pregnancy,[3] and paracetamol use in the first 12 months of life is associated with an increased risk of wheezing at 3 years [4,5] and 6-7 years.[6] Cross-sectional surveys in children,[6] adolescents [7] and adults [8-11] consistently demonstrate an association between current paracetamol use and asthma in populations with widely differing lifestyles, standards of living, medical practice and availability of paracetamol. However, there is also evidence that these associations may, in part, be due to confounding by indication in some,[12-14] but not all cohort studies in childhood.[15] Cohort studies in adults have demonstrated that increasing frequency of paracetamol use is positively associated with newly-diagnosed (adult-onset) asthma.[16,17]

There is also evidence that paracetamol may increase the severity of asthma in those with the disease. This primarily comes from the only randomised controlled trial of the effect of paracetamol use for fever and asthma outcomes, in which asthmatic children experiencing a current febrile illness were randomised to receive either paracetamol or ibuprofen.[18] The children who received paracetamol were more likely to require an outpatient visit for asthma compared to children in the ibuprofen group. The increased risk with paracetamol was dose dependent and related to respiratory febrile illnesses rather than other causes of fever. In a case-control study which reported a dose-dependent association between paracetamol use and asthma, a progressively greater risk in those with more severe disease was noted, suggesting an effect on both causation and severity of the disease.[10]

The mounting epidemiological evidence, supported by several biologically plausible mechanisms [19-28] has led to repeated calls [2,5-7,13,29-32] for randomised controlled trials to be undertaken

to explore the relationship between paracetamol and asthma. This study is the first randomised controlled trial undertaken to investigate the effect of regular daily paracetamol on asthma severity in adult patients with asthma. It was powered to detect a one doubling dose change in PC_{20} methacholine bronchial hyperresponsiveness (BHR). Markers of airways inflammation and systemic immunological responses were monitored to provide insight into possible mechanisms of action. The hypothesis was that regular paracetamol use would result in a worsening in BHR and asthma control.

METHODS

The study design was a double-blind, randomised, placebo-controlled, parallel group trial based in Wellington, New Zealand. The study methods are summarised with additional details provided in the supplementary appendix. The study was approved by the Central Regional Ethics Committee (CEN/08/12/070) and all participants gave written informed consent. The trial was registered on the Australian New Zealand Clinical Trials Registry (ACTRN12609000551291).

Participants

Participants were identified from the Medical Research Institute of New Zealand (MRINZ) asthma register, general practitioner patient databases, and the general public through advertising. Inclusion criteria included age between 18 and 65 years, wheeze in the previous 12 months and a doctor's diagnosis of asthma, forced expiratory volume in 1 second (FEV_1) $\geq$70% predicted at screening and baseline and a PC_{20} MCh (the provocation concentration of methacholine causing a 20% reduction in FEV_1) of between 0.125 and 16 mg/ml at baseline. Exclusion criteria included regular use of theophylline, ipratropium bromide, tiotropium or leukotriene receptor antagonists in the previous 3 months, alanine aminotransferase (ALT) levels greater than 1.5 times the upper limit of normal at baseline, a history of liver disease or the current use of hepatotoxic drugs, an exacerbation of asthma within the previous two months requiring prednisone or nebulised bronchodilator, current or past cigarette smoking >10 pack years, history of sensitivity or allergy to paracetamol or current regular use of paracetamol, use of high-dose aspirin or non-steroidal anti-inflammatory drugs, history of alcoholism or current excessive alcohol intake, history of previous intentional overdose of paracetamol, previous suicide attempt or current unstable depression, body mass index <16 kg/m^2, pregnant or breast-feeding women or women not using adequate contraception and participants unsuitable for BHR challenge testing in accordance with American Thoracic Society (ATS) criteria.[33]

Interventions

Participants were randomised to receive one of two treatment regimens for 12 weeks. The treatments were paracetamol 1g, administered as two 500mg tablets, or placebo administered as two identically appearing tablets, taken twice daily. The paracetamol and placebo tablets were supplied by Aspen Asia Pacific Ltd, Sydney, Australia. All participants were instructed to avoid taking other forms of paracetamol (including over-the-counter remedies containing paracetamol) or non-steroidal anti-inflammatory drugs (NSAIDs) for the duration of the study. All participants were provided with a prescription for codeine to use as an analgesic during the study.

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Randomisation

A computer-generated randomisation schedule was generated by the study statistician and was administered by the study pharmacists. It was necessary to randomise the participants prior to their final eligibility screening visit (visit 2) to enable the study pharmacists adequate time to prepare the study medication for dispensing at visit 2 following final determination of eligibility. If a participant failed one of the eligibility criteria at visit 2, the randomised medication was not dispensed and the participant was withdrawn from the study. The randomisation code was not re-used.

Blinding

Study investigators, participants, and participant health care providers were blinded through provision of medication as identically appearing tablets in bottles, with neither the investigator dispensing the medication or the participants aware of the allocated treatment.

Design

The trial involved four study clinic visits and between two and four additional blood tests over 13 weeks (Figure 1). A screening visit (visit 1) was held approximately one week prior to baseline and consisted of a medical history and brief physical examination, pregnancy test where applicable, bronchodilator reversibility testing, liver function screen and allergy skin prick tests (see online supplement for details). A diary was used to record morning and evening peak expiratory flow

(PEF) values (prior to asthma medication use) for one week prior to the second visit. Participants who met initial eligibility criteria were randomised at this stage, prior to final eligibility assessment at visit 2.

At visit 2, designated the baseline visit, the Qoltech asthma control questionnaire (ACQ)[34] was administered and PEF_{var} (PEF variability measured as the amplitude as a percentage of the mean) calculated. Baseline assessments of FEV_1 were undertaken using a Micro Medical Microlab spirometer (Micro Medical, Kent, UK) and Fractional exhaled Nitric Oxide (FeNO) was assessed using a NiOX Flex chemiluminescence analyser (Aerocrine AB, Stockholm, Sweden). Methacholine (Methapharm, Ontario, Canada) challenge testing was undertaken via the two-minute tidal breathing dosing protocol recommended by the ATS,[33] as outlined in the online supplement. Participants who met all the eligibility criteria were then dispensed a six-week supply of randomised medication, a medication diary to record administered doses and a prescription for codeine phosphate for emergency pain relief during the trial period. These participants then underwent blood tests including full blood count (eosinophils), total serum immunoglobulin E (IgE), and serum cytokine levels (interferon (IFN)-γ, interleukin (IL)-4, IL-5, IL-13) (see online supplement for details).

At visits 3 and 4, six and 12 weeks after baseline, FEV_1, ACQ, FeNO and blood tests were repeated and medication compliance checked via pill count and medication diary check (see online supplement for details). At the third visit, participants were given a further six-week supply of study medication, a second medication diary, and a diary to record morning and evening PEF values in the final intervention week. At the fourth and final visit, BHR testing was repeated. Liver function tests were monitored throughout the study (see online supplement for details).

Outcomes

The primary outcome variable was PC_{20} MCh at 12 weeks, adjusted for baseline. This direct measure of BHR was chosen as an objective well standardised physiological measure of asthma

severity, recommended for monitoring the effects of therapy which may modify asthma severity.[33,35] Secondary outcome measures were FEV_1, FEV_1 % predicted, ACQ score and FeNO at six and 12 weeks, and the mean morning peak flow, PEF_{var}, and exacerbations of asthma (requiring a doctor's visit and need for prednisone or nebulised bronchodilator) at 12 weeks. Blood eosinophil, serum IgE, and serum cytokine (IFN-γ, IL-4, IL-5 and IL-13) levels were measured at six and 12 weeks.

Statistical Methods

The primary analysis method was ANCOVA. The logarithm base two PC_{20} for methacholine at 12 weeks was the primary response variable, with the baseline logarithm base two PC_{20} as a covariate, and a categorical variable for the paracetamol group. The difference in logarithm base two PC_{20} was the doubling dose difference between the two randomised groups. Secondary outcome variables, including FEV_1, FEV_1 % predicted, ACQ score, FeNO, mean morning peak flow and PEF_{var} were also analyzed by ANCOVA. The distribution of FeNO, serum IgE and eosinophil count was skewed and normality assumptions for these variables were best met on the natural logarithm scale.

The proportion of participants with at least one asthma exacerbation was compared as an absolute risk difference, with an appropriate confidence interval, because in the event there were no asthma exacerbations in one of the randomised groups so that a relative risk could not be calculated. Simple t-tests were used to compare mean values for ALT by randomised group. FeNO, eosinophil count and IgE were logarithm transformed because of skewed distributions, and the difference in logarithms was compared by a t-test. For those three variables with a logarithm transformation, the exponent of the difference in logarithms is interpreted as the ratio of mean values.~~A risk difference and appropriate confidence intervals were calculated for the categorical variable, the number of participants with at least one asthma exacerbation. Simple t tests were used to compare mean values for ALT, the logarithm transformed FeNO, eosinophil count and IgE by paracetamol or placebo group, as the latter three had skewed distributions. For those variables with a logarithm~~

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~~transformation, the exponent of the difference in logarithms was interpreted as the ratio of mean values.~~

The analysis was by intention to treat of randomised participants who passed the final eligibility screening and as a result received randomised treatment. No randomised participants who failed the final eligibility screen received randomised treatment or underwent any outcome assessments. For each individual analysis, a two-sided P value of 0.05 was used, with 95% confidence intervals for each estimate. We have not adjusted for multiple statistical testing.

Sample Size

A sample size of 60 in each group has 80% power at the 5% level of significance to detect a difference of one doubling dose in PC_{20} MCh between the groups, based on a standard deviation of 1.9.[~~35~~36] To allow for the possibility of up to 10% of study participants withdrawing early from the study, a recruitment target of 66 participants was set for each group.

RESULTS

Recruitment commenced in June 2009 and ended in September 2011. The planned study period of two years was extended by three months due to difficulties in recruitment. Figure 2 shows the flow of participants. There were 724 patients assessed for eligibility at phone screening and/or visit 1; of these, 338 failed to meet the inclusion criteria and 205 declined to participate (see online supplement). There were 181 participants randomised prior to visit 2 based on initial eligibility at visit 1; 91 to the paracetamol group and 92 to the placebo group. 53/91 participants allocated to the paracetamol group and 34/92 allocated to the placebo group were withdrawn at visit 2 as they either did not meet the inclusion/exclusion criteria (PC_{20} >16mg/ml, n=68; PC_{20} <0.125mg/ml, n=3; FEV_1 <70% predicted, n=6; unable to perform spirometry, n=1) or were lost to follow-up or withdrew consent (n=9). No study medication was dispensed to the participants who were withdrawn at visit 2 (see online supplement).

Medication was dispensed to 94 participants who commenced the intervention phase following visit 2: 36 randomised to paracetamol and 58 to placebo. The characteristics of the subjects are shown in Table 1. The mean age of participants was 40 years and there were 59 female participants. Approximately 30% of study participants were prescribed inhaled corticosteroids and 18% prescribed long-acting beta agonist drugs. Around 90% of participants had positive skin prick tests to either cat, mixed grass or house dust mite. Participants had mild to moderate asthma, with a baseline ACQ score of 0.86 (SD 0.59). The baseline mean FeNO was 48.9 ppb (SD 41.3) and the mean FEV_1 was 94% of predicted (SD 12.0). The baseline mean PC_{20} was 4.29 mg/ml (SD 4.54).

There were 85/94 participants who completed the study. Five participants were withdrawn from the paracetamol group; two withdrew at the participant's own discretion, one was excluded due to a raised ALT (119 IU/L), one was lost to follow-up and one was excluded due to intercurrent illness. Four participants were withdrawn from the placebo group; two were excluded due to a raised ALT

(207 and 227 IU/L respectively), one withdrew at the participant's own discretion and one was lost to follow-up.

Primary Outcome Variable

At 12 weeks the mean (SD) logarithm base two PC_{20} was 1.07 (2.36) in the control group (N=54) and 0.62 (2.09) in the paracetamol group (N=31). After controlling for baseline PC_{20}, the difference (expressed as a doubling dose difference, paracetamol minus placebo) was not statistically significant: -0.48 (95% CI -1.28 to 0.32), P=0.24 (Table 2).

Secondary Outcome Variables

There were no statistically significant differences in FEV_1, FEV_1 % predicted, ACQ score, mean morning peak flow or PEF_{var} between the control and paracetamol groups at Week 12 (Table 2) or in FEV_1 or ACQ score at Week 6 (Online Supplement). There were three asthma exacerbations in the placebo group and none in the paracetamol group, an absolute difference of 5.6% (95% CI -0.5 to 11.7%). There was 93.2% compliance in the control group and 90.8% compliance in the paracetamol group when assessed by pill count and medication diaries, a difference of 2.4%, (95% CI -1.0 to 5.8). Serum paracetamol levels (greater than the 30 µmol/L threshold) were detectable in between 31.3 to 38.7% of participants in the paracetamol group and were undetectable in all participants in the placebo group between week 2 and week 12 of the study.

There were no statistically significant differences observed in log FeNO at Week 6 (see Online Supplement), or at Week 12, or in log eosinophil or log IgE levels between the two groups at week 12 (Table 3). Only a proportion of participants had measurable levels of IFN-γ, IL-4, IL-5 and IL-13 at baseline or at other times throughout the trial, precluding meaningful analysis (see online supplement). ALT levels were significantly higher in the paracetamol group, with a mean ALT of 25.4 (SD 9.7) and 19.0 (SD 6.0) in the paracetamol and placebo groups respectively at visit 4, difference 6.3 (95% CI 2.9 to 9.7, p <0.001).

DISCUSSION

This double-blind, randomised, placebo-controlled, parallel group study found no statistically significant ~~reduction in PC_{20}~~ increase in BHR with 12-weeks paracetamol treatment. However, the results did not rule out a clinically significant effect, with the 95% confidence interval containing the pre-specified difference of one doubling dose reduction in PC_{20}. There were no significant differences observed in any of the pre-specified secondary outcome variables of asthma control, inflammatory or immunological markers.

This is the first reported randomised placebo-controlled trial of the effects of daily paracetamol in stable adult asthma. The only other published randomised controlled trial of paracetamol and asthma was the Boston University Fever Study.[18] Children randomised to the ibuprofen group had a reduced risk of having an outpatient visit for asthma during the 4 week study period (OR 0.56, 95% CI 0.34 to 0.95) compared with children in the paracetamol group. Because the study did not include a placebo treatment, it was not possible to determine whether the observed difference in morbidity according to treatment group was attributable to an increased risk with paracetamol or a decreased risk with ibuprofen.

There are several methodological issues relevant to the interpretation of our study findings. First, as enshrined in the Declaration of Helsinki [~~36~~37] there is a requirement to study the least vulnerable populations wherever applicable. Most, but not all, of the putative adverse effects of paracetamol on asthma have been shown in observational studies of children and suggest that paracetamol may increase the risk of developing asthma.[1,2] However, as there is some data to suggest that regular paracetamol use may lead to a deterioration in asthma control in adults,[1,10] we opted to firstly examine the effects of paracetamol in adults with stable asthma.

Second, this trial was powered to determine whether there was an effect on BHR of at least one-doubling dose reduction in PC_{20} MCh. Our ability to achieve the designated sample size completing

the study was affected by several factors. First, despite a rigorous recruitment campaign during which over 700 patients were screened, due to the inclusion and exclusion criteria employed to ensure participant safety, only 94 screened participants were dispensed randomised medication. Secondly, variability in PC_{20} from baseline to week 12 was larger than anticipated, with a pooled SD of 2.27 doubling doses compared to that used in the sample size calculation based on a SD of 1.9, derived from previous studies.[~~35~~36] Another factor which affected the study power was the requirement to randomise subjects prior to their final screening visit in order to allow the pharmacy adequate time for dispensing at visit 2, following final determination of eligibility. If the participant failed this final eligibility, the randomised medication was not dispensed, the participant was withdrawn from the study, and the randomisation code was not reused. By chance this resulted in a disparity between the proportion of participants receiving active or placebo study medication. The power was reduced further due to the withdrawal of 10% of participants following randomisation. As there is an uncertain association between observed variables and missing BHR data in these participants, it was not possible to perform a robust imputation.

Compliance was high when measured via pill count, and although less than half of participants in the paracetamol group had measurable levels of paracetamol in the blood at the times tested throughout the study, this is likely to be due to the laboratory cut-off for a detectable paracetamol level (30 µmol/L). Following a 1g dose, participant blood levels may fall below this laboratory cut-off level in as little as 3 hours (given an paracetamol half-life of 2 hours and a peak plasma concentration 1 hour after administration of 80 µmol/L [~~37~~38]). The use of this laboratory cut-off for paracetamol levels meant that it was not possible to investigate medication compliance through this method.

Our 12-week dosing period was chosen based on evidence that regular, long-term use of paracetamol is associated with an increased risk of asthma in adults [9-11,16,17] and that chronic ingestion of therapeutic doses can reduce serum antioxidant capacity in as little as two weeks.[~~38~~39] We had originally intended to use the maximum daily dose of 4g paracetamol,

however chose to administer half this dose due to concerns of liver toxicity. These concerns were based on a previous clinical trial of paracetamol in which the incidence of ALT elevations more than three times the upper limit of normal in healthy participants taking 4g/day for 14 days was 31 to 44%.[3940] Our results showed no clinically significant liver function derangement with paracetamol administered at a dose of 2g/day for 12 weeks.

Whilst the study did not demonstrate a statistically significant effect of paracetamol on BHR to MCh, the results do not rule out a clinically significant effect, with the upper 95% confidence interval of a 1.28 doubling-dose worsening in BHR containing the pre-specified difference of one doubling-dose. Furthermore, our point estimate of a reduction in PC_{20} of 0.48 of a doubling-dose could potentially be of major public health significance. As proposed by Mitchell,[4041] a small shift to the left of the BHR curve in a population could lead to a relatively large increase in the prevalence of severe asthma. Relevant to the interpretation of our findings it has recently been calculated that a one half doubling dose increase in BHR increases the prevalence of moderate and severe BHR by about 30%.[4142] Likewise, although the 9% increase in FeNO with paracetamol was not statistically significant, a change of this magnitude is considered clinically significant.[4243] For FEV_1, the point estimate was consistent with a lower value in the paracetamol group, however the difference was of uncertain clinical significance and was associated with wide confidence intervals.

No significant effect was seen on serum IgE or peripheral blood eosinophil levels. It was not possible to undertake any meaningful analysis of the cytokine measurements, due to the low numbers of participants with detectable levels, and as a result we were unable to determine if paracetamol influenced the Th1/Th2 balance. Another less recognised potential mechanism of action, which was not directly assessed in this study, relates to neurogenic inflammation of the airways through the stimulation of the transient receptor potential ankyrin-1 (TRPA-1) cation channel by NAPQI, the metabolite of paracetamol.[26] This pathway, which is activated following therapeutic doses of paracetamol, mediates a non-eosinophilic inflammatory response and has

been implicated in the pathogenesis or provocation of asthma by isocyanates, aldehydes, cigarette smoke and chlorine.[~~43~~44,~~44~~45]

Our findings provide information on which the design of further studies could be based. A trial of similar design, utilising the same duration and dose of paracetamol and with BHR testing to MCh as the primary outcome variable, based on the standard deviation derived from this study, would require a sample size of approximately 650 to attain adequate power to detect a difference of 0.5 doubling-doses. Alternatively, a study of short-term use of paracetamol at higher doses could be undertaken, to more closely replicate the common use of paracetamol for relief of fever or pain in self-limited illnesses. Based on our findings, a sample size of 140 would be adequate to determine a 0.5 doubling-dose difference in MCh BHR, and a 10% increase in FeNO, in a short-term study of cross-over design. Important issues with the design of such a study are the duration of both the treatment periods and the crossover period. It would be important if possible to include a placebo rather than ibuprofen arm, as NSAIDs may have the potential to both cause NSAID-induced bronchospasm, as well as reducing asthma severity with long term use.[29]

Finally, our study investigated the effect of paracetamol on asthma severity and not whether paracetamol has a role in the pathogenesis of asthma. Testing this hypothesis would require ~~a~~ clinical trials both of the effect of paracetamol use in pregnancy on the development of asthma in childhood, and the effect of paracetamol use in infants and older children and subsequent asthma risk. ~~, which~~Such studies would raise ethical and practical issues regarding consent and the use of placebo for the management of pain or fever during pregnancy and in young children. However given the common usage of paracetamol in all age groups including pregnancy and the global burden of asthma, we propose that randomised controlled trials are required to determine the effect of paracetamol use on the development of asthma in infancy and early childhood.

In conclusion, this study has shown no significant effect of 12 weeks of treatment with paracetamol at half the maximum therapeutic daily dose on BHR and asthma control in adults with well

controlled asthma. Whilst this outcome provides some reassurance that regular paracetamol use has no marked deleterious effect in adult asthma, further adequately powered studies are needed before the safety of paracetamol for patients with asthma is assured. Furthermore, the study findings do not preclude an effect of paracetamol on the development of asthma in infancy, childhood or adult life.

COMPETING INTERESTS

R Beasley has been a member of the GlaxoSmithKline (NZ) Advisory Board, and received research grants, payment for lectures or support to attend meetings from GlaxoSmithKline, a manufacturer of paracetamol.

FUNDING

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Table 1: Characteristics of participants who received randomised treatment

	Paracetamol Group	Placebo Group
Number	36	58
Demographic		
Mean age, y ±SD	41.5 ±13.9	38.3 ± 12.5
Male sex, No. (%)	15 (41.7)	20 (34.5)
Weight, Kg ±SD	75.1 ± 16.7	77.4 ± 17.8
Height, m ±SD	1.7 ± 0.1	1.69 ± 0.11
BMI, Kg/m^2 ±SD	25.9 ± 4.2	27.1 ± 5.8
Medication Use		
ICS, No. (%)	9 (25%)	20 (34%)
SABA, No. (%)	33 (92%)	55 (95%)
LABA, No. (%)	9 (25%)	8 (14%)
Defining Study Population		
FEV_1, L ±SD	3.09 ± 0.78	3.12 ± 0.87
FEV_1 % Predicted ±SD	94.1 ± 11.3	94.0 ± 12.4
Bronchodilator Reversibility (%)	9.1 ± 6.0	7.8 ± 5.5
SPT Cat pelt, No. (% +ve)	20 (55.6)	33 (57.9)
SPT D. pteronyssinus No. (% +ve)	30 (83.3)	52 (91.2)
SPT Mixed grass, No. (% +ve)	25 (69.4)	38 (66.7)
SPT at least one positive, No. (% +ve)	33 (91.7)	55 (96.5)
Clinical and Physiological Measurements		
PC_{20} MCh, mg/ml ±SD	4.14 ± 4.42	4.39 ± 4.66
Mean morning peak flow, L/min ±SD	424.0 ± 83.8	419.5 ± 92.3
$PEF_{var,}$ %, ±SD	19.0 ± 9.3	22.2 ± 10.5
ACQ Score ±SD	0.93 ± 0.63	0.82 ± 0.56
Inflammation and Immunology		
FeNO, ppb ±SD	44.9 ± 39.2	51.3 ± 42.6
Eosinophils, x 10^9/L, ±SD	0.26 ± 0.12	0.32 ± 0.17
IgE, kU/L, ±SD	518.4 ± 705.7	480.4 ± 914.0

Abbreviations: BMI = Body mass index; ICS = Inhaled corticosteroid; SABA = Short-acting beta agonist; LABA = Long-acting beta agonist; FEV_1 = Forced expiratory volume in 1 second; SPT = Skin prick test; PC_{20} MCh = Provocation concentration of methacholine causing a 20% fall in FEV_1; PEF_{var} = Peak flow variability; ACQ = Asthma Control Questionnaire; FeNO = Fractional exhaled nitric oxide; IgE = Immunoglobulin E

Table 2: Effect of paracetamol use on BHR, lung function and asthma control

	BASELINE		WEEK 12		Difference
	Paracetamol N=36	Placebo N=58	Paracetamol N=31	Placebo N=54	(adjusted for baseline)
Log 2 PC_{20} (mg/ml)	1.30 (1.50)	1.09 (1.96)	0.62 (2.09)	1.07 (2.36)	-0.48 (-1.28 to 0.32) P=0.24†
FEV_1 (L)	3.06 (0.73)	3.05 (0.83)	3.01 (0.74)	3.07 (0.86)	-0.07 (-0.15 to 0.01) P=0.08
ACQ score	0.81 (0.47)	0.93 (0.59)	0.88 (0.56)	1.03 (0.71)	-0.04 (-0.27 to 0.18) P=0.71
Mean morning peak flow (L/min)	424.0 (83.8)	419.5 (92.3)	417.1 (82.3)	417.5 (85.9)	-8.6 (-26.7 to 9.5) P=0.35
PEF_{var} (%)	19.0 (9.3)	22.2 (10.5)	20.4 (10.3)	21.7 (11.7)	0.21 (-4.3 to 4.8) P=0.93

Numbers are mean (SD)

Abbreviations:

PC_{20} = Provocation concentration of methacholine causing a 20% fall in FEV_1; FEV_1 = Forced expiratory volume in one second;

PEF_{var} = PEF variability (measured as amplitude as a percentage of the mean); ACQ = Asthma Control Questionnaire;

† = Difference in doubling doses

Table 3: Effect of paracetamol use on FeNO, blood eosinophil count and serum IgE

	BASELINE		WEEK 12		Difference (adjusted for baseline)
	Paracetamol N=36	Placebo N=58	Paracetamol N=31	Placebo N=54	
Log FeNO (ppb)	3.53 (0.71)	3.66 (0.78)	3.69 (0.70)	3.65 (0.76)	0.09 (-0.097 to 0.27) P=0.36
Log eosinophils ($x10^9$/L)	-1.41 (0.47)	-1.27 (0.53)	-1.33 (0.54)	-1.32 (0.58)	-0.056 (-0.25 to 0.14) P=0.57
Log IgE (kU/L)	5.28 (1.52)	5.29 (1.30)	5.02 (1.56)	5.20 (1.37)	0.098 (0.009 to 0.21) P=0.073

Abbreviations:

FeNO = Fractional exhaled nitric oxide; IgE = Immunoglobulin E

FIGURE LEGENDS

Figure 1:

Study design flow chart

Abbreviations: SPT = Skin prick test; Preg test = pregnancy test; FEV_1/FVC = Forced expiratory volume in 1 second/forced vital capacity; BHR = bronchial hyperresponsiveness testing; ACQ = Asthma Control Questionnaire; LFT = liver function test; FeNO = Fractional exhaled nitric oxide; IgE = Immunoglobulin E; FBC = full blood count

Figure 2:

CONSORT participant flow diagram

Figure 1:

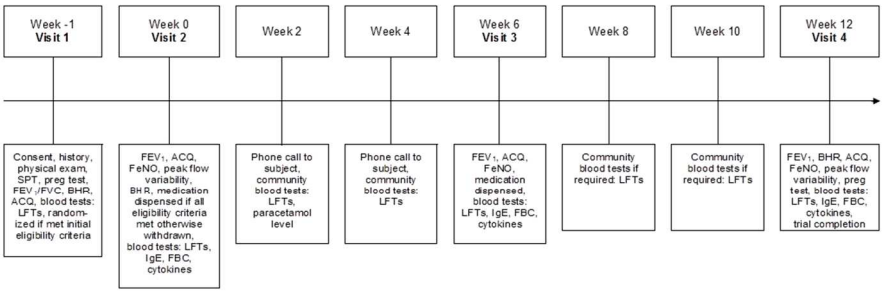

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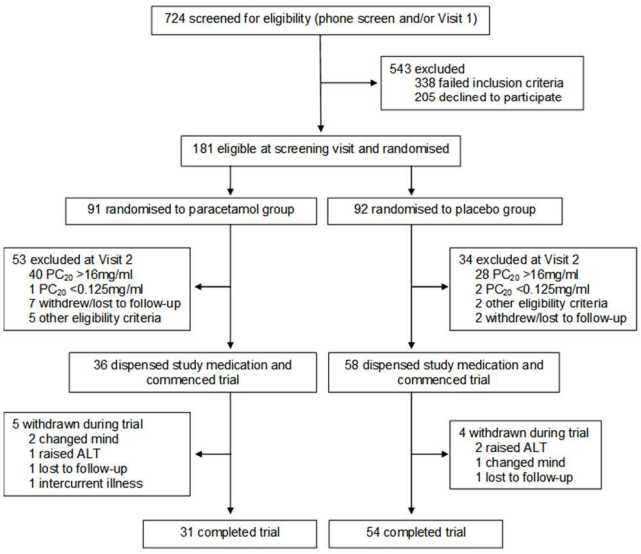
Figure 2:



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ONLINE SUPPLEMENT

RANDOMISED PLACEBO CONTROLLED STUDY OF THE EFFECT OF PARACETAMOL ON ASTHMA SEVERITY

[1,2,3]Sally J Ioannides, [1]Mathew Williams, [1,2]Sarah Jefferies, [1,2]Kyle Perrin

[2,3]Mark Weatherall, [3]Rob Siebers, [3]Julian Crane, [1,2]Mitesh Patel,

[1]Justin Travers, [1,2]Philippa Shirtcliffe, [1,2]Richard Beasley

[1]Medical Research Institute of New Zealand, Wellington, New Zealand

[2]Capital & Coast District Health Board, Wellington, New Zealand

[3]University of Otago Wellington, Wellington, New Zealand

METHODOLOGY

Randomisation

A computer-generated randomisation schedule was generated by the study statistician and was administered by the study pharmacists. It was necessary to randomise the subjects prior to their final eligibility screening visit (visit 2) to enable the study pharmacists adequate time to prepare the study medication for dispensing at visit 2 following final determination of eligibility. Pharmacists received notification from the study investigators that a participant was due to attend visit 2, and assigned the appropriate treatment group to the participant based on the randomisation schedule. Allocated medication was then delivered to the MRINZ research offices in labelled medication bottles, ready for dispensing to study participants at the end of visit 2 if they were eligible for the study. If a participant failed one of the eligibility criteria at visit 2, the randomised medication was not dispensed and the participant was withdrawn from the study. The randomisation code was not re-used.

Skin Prick Testing

Skin prick testing was undertaken to grass (grass mix #7, Hollister Stier Laboratories, USA), house dust mite (Dermatophagoides pteronyssinus, Hollister Stier Laboratories, USA), cat pelt (Stallergenes Laboratories, France), and positive (histamine) and negative controls (Hollister Stier Laboratories, USA), performed in accordance with Australasian Society of Clinical Immunology and Allergy (ASCIA) guidelines (Australasian Society of Clinical Immunology and Allergy 2006 (Revised March 2009)).

Methacholine Challenge Testing

Participants were asked to withhold long-acting beta-agonists (LABAs) for 48 hours and short-acting beta-agonists (SABAs) and food or drink containing caffeine for eight hours prior to BHR testing. Methacholine (provocholine) was sourced from Methapharm Inc

(Ontario, Canada) as 1280mg vials, and was diluted with normal saline in a sterile manner, and refrigerated at a concentration of 128mg/ml for a period of up to three months. Methacholine was further diluted for each individual challenge test into doubling concentrations of 0.0125, 0.03, 0.06, 0.125, 0.05, 1,2, 4, 8, 16, and 32mg/ml and left to warm to room temperature for at least 30 minutes prior to each test. An English Wright nebuliser (Roxon Meditec, Montreal, Canada) was used to deliver the methacholine dose. Basic spirometry was performed prior to challenge testing, and a saline (diluent) dose was given prior to the first methacholine dose. At each inhaled dose, the subject was asked to breath normally though the mouthpiece (with nose clip in place) for two minutes, after which time FEV_1 was measured at 30s and 90s. The next concentration of methacholine was then administered within 5 minutes of the original dose commencement. If FEV_1 fell by $\geq$ 20% from baseline (or if subject finished all concentrations without a drop in FEV_1), no further medication was given and nebulised salbutamol (5mg/2.5ml) was administered immediately, followed by a 10-minute rest period. The subject was monitored and salbutamol nebuliser repeated if necessary until FEV_1 was within 10% of post-saline baseline. PC20, defined as the provocation concentration of inhaled methacholine required to produce a 20% reduction in FEV_1 was calculated via the formula:

Logarithmic PC20 = Antilog [(20-R1)(logC2-logC1)/(R2-R1) + logC1]

where C1 is the methacholine concentration producing less than a 20% Fall in FEV_1 and C2 is that producing a greater than 20% fall in FEV_1. R1 and R2 are the percent FEV_1 reductions produced by C1 and C2 respectively (Cockcroft, Murdock et al. 1983).

Liver Function Tests

Liver function tests included alanine aminotransferase (ALT), alkaline phosphatase (ALP), bilirubin, albumin, total protein and gamma-glutamyl transferase (GGT). Any

participant who developed an elevation in ALT of greater than three times the upper limit of normal during the study period was withdrawn from the trial. Blood tests to monitor liver function were undertaken at two and four weeks after randomisation and were accompanied by a phone call to the participant to monitor adverse events. Participants who experienced a rise in ALT two to three times the upper limit of normal during the first six weeks of the study were required to have additional blood tests to monitor liver function eight and 10 weeks after randomisation. In order to maintain investigator blinding, results of liver function tests were kept from the study investigators and viewed only by the allocated safety data reviewers (JT and PS). If further blood tests were required at weeks eight and 10, contact was made with the participant by the safety reviewer directly so as to maintain investigator blinding. If, during the course of the study, any participant was found to have abnormal liver function which required their withdrawal from the study, the safety investigator unblinded the participant in order to inform their ongoing management and notified their health care provider.

Cytokine Measurement

Concentrations of IFN- γ, IL-4, IL-5 and IL-13 were measured by ELISA (Quantikine, R&D Systems, Minneapolis, MN), according to the manufacturer's protocols. The ELISA minimum detectable level for IFN- γ was 12.5 pg/ml, for IL-4 was 27.7 pg/ml, for IL-5 was 3.5 pg/ml and for IL-13 was 55.3 pg/ml.

Medication Compliance Monitoring

Compliance with study medication was determined by a review of the medication diary, a count of the units of medication returned at the end of the first and second 6-week study period, and blood paracetamol levels taken at weeks 2, 6 and 12.

At visit 3 and 4, participants returned their medication diary and any remaining study medication from the first or second 6-week period of the study. All participants were given

188 tablets of study medication at visit 2 and visit 3, which equated to 6 weeks of fully compliant medication dosing and one extra week in case of a delay in follow-up. The number of days that the participant had been randomised, and therefore the number of doses of study medication expected to have been consumed over that time period were calculated based on the entries in the medication diary. The remaining tablets of study medication were then counted and were compared with the number of tablets expected to be returned.

References

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Cockcroft DW, Murdock KY, et al. Determination of histamine PC20. Comparison of linear and logarithmic interpolation. *Chest* 1983;**84**:505-6

Table E1: Participant recruitment failures

Excluded at Phone Screen (n=486)	
200	Declined to participate
56	Smoker/Ex-smoker
39	Contraindication to trial/paracetamol (incl: planned surgery, use of contraindicated meds, chronic pain conditions, allergy to NSAIDS/paracetamol)
37	Asthma too severe
35	Currently using regular paracetamol
35	Asthma too mild/no asthma
34	Unable to travel to study site
18	History suicide attempt/current depression
10	Breastfeeding, pregnant, no contraception
8	Trial period ended
7	History of liver disease
6	Age outside range
1	High weekly alcohol intake
Excluded at Visit 1 (n=57)	
19	FEV_1<70% predicted
11	Raised ALT
10	History suicide attempt/current depression
5	Lost to follow up/withdrew consent
4	Smoker/ex-smoker>10py
3	Contraindication to trial/paracetamol (incl: planned surgery, use of contraindicated meds, chronic pain conditions, allergy to NSAIDS/paracetamol)
2	High weekly alcohol intake
1	No contraception
1	High blood pressure
1	Age outside range
Excluded at Visit 2 (n=87)	
68	PC_{20} > 16 mg/ml
9	Lost to follow up/withdrew consent
7	FEV_1 < 70% predicted
3	PC_{20} < 0.0125 mg/ml

Table E2: Participants with detectable levels of cytokines

Variable (detectable level)	N/N (%)	
	Paracetamol	Placebo
IFN-γ (12.5 pg/ml)		
Visit 2	21/36 (58.3)	33/58 (56.9)
Visit 3	25/29 (86.2)	40/55 (72.7)
Visit 4	26/31 (83.9)	44/53 (83.0)
IL-4 (27.7 pg/ml)		
Visit 2	1/36 (2.8)	3/58 (5.2)
Visit 3	4/29 (13.8)	1/55 (1.8)
Visit 4	2/31 (6.5)	2/53 (3.8)
IL-5 (3.5 pg/ml)		
Visit 2	1/36 (2.8)	2/58 (3.5)
Visit 3	3/29 (10.3)	4/55 (7.8)
Visit 4	3/31 (9.7)	0/53 (0)
IL-13 (55.3 pg/ml)		
Visit 2	0/36 (0)	4/58 (6.9)
Visit 3	1/29 (3.5)	3/55 (5.5)
Visit 4	1/31 (3.2)	7/53 (13.2)

Abbreviations: IFN-γ = Interferon gamma; IL-4/5/13 = Interleukin 4/5/13

Table E3: Effect of paracetamol use on BHR, lung function and asthma control

	BASELINE		WEEK 6		Difference
	Paracetamol N=36	Placebo N=58	Paracetamol N=32	Placebo N=55	(adjusted for baseline)
FEV_1 (L)	3.06 (0.73)	3.05 (0.83)	3.08 (0.78)	3.13 (0.83)	-0.03 (-0.14 to 0.08) P=0.54
ACQ score	0.81 (0.47)	0.93 (0.59)	0.74 (0.49)	0.78 (0.50)	0.04 (-0.13 to 0.22) P=0.62
Log FeNO (ppb)	3.53 (0.71)	3.66 (0.78)	3.59 (0.68)	3.67 (0.71)	0.001 (-0.15 to 0.16) P=0.99

Numbers are mean (SD)

Abbreviations:

FEV_1 = Forced expiratory volume in one second; ACQ = Asthma Control Questionnaire;

FeNO = Fractional exhaled nitric oxide

CONSORT 2010 checklist of information

Page numbers refer to the page in the manuscript [top right of document]. OS: Online supplement. P: Protocol, N/A: Not applicable

Section/Topic	Item No	Checklist item	Reported on page No
Title and abstract			
	1a	Identification as a randomised trial in the title	1
	1b	Structured summary of trial design, methods, results, and conclusions (for specific guidance see CONSORT for abstracts)	2-3
Introduction			
Background and objectives	2a	Scientific background and explanation of rationale	4
	2b	Specific objectives or hypotheses	5
Methods			
Trial design	3a	Description of trial design (such as parallel, factorial) including allocation ratio	6-8, Fig 1
	3b	Important changes to methods after trial commencement (such as eligibility criteria), with reasons	N/A
Participants	4a	Eligibility criteria for participants	6
	4b	Settings and locations where the data were collected	6-8
Interventions	5	The interventions for each group with sufficient details to allow replication, including how and when they were actually administered	7-8
Outcomes	6a	Completely defined pre-specified primary and secondary outcome measures, including how and when they were assessed	8, OS
	6b	Any changes to trial outcomes after the trial commenced, with reasons	None
Sample size	7a	How sample size was determined	10
	7b	When applicable, explanation of any interim analyses and stopping guidelines	None
Randomisation:			
Sequence generation	8a	Method used to generate the random allocation sequence	7
	8b	Type of randomisation; details of any restriction (such as blocking and block size)	7
Allocation concealment mechanism	9	Mechanism used to implement the random allocation sequence (such as sequentially numbered containers), describing any steps taken to conceal the sequence until interventions were assigned	7
Implementation	10	Who generated the random allocation sequence, who enrolled participants, and who assigned participants to interventions	7, OS

Blinding	11a	If done, who was blinded after assignment to interventions (for example, participants, care providers, those assessing outcomes) and how	7
	11b	If relevant, description of the similarity of interventions	7
Statistical methods	12a	Statistical methods used to compare groups for primary and secondary outcomes	9
	12b	Methods for additional analyses, such as subgroup analyses and adjusted analyses	9
Results			
Participant flow (a diagram is strongly recommended)	13a	For each group, the numbers of participants who were randomly assigned, received intended treatment, and were analysed for the primary outcome	11, Fig 2
	13b	For each group, losses and exclusions after randomisation, together with reasons	11, Fig 2, OS Table 1
Recruitment	14a	Dates defining the periods of recruitment and follow-up	11
	14b	Why the trial ended or was stopped	11
Baseline data	15	A table showing baseline demographic and clinical characteristics for each group	Table 1
Numbers analysed	16	For each group, number of participants (denominator) included in each analysis and whether the analysis was by original assigned groups	11,12
Outcomes and estimation	17a	For each primary and secondary outcome, results for each group, and the estimated effect size and its precision (such as 95% confidence interval)	11,12, Tables 2 and 3
	17b	For binary outcomes, presentation of both absolute and relative effect sizes is recommended	11,12
Ancillary analyses	18	Results of any other analyses performed, including subgroup analyses and adjusted analyses, distinguishing pre-specified from exploratory	OS Tables 2 and 3
Harms	19	All important harms or unintended effects in each group (for specific guidance see CONSORT for harms)	11,12
Discussion			
Limitations	20	Trial limitations, addressing sources of potential bias, imprecision, and, if relevant, multiplicity of analyses	13-15
Generalisability	21	Generalisability (external validity, applicability) of the trial findings	13
Interpretation	22	Interpretation consistent with results, balancing benefits and harms, and considering other relevant evidence	15,16
Other information			
Registration	23	Registration number and name of trial registry	3
Protocol	24	Where the full trial protocol can be accessed, if available	3
Funding	25	Sources of funding and other support (such as supply of drugs), role of funders	17