Cancer prevention with aspirin in hereditary colorectal cancer (Lynch syndrome), 10-year follow-up and registry-based 20-year data in the CAPP2 study: a double-blind, randomised, placebo-controlled trial

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Summary

Background Lynch syndrome is associated with an increased risk of colorectal cancer and with a broader spectrum of cancers, especially endometrial cancer. In 2011, our group reported long-term cancer outcomes (mean follow-up 55·7 months [SD 31·4]) for participants with Lynch syndrome enrolled into a randomised trial of daily aspirin versus placebo. This report completes the planned 10-year follow-up to allow a longer-term assessment of the effect of taking regular aspirin in this high-risk population.

Methods In the double-blind, randomised CAPP2 trial, 861 patients from 43 international centres worldwide (707 [82%] from Europe, 112 [13%] from Australasia, 38 [4%] from Africa, and four [<1%] from The Americas) with Lynch syndrome were randomly assigned to receive 600 mg aspirin daily or placebo. Cancer outcomes were monitored for at least 10 years from recruitment with English, Finnish, and Welsh participants being monitored for up to 20 years. The primary endpoint was development of colorectal cancer. Analysis was by intention to treat and per protocol. The trial is registered with the ISRCTN registry, number ISRCTN59521990.

Findings Between January 1999, and March 2005, 937 eligible patients with Lynch syndrome, mean age 45 years, commenced treatment, of whom 861 agreed to be randomly assigned to the aspirin group or placebo; 427 (50%) participants received aspirin and 434 (50%) placebo. Participants were followed for a mean of 10 years approximating 8500 person-years. 40 (9%) of 427 participants who received aspirin developed colorectal cancer compared with 58 (13%) of 434 who received placebo. Intention-to-treat Cox proportional hazards analysis revealed a significantly reduced hazard ratio (HR) of 0·65 (95% CI 0·43–0·97; p=0·0085) for aspirin versus placebo. Negative binomial regression to account for multiple primary events gave an incidence rate ratio of 0·58 (0·39–0·87; p=0·0085). Per-protocol analyses restricted to 509 who achieved 2 years’ intervention gave an HR of 0·56 (0·34–0·91; p=0·019) and an incidence rate ratio of 0·50 (0·31–0·82; p=0·0057). Non-colorectal Lynch syndrome cancers were reported in 36 participants who received aspirin and 36 participants who received placebo. Intention-to-treat and per-protocol analyses showed no effect. For all Lynch syndrome cancers combined, the intention-to-treat analysis did not reach significance but per-protocol analysis showed significantly reduced overall risk for the aspirin group (HR=0·63, 0·43–0·92; p=0·018). Adverse events during the intervention phase between aspirin and placebo groups were similar, and no significant difference in compliance between intervention groups was observed for participants with complete intervention phase data; details reported previously.

Interpretation The case for prevention of colorectal cancer with aspirin in Lynch syndrome is supported by our results.

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randomly assigned over 18 000 women to alternate day 100 mg aspirin or vitamin E supplement. Intervention over 10 years showed no effect on cancer incidence. A subsequent post-trial review up to 18 years revealed a significantly lower incidence of colorectal cancer in those randomly assigned to aspirin.4

The Cancer Prevention Programme (CaPP), originally called the Concerted Action Polypsis Prevention (CAPP) project, was launched in 1993 to investigate therapeutic prevention in those with a proven genetic predisposition to colorectal and other cancers. CAPP1 focused on adolescents with familial adenomatous polyposis.5 CAPP2,6 which began in 1999, focused on people with Lynch syndrome, formerly known as hereditary non-polyposis colon cancer, which results from pathogenic variants in one of the DNA mismatch repair genes.7 In both trials, the potential cancer preventives were aspirin and resistant starch and a factorial design was used; in CAPP2, participants received 600 mg entericoated aspirin or placebo and 30 g of Novolose, a resistant starch, or placebo corn starch, daily. Recruits could opt to be randomly assigned for a single agent only. If a participant agreed to be randomly assigned for aspirin, recruits were treated for 2 years with aspirin or placebo; after a formal review, the design was adapted to allow recruits to consent to continue for a further 2-year period. When participants had completed this intervention phase, data analysis revealed no significant impact on neoplasia which combined colorectal adenoma and carcinoma formation.3 At that stage, there were 20 diagnosed colorectal cancers.8 The protocol had anticipated a delayed effect on cancer incidence as is evident from epidemiological studies in the general population9 and provided for follow-up to 10 years. When the first recruits reached their 10-year follow-up (mean follow-up of 4 years 7 months), intention-to-treat analysis showed a non-significant protective effect on colorectal cancer in the aspirin limb compared with placebo (hazard ratio [HR]=0·63, 95% CI 0·35–1·13; p=0·12) with a similar result for all Lynch syndrome cancers. Per-protocol analysis was restricted to those who took aspirin or placebo for the defined minimum 2-year intervention period. This showed significant protection against colorectal cancer (HR=0·41, 95% CI 0·19–0·86; p=0·02) and a similar reduction for all Lynch syndrome cancers (HR=0·45, 95% CI 0·26–0·79; p=0·005).5 We now report the planned 10-year analysis, in which all participants were beyond the 10-year

Evidence before this study
There is extensive evidence from case-control studies, epidemiology, polyp prevention studies, and long-term review of historical aspirin cardiovascular prevention trials that regular intake of aspirin (acetyl salicylic acid) and other non-steroidal anti-inflammatory drugs over long periods is associated with reduced incidence of colorectal and other cancers. Two trials explored the protective effects of aspirin with cancer as a primary endpoint; the Women’s Health Study showed no effect of alternate day 81 mg aspirin up to study end at 10 years, but a subsequent reduction in colorectal cancer in the second decade. The CAPP2 Study randomised 861 carriers of hereditary cancer, Lynch syndrome, average age 42 years, to 600 mg aspirin or 30 g resistant starch, or both in a factorial design. There was no effect at the end of intervention (average 2·5 years) but there was a significant per-protocol protective effect of the aspirin at an average of 4·6 years follow-up.

Added value of this study
The mechanisms of action of aspirin relevance to colorectal cancer prevention, including for Lynch syndrome, are unknown, thus there is no insight into the time that the intervention takes to come into full effect or the period over which a time-limited intervention will allow protection. By monitoring people with known intervention and disease status, this study examines the magnitude of the effect and provides some indications as to the magnitude of the long-term effect.

The cancer histories of all participants in CAPP2 were reviewed where possible up to the planned 10-year follow-up and a subset in three countries was followed via national registries for up to 20 years. Aspirin prescription ended in 2007 at the latest. Intention-to-treat Cox proportional hazards analysis showed that aspirin protected against the primary endpoint of colorectal cancer (HR=0·65 [95% CI 0·43–0·97], p=0·035). Negative binomial regression, considering all primary cancer diagnoses in the cancer spectrum of Lynch syndrome found similar evidence of aspirin protection (incidence rate ratio 0·58, 95% CI 0·39–0·87, p=0·0085). For those who took aspirin for the planned minimum 2 years, the effect was similar; HR 0·56, CI 0·34–0·91, p=0·019.

There were half as many endometrial cancers in the aspirin group but overall, non-colorectal cancer Lynch syndrome cancers were not significantly different in the longer follow-up. In the second decade, there was some evidence of a decline in non-Lynch syndrome cancers that did not reach significance.

Implications of all the available evidence
Two standard aspirins per day for 2 years results in a significant reduction in colorectal cancer incidence in Lynch syndrome carriers, which persists for over a decade but does not become apparent until about 5 years from commencement. During intervention, serious adverse events did not differ significantly from the placebo group in this relatively young group. The ongoing CaPP3 Study is a dose non-inferiority trial which will inform optimal doses for cancer prevention versus adverse events. There is now a strong case for prescribing aspirin to young adult carriers of a germline DNA mismatch repair gene defect.
anniversary of their recruitment; this includes the period in which the participant was taking the agent. In addition, we complemented these data through access to the National Cancer Registration & Analysis Service via Public Health England, which provided robust cancer data for the English and Welsh recruits up to 20 years; equivalent data was obtained for the Finnish participants over the same time period.

**Methods**

**Study design and participants**

Between January, 1999, and March, 2005, 937 (87%) of 1071 assessed carriers of Lynch syndrome started intervention in the CAPP2 study. Eligible patients were older than 25 years of age and were proven carriers of a pathological mismatch-repair mutation (ie, genetic diagnosis) or were members of a family that met the Amsterdam diagnostic criteria and had a personal history of a cured Lynch syndrome neoplasm but a largely intact colon (ie, clinical diagnosis). Trial design and randomisation blocks have been described previously as has a detailed description of participant characteristics; a summary of some of the characteristics of the participants is shown in the appendix (p 8). All data relating to participants, their random assignment and all clinical outcomes in the trial were collected by the local clinical management centre for each participant and then sent to the CAPP2 Offices at Newcastle University, UK, where the dedicated CAPP2 study team maintained the information in a TrakGene database. These data were then linked to study number, anonymised, and sent to the University of Leeds (DTB and FE) for statistical analysis. Participants consented in writing to have their health records followed for 10 years. The study had a pre-planned design for 10-years’ follow-up and at the time of this analysis, the last enrolled participant had reached the 10-year threshold. All participants consented to long-term follow-up at recruitment and consent was refreshed in the later stages of the study.

**Randomisation and masking**

Briefly, of the 937 participants, 427 were randomly assigned to 600 mg aspirin and 434 to aspirin placebo (hereafter placebo; figure 1). The remaining recruits were not randomly assigned for the aspirin intervention, having opted not to participate in this part of the study (n=76, mostly owing to perceived aspirin sensitivity or history of peptic ulceration). All participants were also separately randomly assigned to resistant starch or resistant starch placebo intervention in a 2 × 2 factorial design. Details of the starch randomisation and outcomes were reported in 2012, and an update is in preparation (J Burn; personal communication). Participants and investigators were masked to intervention allocation. Participants and their clinicians were informed of their randomisation category at their 10-year review or later when contact was achieved.

**Procedures**

Recruits received intervention over 2 years with an option to continue for a further 2 years. We also included data from analysis beyond the 10-year period and up to 20 years of follow-up for participants resident in England or Wales. For these participants, cancer history was assessed by means of national cancer registration information made available by Public Health England. Similarly, all participants in Finland are monitored centrally, and long-term cancer information was available for these participants from the Finnish Lynch syndrome registry. For the analysis between 10 and 20 years of follow-up, we combined information for 360 participants from England, Finland, and Wales.

Details of adenoma recurrence, adverse events during and post-intervention, and compliance (ie, proportion of scheduled tablets taken during the intervention phase) have been described previously.

**Outcomes**

The primary outcome of the CAPP2 study was the number, size, and histological stage of colorectal carcinomas found after a minimum of 2 years’ intervention with aspirin. Secondary clinical outcomes were the size and number of adenomas and of other Lynch syndrome-related cancers.

This analysis focused on the 861 CAPP2 study participants randomly assigned to 600 mg aspirin (n=427) or placebo (n=434) from the date of entry until the latest date for which we had information about cancer status, often corresponding to the date of last surveillance attendance and, for recruits in England, Finland, and Wales, supplemented with passive recording of cancer registration. The analysis included Lynch syndrome cancer diagnoses; those that occurred during the intervention phase and subsequent to exit from the intervention phase. Designation of a reported diagnosis as being within the Lynch syndrome cancer spectrum was a clinical assessment, masked to intervention; endometrial, ovarian, pancreatic, small bowel, gall bladder, ureter, stomach, and kidney cancers and cancer of the brain were included. Adverse events during the intervention phase between aspirin and placebo groups were reported previously.

**Statistical analysis**

Power calculations suggested that to detect a 40% reduction in cancer risk among those taking aspirin with 90% power at a 0.05 significance level, about 100 cancer diagnoses post-recruitment were required, indicating approximately 1000 recruits and a 10-year follow-up. In total, 937 eligible patients with Lynch syndrome, mean age 45 years, commenced treatment, of which 861 agreed to be randomly assigned to the aspirin group or placebo and the mean intervention period was 2.5 years. When participants had completed this intervention phase, data analysis revealed no significant effect on neoplasia which
combined colorectal adenoma and carcinoma formation.\textsuperscript{10} At that stage, there were 20 diagnosed colorectal cancers.\textsuperscript{10} The protocol had anticipated a delayed effect on cancer incidence as is evident from epidemiological studies in the general population\textsuperscript{12} and provided for follow-up to 10 years. When the first recruits reached their 10-year follow-up (mean follow-up of 4 years 7 months), intention-to-treat analysis showed a non-significant protective effect on colorectal cancer in the aspirin group compared with placebo with a similar result for all Lynch syndrome cancers.\textsuperscript{11} Per-protocol analysis was restricted to those who took aspirin or placebo for the defined minimum 2-year intervention period. This showed significant protection against colorectal cancer and a similar reduction for all Lynch syndrome cancers.\textsuperscript{11}

Intention-to-treat analyses were done (ie, according to aspirin randomisation; aspirin or placebo). However, as the intention of this trial was to test the efficacy of 2-year intervention with aspirin, we also did a per-protocol analysis that was restricted to those participants who achieved the full 2-year intervention. Participants were provided with two 300 mg tablets daily over the first 2 years of the intervention phase and the numbers of aspirin (or placebo tablets) remaining were recorded. At clinic visits during the intervention period, each participant was asked to show the aspirin (or placebo) remaining, this number was recorded to allow estimation of the number of tablets taken. Participants whose study records indicated having taken at least 1400 tablets were considered as per protocol.

Two analytical approaches were used: time to first occurrence of colorectal cancer (our primary endpoint) was examined by means of life-table methods and Cox proportional hazards; and investigation of multiple primary cancers at the same anatomical site or multiple anatomical sites, a feature of Lynch syndrome, by means of negative binomial modelling which considers the complete Lynch syndrome cancer history since randomisation. Previously, we had applied Poisson regression but analysis of this extended dataset indicated over-dispersion, so we have applied negative binomial regression.\textsuperscript{11}

For life-table analysis and Cox proportional hazards analysis, end of follow-up was determined as the time to first diagnosis of colorectal cancer (or other Lynch syndrome cancer, as appropriate), if the participant was diagnosed with cancer following random assignment, or the last recorded date at which clinical status was known. For the negative binomial regression analysis, exposure time was calculated from randomisation until the date of last known clinical status, or 10 years if this came earlier (20 years if resident in England, Finland, or Wales). Analyses were further done as intention to treat (ie, intervention assigned at randomisation) and per protocol. Beyond 10 years, cancer diagnosis follow-up data from England and Wales were obtained from Public Health England and their Welsh counterparts (see appendix p 3); all data released by Public Health England was with the approval of their Office for Data Release and within the policy and legal frameworks for the use of patient data collected by the National Cancer Registration and Analysis Service. Data from the Finnish national registry maintained by the Department of Surgery, Central Finland Healthcare District, Jyväskylä were accessed similarly (see appendix p 3).

Sex-adjusted and age-adjusted hazard ratio (HR) estimates and 95% CIs were calculated by means of Cox
proportional hazard models, and Kaplan-Meier curves were used to assess non-parametrically the outcome differences between the aspirin and placebo groups; these adjustments were deemed desirable given the variation of cancer risk with age and the different spectrum of cancer in females and males. The assumption of proportional hazard was tested by means of Schoenfeld residuals. Sex-adjusted and age-adjusted incidence rate ratios were calculated by means of negative binomial regression to estimate the effect of aspirin from log-linear models for the number of primary cancers diagnosed after randomisation and until the last follow-up.

A secondary analysis examined the incidence of non-colorectal Lynch syndrome cancers. A final analysis examined the total burden of Lynch syndrome-related cancers. In keeping with the original sample size calculations, all p values were two-sided. All analyses were carried out in Stata (version 14).

The trial is registered with the ISRCTN registry, number ISRCTN59521990.

Role of the funding source
Neither the funders nor the sponsors of the study had any role in study design, data collection, data analysis, data interpretation, or writing of the report. The corresponding authors had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Results
Between January, 1999, and March, 2005, 937 carriers of Lynch syndrome in England, Finland, and Wales of 1071 assessed started intervention in the CAPP2 study. Table 1 documents the characteristics of the 427 CAPP2 participants randomly assigned to aspirin and the 434 participants randomly assigned to placebo. Each group had approximately 25 months of intervention and a mean of more than 7 years’ follow-up post-intervention.

The distribution of time since recruitment was also similar between the groups (table 1); 58 (14%) of the aspirin group and 67 (15%) of the placebo group had no follow-up after the intervention phase, predominantly because of refusal to consent to long-term follow-up (61%) or loss to follow-up (34%; figure 1). Since randomisation, 40 (9%) of 427 participants randomly assigned to aspirin developed colorectal cancer compared with 58 (13%) of 434 allocated to placebo (table 1). When all Lynch syndrome cancers are included, 74 (17%) of 427 participants from the aspirin group had developed cancer compared with 89 (21%) of 434 in the placebo group (table 1).

We present analyses of the combined information from the post-trial surveillance of participants for the first 10 years across all centres with that collected for up to 20 years from national cancer data registry data sources for England (58%), Finland (41%), and Wales (16%). Information on the separate analyses of these datasets can be found in the appendix. For completeness, the numbers are reported for the overall 10-year follow-up of all participants in the appendix (p 9) and for the 20-year follow-up involving participants in England, Finland, and Wales only in the appendix (p 12). The close alignment between data collected by the CAPP Centres in the first 10 years of follow-up for England, Finland, and Wales and the information collected directly from national health data sources for the same time period are shown in the appendix (p 11). There was almost complete concordance in reporting of colorectal cancer diagnoses between the CAPP centre and the national sources; however, concordance for both non-colorectal cancer Lynch syndrome diagnoses and non-Lynch syndrome diagnoses was lower, most notably for Finland. These observations reflect the fact that most recruiting centres took responsibility for organising and reviewing bowel

| Table 1: The whole CAPP2 cohort at 10 years plus England, Finland, and Wales registry data to 20 years |
|---|---|---|
| Aspirin (n=427) | Placebo (n=434) | Total (n=861) |
| Time in CAPP2 intervention study (months)* | 25.0 | 25.4 | 25.2 |
| (12.5, 0.8–60.6) | (14.2, 1.1–74.4) | (13.4, 0.8–74.4) |
| Months between study entry and last known follow-up date | 120.4 | 115.3 | 118.4 |
| (63.3, 1.6–238.7) | (63.7, 1.1–238.9) | (63.5, 1.1–238.9) |
| Years between study entry and last known follow-up date | ≤2 | 2 (10%) | 42 (10%) |
| (63.5, 1.1–238.7) | (63.7, 1.1–238.9) | (63.5, 1.1–238.9) |
| >2 and ≤6 | 80 (19%) | 87 (20%) | 167 (19%) |
| >6 and ≤10 | 133 (31%) | 144 (33%) | 277 (32%) |
| >10 and ≤14 | 54 (13%) | 43 (10%) | 97 (11%) |
| >14 and ≤18 | 104 (24%) | 101 (23%) | 205 (24%) |
| >18 and ≤20 | 20 (5%) | 17 (4%) | 37 (4%) |
| Participants with first colorectal cancer | | | |
| Since randomisation | 40 (9%) | 58 (13%) | 98 (11%) |
| Within 2 years of randomisation | 10 (2%) | 10 (2%) | 20 (2%) |
| More than 2 years from randomisation | 30 (7%) | 48 (11%) | 78 (9%) |
| Participants with other Lynch syndrome cancers (excluding colorectal) | | | |
| Since randomisation | 36 (8%) | 36 (8%) | 72 (8%) |
| Within 2 years of randomisation | 7 (2%) | 9 (2%) | 16 (2%) |
| More than 2 years from randomisation | 29 (7%) | 27 (6%) | 56 (7%) |
| Participants with one or more Lynch syndrome cancers (including colorectal) | | | |
| Since randomisation | 74 (17%) | 89 (21%) | 163 (19%) |
| Within 2 years of randomisation | 17 (4%) | 19 (4%) | 36 (4%) |
| More than 2 years from randomisation | 57 (13%) | 70 (16%) | 127 (15%) |
| Types of extracolonic Lynch syndrome cancers | | | |
| Brain | 2 (<1%) | 0 | 2 (<1%) |
| Stomach, duodenum | 5 (1%) | 6 (1%) | 11 (1%) |
| Bile duct, pancreas | 8 (2%) | 3 (1%) | 11 (1%) |
| Urinary† | 7 (2%) | 6 (1%) | 13 (2%) |
| Ovarian | 2 (<1%) | 2 (<1%) | 4 (<1%) |
| Endometrium–uterine | 8 (2%) | 17 (4%) | 25 (3%) |
| Multiple sites | 4 (1%) | 2 (<1%) | 6 (1%) |
| Participants with non-Lynch syndrome cancers | | | |
| Since randomisation | 36 (8%) | 42 (10%) | 78 (9%) |
| Within 2 years of randomisation | 2 (<1%) | 7 (2%) | 9 (1%) |
| More than 2 years from randomisation | 34 (8%) | 35 (8%) | 69 (8%) |

*Data are mean (SD, range) or n (%). †Urinary cancers include ureter and kidney cancers.
surveillance while the spectrum of non-colorectal cancers challenged the capabilities of some centres to obtain complete information.

Intention-to-treat analysis showed a reduced HR of 0.65 (95% CI 0.43–0.97; p=0.035) for aspirin versus placebo (table 2; figure 2A; appendix p 16). Per-protocol analysis restricted to 509 participants who had achieved a minimum of 2 years on treatment showed a significantly reduced HR of 0.56 (0.27–1.19; p=0.13) for aspirin versus placebo (HR=0.56, 95% CI 0.27–1.19; p=0.13). The threshold for 2 years’ intervention was consumption of more than 1400 aspirin tablets; rounded from a 2-year total of 1461 to allow for early scheduling of the exit colonoscopy or occasional missed dosage. ¶Units of 100 aspirin=total number of aspirin taken divided by 100.

Separate 10-year and 20-year analyses are reported in the appendix (pp 10, 13, 17–18) with similar findings with respect to effect sizes.

For non-colorectal Lynch syndrome cancers, neither intention-to-treatment analysis (HR=0.94, 95% CI 0.59–1.50; p=0.81) nor per-protocol analysis (HR=0.75, 0.42–1.34; p=0.035; table 2) showed any significant effect of aspirin chemoprevention.

Separate 10-year and 20-year analyses are also reported in the appendix (pp 10, 13, 17–18); for this analysis, there is less consistency in the estimates between the analyses but there is no evidence of a cancer-prevention effect overall. Examination of individual anatomical sites is not feasible given the numbers of cases. However, for endometrial cancer, the most common Lynch syndrome cancer after the colorectum, the observation of only seven cases among women on aspirin compared with 17 on placebo is suggestive but not conclusive of a protective effect of aspirin (HR=0.50, 95% CI 0.22–1.11; p=0.09; appendix p 19).

For all Lynch syndrome cancers, intention-to-treat analysis showed no significant effect (HR=0.76, 95% CI 0.56–1.03; p=0.081) with similar results for the incidence rate ratio analysis. However, per-protocol analysis showed reduced risk among aspirin takers (HR=0.63, 0.43–0.92; p=0.018) with similar estimates and significance for the incidence rate ratio analysis (table 2; appendix p 16). Intention-to-treat and per-protocol analysis for non-colorectal Lynch syndrome cancers are shown in the appendix (p 14) and the results for the separate 10-year and 20-year analyses are shown in the appendix (pp 17–18).

Although evidence of the beneficial effect of aspirin on cancer risk seems strongest for colorectal cancer, there is some evidence of a broader spectrum of activity so we examined the effect of aspirin on risk of all non-Lynch syndrome cancers (details in appendix p 14). There was no significant evidence of any effect of aspirin on non-Lynch syndrome cancer risk (appendix p 10). In the data available for the second decade, there were five cancers in the aspirin group and 12 in the placebo group (HR=0.56, 95% CI 0.27–1.19; p=0.03; appendix p 14).

We investigated whether aspirin treatment affected the stage at which cancers were diagnosed. For the 54 tumours for which Dukes’ stage information was available, there was no evidence of any stage differences between those randomly assigned to aspirin and to placebo (p=0.37; appendix p 15).

**Discussion**

Evidence accumulated over 30 years shows that frequent aspirin ingestion reduces cancer risk in the general population;15,16 analysis of data from observational studies, from trials with cardiovascular disease as the primary endpoint and from one trial with cancer as an endpoint, shows that the protective effect of aspirin takes 3–10 years to become apparent in the general population. Follow-up
This analysis of data from people with Lynch syndrome recruited to the CAPP2 study shows that the protective effects of aspirin against colorectal cancer has persisted in this long-term analysis of up to 20 years’ follow-up. The CAPP2 study data were analysed at the end of the intervention, again when the first recruits reached their 10-year follow-up and now when all participants reached 10-years’ follow-up and some approached 20 years since recruitment. Colorectal cancer incidence began to diverge about 5 years after initiating aspirin treatment and this lower cancer incidence was maintained throughout the period of observation. This pattern is similar to that observed in the long-term follow-up of participants randomly assigned to aspirin in cardiovascular disease prevention trials. This analysis confirms the extended effect both in the per-protocol group but, now, also in the intention-to-treat analysis of all participants. As would be expected, the effect sizes in the intention-to-treat analysis are less extreme than the per-protocol analysis. The support from this intention-to-treat analysis reduces any concerns that the previous per-protocol finding was attributable, not to aspirin, but to an unidentified confounding factor which associated with non-adherence.

Whereas the evidence for CRC chemoprevention with aspirin for the genetically predisposed has increased, the evidence for prevention at the other anatomical sites relevant to Lynch syndrome has weakened.

The mechanism of action of aspirin in cancer prevention remains to be established; the beneficial effect of a range of NSAIDs in cancer prevention and the association between PIK3CA mutation and response of colorectal cancers to aspirin use in the Nurses’ Health Study point to a long-term influence of the suppression of inflammation. The benefits seen in the Women’s Health Study followed use of alternate day low-dose aspirin, however, which is too low to suppress inflammation directly.

The response to aspirin might reflect an effect on the viability of cells with malignant potential as suggested by studies in cell lines and mouse models. Salicylates in
plants modulate the apoptotic response to infection and might have a similar pro-apoptotic influence in the gut. Enhanced destruction of premalignant abnormal cells would offer an explanation for the long-time-lag in response to aspirin intervention. The progressive decline in mitochondrial function, on which apoptosis is reliant, in the gut in old age might then contribute to the lesser response to aspirin chemoprevention in old age. The widespread occurrence of aberrant colonic crypts, defective in mismatch repair, in Lynch syndrome suggests that these might be the premalignant lesions that are suppressed or destroyed by long-term aspirin exposure, but this hypothesis remains to be tested. In addition, whether this occurs via enhanced apoptosis or improved immune surveillance, or a combination of these and other mechanisms are important areas for future investigation.

It has been suggested that the results of the first follow-up analysis might have reflected a temporary delay in progression of premalignant lesions rather than a true prevention of cancer. This is not supported by the continued separation of the cumulative incidence of colorectal cancer in the two treatment groups. It is noteworthy that the effect on non-colorectal Lynch syndrome cancers was of similar magnitude to the lower intestinal effects in the 10-year data. The benefit in prevention of non-colorectal cancer tumours was not apparent in the data available for the second decade, suggesting that any preventive effect is not sustained. This is in keeping with the long-term follow-up of the Women’s Health Study in which the effect of low dose aspirin, which appeared at 10 years, was evident for colorectal cancer only.

Weaknesses of this trial are that the geographically dispersed recruitment over a long period made collection of details of endoscopy difficult, so data on adenomas are incomplete and the current analysis is restricted to cancer as an endpoint. We were unable to comment on effect on mortality as the death rate in patients with Lynch syndrome undergoing surveillance is low; that would require a much larger study. Our study attempted to recruit patients with a confirmed, significant mutation in a mismatch repair gene, defective in mismatch repair, in Lynch syndrome, in which the effect of low dose aspirin, which appeared at 10 years, was evident for colorectal cancer only.

In conclusion, the data reported here support the recommendation that adult carriers of a pathogenic mismatch repair gene defect (Lynch syndrome) should be advised that taking 600 mg aspirin daily for at least 2 years significantly reduces the risk of a future cancer, bearing in mind that this effect does not become apparent for at least 4 years.

**Contributors**

DTB, JB, LB, DGE, AL, FM, JCM, P/M, HJWT, and RR contributed to the design of the study. JB, LB, DGE, A-MG, JWCH, AL, FM, J-PM, P/M, GM, KP, TS, RR, and HJWT identified patients, collected relevant data, and ensured local compliance with protocol and the provision of pseudo-anonymised data to the Newcastle Centre. LB and GMB ensured that the data held at the Newcastle Centre was quality checked and complete. FEM, JR, and TS were responsible for identifying and providing long-term follow-up data on participants in England, Finland, and Wales. JB, GMB, DTB, JCM, and HS were responsible for the implementation of the analysis. JB, GMB, DTB, FE, FM, P/M, JCM, TS, and HJWT interpreted the results. GMB, FE, LR, and JB collated the final dataset. DTB, FE, and HS performed the statistical analysis. DTB and JB created the initial drafts of the manuscript. DGE, MB, JB, and JCM were responsible for essential revisions of the manuscript and for incorporation of important intellectual content. All authors reviewed the manuscript and gave final approval for submission. JB, DTB, and JCM supervised the study.

**Declaration of interests**

DGE reports personal fees and other from Astrazeneca, outside the submitted work. JCM reports grants from MRC and Bayer; during the conduct of the study. TS reports grants from Sigrid Juselius Foundation, Instrumentarium Science Foundation, Emil Aaltonen Foundation, Finnish Medical Foundation and travel expenses from Medtronic Finland Oy (outside the submitted work); and Co-owner of Healthfund Finland Oy. DTB reports grants from Cancer Research UK during the conduct of the study. GM reports having being paid for consultancy by Bayer (more than 3 years ago) plus engagement with non-ASS companies investigating the effect of chemoprevention. FM is supported by Cancer Council of Victoria and NSW; Cancer Australia; J-PM and P/M are supported by The Finnish Cancer Foundation & Jane and Aatos Erkko Foundation, Finland. DGE is supported by the all Manchester NIHR Biomedical Research Centre (IS-BRC-1215-20007). RR is supported by Medical Research Council (MRC) of South Africa. JB received a fee as a speaker at a Bayer workshop in 2010. All other authors declare no competing interests.
Data sharing
For further access to data, please contact the corresponding author (JB).

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