




European guidelines from the EHTG and ESCP for Lynch syndrome: an updated third edition of the Mallorca guidelines based on gene and gender

T. T. Seppälä ^{1,2,*}, A. Latchford^{3,4}, I. Negoi¹¹, A. Sampaio Soares¹², R. Jimenez-Rodriguez ¹³, L. Sánchez-Guillén ¹⁴, D. G. Evans⁵, N. Ryan^{6,7}, E. J. Crosbie⁶, M. Dominguez-Valentin¹⁵, J. Burn⁸, M. Kloor^{16,17}, M. von Knebel Doeberitz^{16,17}, F. J. B. van Duijnhoven²⁰, P. Quirke⁹, J. R. Sampson¹⁰, P. Møller^{15,19}, G. Möslein^{18,19}, on behalf of the European Hereditary Tumour Group (EHTG) and European Society of Coloproctology (ESCP)

¹Department of Surgery, Helsinki University Hospital, and University of Helsinki, Helsinki, Finland

²Department of Surgical Oncology, Johns Hopkins Hospital, Baltimore Maryland, USA

³Department of Cancer and Surgery, Imperial College London, UK

⁴St Mark's Hospital, London North West Healthcare NHS Trust, London, UK

⁵Manchester Centre for Genomic Medicine, Division of Evolution and Genomic Sciences, University of Manchester, Manchester University Hospitals NHS Foundation Trust, UK

⁶Division of Cancer Sciences, Faculty of Biology, Medicine and Health, University of Manchester, St Mary's Hospital, Manchester, UK

⁷Centre for Academic Women's Health, University of Bristol, Bristol, UK

⁸Faculty of Medical Sciences, Newcastle Upon Tyne Hospitals NHS Foundation Trust, Newcastle upon Tyne, UK

⁹Pathology and Data Analytics, School of Medicine, University of Leeds, Leeds, UK

¹⁰Institute of Medical Genetics, Division of Cancer and Genetics, Cardiff University School of Medicine, Heath Park, Cardiff, UK

¹¹Department of Surgery, Emergency Hospital of Bucharest, Carol Davila University of Medicine and Pharmacy, Bucharest, Romania

¹²Hospital Prof. Dr Fernando Fonseca, EPE, Lisbon, Portugal

¹³Department of Surgery, Hospital Universitario Virgen del Rocío, Seville, Spain

¹⁴Colorectal Unit, Department of General Surgery, Elche University General Hospital Elche, Alicante, Spain

¹⁵Department of Tumour Biology, Norwegian Radium Hospital, Oslo University Hospital, Oslo, Norway

¹⁶Department of Applied Tumour Biology, Institute of Pathology, University Hospital Heidelberg, Germany

¹⁷Cooperation Unit Applied Tumour Biology, German Cancer Research Centre, Heidelberg, Germany

¹⁸Centre for Hereditary Tumours, Bethesda Hospital, Duisburg, Germany

¹⁹University of Witten/Herdecke, Witten, Germany

²⁰Division of Human Nutrition and Health, Wageningen University and Research, Wageningen, the Netherlands

*Correspondence to: Dr T. T. Seppälä, PO Box 340, 00029 HUS, Helsinki, Finland (e-mail: toni.seppala@fimnet.fi; @Adductor, @AndyLatchford, @IonutNegoi, @ASampaioSoares, @LuisSanchezGln, @neilajryan, @ProfEmmaCrosbie, @mev_dv, @CaPP3, @GabrielaMoslein, @EHTG_Tweets, @escp_tweets, @YouESCP, @amchelsinki, @Lynch_fi, @StMarksFCC, @Lynchsyndromirl, @LynchSyndromeUK, @Colores_ry, @me4_so, @SoMe4GenRisk)

Abstract

Background: Lynch syndrome is the most common genetic predisposition for hereditary cancer but remains underdiagnosed. Large prospective observational studies have recently increased understanding of the effectiveness of colonoscopic surveillance and the heterogeneity of cancer risk between genotypes. The need for gene- and gender-specific guidelines has been acknowledged.

Methods: The European Hereditary Tumour Group (EHTG) and European Society of Coloproctology (ESCP) developed a multidisciplinary working group consisting of surgeons, clinical and molecular geneticists, pathologists, epidemiologists, gastroenterologists, and patient representation to conduct a graded evidence review. The previous Mallorca guideline format was used to revise the clinical guidance. Consensus for the guidance statements was acquired by three Delphi voting rounds.

Results: Recommendations for clinical and molecular identification of Lynch syndrome, surgical and endoscopic management of Lynch syndrome-associated colorectal cancer, and preventive measures for cancer were produced. The emphasis was on surgical and gastroenterological aspects of the cancer spectrum. Manchester consensus guidelines for gynaecological management were endorsed. Executive and layperson summaries were provided.

Conclusion: The recommendations from the EHTG and ESCP for identification of patients with Lynch syndrome, colorectal surveillance, surgical management of colorectal cancer, lifestyle and chemoprevention in Lynch syndrome that reached a consensus (at least 80 per cent) are presented.

Received: March 24, 2020. Revised: May 16, 2020. Accepted: June 14, 2020

© The Author(s) 2021. Published by Oxford University Press on behalf of BJS Society Ltd.

This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted reuse, distribution, and reproduction in any medium, provided the original work is properly cited.

Definitions used in these guidelines

- Consensus: at least 80 per cent agreement
- Majority: 50–79 per cent agreement
- Subtotal colectomy: anastomosis is ileosigmoidal
- Total colectomy: anastomosis is ileorectal
- Extended surgery: refers either to subtotal colectomy with ileosigmoidal anastomosis or total colectomy with ileorectal anastomosis, when used to replace an operation that would be oncological standard practice for a sporadic colorectal cancer, because of a pathogenic germline variant
- Amsterdam criteria: these criteria were introduced for uniform classification based on family history and require at least three affected members on the same side of the family in two or more generations, with one being a first-degree relative of the other two and at least one individual diagnosed before 50 years of age. The Amsterdam I criteria apply to families with three or more colorectal cancers, and the Amsterdam II criteria also include extracolonic tumours: endometrial cancer, cancer of the upper urinary tract and cancer of the small bowel
- Carrier: a person with a germline *path_MMR* variant
- Lynch syndrome (LS): the dominantly inherited cancer syndrome caused by the presence of a pathogenic mismatch repair gene variant
- Revised Bethesda guidelines: guidance developed for testing colorectal tumours for microsatellite instability (MSI), when: colorectal or uterine cancer is diagnosed in a patient who is less than 50 years of age; synchronous, metachronous colorectal, or other hereditary non-polyposis colorectal cancer (HNPCC)-associated tumours (regardless of age) are present; colorectal cancer with MSI-high is diagnosed in a patient who is aged less than 60 years; colorectal cancer is diagnosed in one or more first-degree relatives with an HNPCC-related tumour, with one of the cancers being diagnosed under age 50 years; colorectal cancer is diagnosed in two or more first- or second-degree relatives with HNPCC-related tumours, regardless of age
- *Path_MMR*: the pathogenic (disease-causing) variants of the specified mismatch repair (MMR) gene associated with cancer, including all structural or epigenetic variants of these

Executive summary of recommendations

Recommendations for the identification of patients with Lynch syndrome (LS), colorectal surveillance, surgical management of colorectal cancer, lifestyle and chemoprevention that reached a consensus (at least 80 per cent) by a combined expert working group from the European Hereditary Tumour Group (EHTG; former Mallorca Group) and the European Society of Coloproctology (ESCP) are presented in Table 1. In addition, there was agreement to endorse the Manchester consensus statement for gynaecological cancer in LS¹. The summary of recommendations for health-care professionals is as follows.

General information

- LS is caused by inherited malfunction in one of the four MMR genes named *MLH1*, *MSH2*, *MSH6* and *PMS2*. The malfunctioning variants are referred to as *path_MLH1*, *path_MSH2*, *path_MSH6* and *path_PMS2*. People carrying inherited *path_MMR* or inherited epigenetically silenced variants of these genes are referred to as carriers.

- Carriers have an increased risk of developing colorectal, endometrial, ovarian, urinary tract, prostate and other cancers, depending on which gene is malfunctioning. Therefore, consideration to the responsible gene and gender should be given where a pathogenic variant has been identified.
- The average risk for cancer stratified by gene, organ, gender and age is available at <http://www.PLSD.eu>. This resource allows personalized genetic counselling to support decision-making.
- The guidelines presented here are designed to empower patients and clinicians to enable informed and individualized decision-making; the authors recognize that there is no universal approach to the care of those who carry *path_MMR* and have LS, and therefore personalized care is critical.

Identification of carriers

- All colorectal and endometrial cancer should be tested for evidence of MMR deficiency to screen for LS. If not limited by resources, all those with colorectal or endometrial cancer can undergo direct germline testing for *path_MMR*.
- The established clinical criteria may be used for selecting people without cancer to be genetically tested.

Surveillance for colorectal cancer

- Colonoscopy is recommended every 2 or 3 years for *path_MLH1*, *path_MSH2* and *path_MSH6* carriers, unless they have had colorectal cancer before, after which biennial colonoscopy is recommended.
- *Path_PMS2* carriers may be considered for 5-yearly colonoscopy.
- Colonoscopy surveillance is recommended starting at age 25 years for *path_MLH1* and *path_MSH2* carriers, and at age 35 years for *path_MSH6* and *path_PMS2* carriers.
- The recommended surveillance for colorectal cancer does not differ between men and women.

Surveillance, management and prevention of gynaecological cancer

- The Manchester International Consensus Group¹ recommendations for the surveillance, management and prevention of gynaecological cancers in LS are endorsed.

Surgical management of colorectal cancer

- Extended surgery is recommended for *path_MLH1* and *path_MSH2* carriers at the time of first diagnosis of a colonic cancer.
- Removing part of the colon or rectum in the absence of cancer or endoscopically non-removable polyps is not generally recommended for *path_MSH6* and *path_PMS2* carriers.

Lifestyle and chemoprevention

- Smoking and obesity increase the risk of colorectal cancer in carriers.
- Alcohol consumption increases the risk of colorectal cancer in carriers.
- Physical activity reduces colorectal cancer risk in carriers.
- Daily acetylsalicylic acid of at least 75 mg reduces cancer risk in carriers.

Recommendations for professionals have been summarized in Fig. 1 and Table S1 (supporting information). Universal laboratory

Table 1 Recommendations that achieved consensus based on GRADE

	Strength of recommendation	% of voters agreeing
Identification of LS		
Amsterdam criteria and/or revised Bethesda criteria are not sufficient to guide tumour testing owing to low sensitivity in detection of patients with LS	Strong*	86
All colorectal cancers should be tested by MMR (MLH1, MSH2, MSH6, PMS2) immunohistochemistry or MSI testing (followed by possible MLH1 hypermethylation testing) to screen for LS	Strong*	91
Immunohistochemistry performed on preoperative colorectal cancer biopsies is at least as accurate as that performed on resection specimens	Strong*	81
Colorectal surveillance		
For <i>path_MLH1</i> , <i>path_MSH2</i> and <i>path_MSH6</i> carriers, 2- or 3-yearly colonoscopic surveillance is recommended†	Strong*	75
For <i>path_PMS2</i> carriers, colonoscopic surveillance should be performed to reduce mortality and incidence of colorectal cancer	Strong*	82
For <i>path_PMS2</i> carriers, 5-yearly surveillance may be considered	Weak†	80
For patients with LS with a history of CRC and segmental colectomy, biennial colonoscopies should be performed	Strong*	88
For patients with LS with a history of CRC and segmental colectomy, biennial rectosigmoidoscopies should be performed	Strong*	88
There is no evidence at the moment to support different surveillance colonoscopy intervals for men and women	Strong*	100
Chromoendoscopy is equivalent to high-definition white-light endoscopy in specialist centres. It may be an adjunct to be considered in the absence of high-definition endoscopy or in centres with lower adenoma detection rates	Weak†	92
If bowel preparation is not entirely adequate, a repeat procedure at 1 year is recommended. If the bowel preparation is completely inadequate or the examination incomplete, an immediate repeat colorectal surveillance procedure should be requested (within next 6 weeks)	Weak, based on very low-quality evidence (expert opinion)	85
Age at onset of surveillance colonoscopy should be stratified according to genotype	Strong*	100
For <i>path_MLH1</i> or <i>path_MSH2</i> carriers, surveillance colonoscopies should be initiated at the age of 25 years	Moderate†	94
For <i>path_MSH6</i> or <i>path_PMS2</i> carriers, surveillance colonoscopies should be initiated at the age of 35 years	Moderate†	93
Age at onset of surveillance should not be stratified by gender	Moderate*	88
Surgical management of colorectal cancer		
For a <i>path_MLH1</i> or <i>path_MSH2</i> carrier with a first colonic cancer, extended surgery with ileosigmoidal/ileorectal anastomosis is preferable to standard resection to reduce the risk of metachronous CRC	Strong*	82
For a <i>path_MSH6</i> or <i>path_PMS2</i> carrier with a first colonic cancer, standard/segmental colonic resection should be offered	Weak*	80
For a <i>path_MMR</i> carrier with a metachronous colonic cancer, the surgical treatment can be extended surgery with ileorectal/ileosigmoidal anastomosis.	Weak, based on very low-quality evidence	93
A decision on extended colorectal surgery for CRC should not be based on dMMR immunohistochemistry (loss of MLH1, MSH2, MSH6 or PMS2) and BRAF staining/MLH1 hypermethylation from the preoperative endoscopic biopsy only	Strong*	94
For a <i>path_MMR</i> carrier, the surgical treatment of a primary rectal cancer (occurring as the first colorectal cancer) should be standard resection (anterior resection or APR)	Strong*	92
In a young <i>path_MMR</i> carrier with a rectal cancer and a synchronous neoplasia or a personal preference, extended surgery can be considered	Weak, based on very low-quality evidence	86
Ileoanal pouch surgery (in agreement with ECCO guidelines for pouch surgery in ulcerative colitis) should be performed in highly specialized colorectal surgical units	Moderate†	92
For endoscopically non-removable polyps with advanced histology, an oncological approach is recommended, as for gene-specific treatment for carcinoma	Strong*	93
Prophylactic colorectal surgery in the absence of neoplastic lesions in the colorectum is not recommended for <i>path_MMR</i> carriers based on their pathogenic variant-related risk only	Strong*	97
Lifestyle and chemoprevention		
<i>Path_MMR</i> carriers should be advised that smoking increases the risk of colorectal cancer	Weak†	100
<i>Path_MMR</i> carriers should be advised that obesity increases the risk of colorectal cancer	Weak†	100
<i>Path_MMR</i> carriers should be advised that physical activity reduces the risk of colorectal cancer	Weak†	90

(continued)

Table 1. (continued)

	Strength of recommendation	% of voters agreeing
<i>Path_MMR</i> carriers should be advised that alcohol consumption increases the risk of colorectal cancer	Weak [†]	82
<i>Path_MMR</i> carriers should be advised that there is a high probability that daily aspirin will reduce cancer risk	Weak#	90
Patients with <i>path_MMR</i> should be advised that there is a high probability that daily aspirin will reduce their cancer risk	Weak*	100
The recommended aspirin dose should be a minimum of 75–100 mg daily. This dose should be increased for people with above-average body mass	Weak [†]	93

*Based on moderate-quality evidence; [†]based on low-quality evidence. [‡]Consensus not reached between 2- and 3-year interval. GRADE, Grading of Recommendations, Assessment, Development and Evaluation; LS, Lynch syndrome; MMR, mismatch repair; MSI, microsatellite instability; CRC, colorectal cancer; dMMR, deficient mismatch repair; APR, abdominoperineal resection; ECCO, European CanCer Organisation.

Table 2 Overview of chromoendoscopy studies in Lynch syndrome

Reference	Study outcomes
Brown et al. ²⁴	CE yielded more people with at least one neoplastic lesion (OR 1.53, 95 per cent c.i. 1.31 to 1.79). However, the authors felt the evidence base was too small
Kamiński et al. ²⁵	The study strongly recommended the routine use of high-definition pancolonic CE in patients with known or suspected LS (conventional CE, NBI, i-SCAN), but acknowledged the low-quality evidence
Lecomte et al. ²⁶	A small series reported that CE improved the adenoma detection rate in tandem colonoscopy studies
Stoffel et al. ²⁷	Patients underwent white-light colonoscopy and were then randomized to CE versus intensive inspection (withdrawal time of at least 20 min). CE was superior to standard white-light examination but not significantly different from intensive inspection
Rahmi et al. ²⁸	Patients underwent tandem colonoscopy with white light then CE. CE was superior, identifying 32 of 78 patients with one or more adenomas versus 18 of 78 ($P < 0.001$) and an additional adenoma in 24 of 78 (31%).
van Rijn et al. ²⁹	A 20% adenoma miss rate in average-risk cohorts was reported in a systematic review of tandem white-light/CE studies
East et al. ³⁰	The authors reported a significantly increased adenoma detection rate with NBI. However, there was no randomization of the order in which NBI and white-light colonoscopy were undertaken in this study, which is a major methodological criticism
Bisschops et al. ³¹	An increased adenoma detection rate was reported with the use of i-SCAN versus high-definition white-light colonoscopy in 61 patients with LS. Patients were randomized to i-SCAN or white light first
Hüneburg et al. ³²	In a comparison of white light with CE and virtual chromoendoscopy, CE was found to be significantly better than NBI and standard white-light colonoscopy
Rondagh et al. ³³	Findings in patients with and without LS were compared. LS adenomas were more likely to be non-polypoid (43 versus 17%; OR 3.6, $P < 0.001$). This was particularly so for those in the proximal colon (58 versus 16%; OR 6.93, $P < 0.001$). Advanced histology was more likely to be found in non-polypoid adenomas in patients with LS than those without (4 of 5 versus 5 of 12). Serrated lesions were more likely to be non-polypoid in LS (49 versus 20%; OR 3.57, $P < 0.001$)

CE, chromoendoscopy; OR, odds ratio; NBI, narrow-band imaging; i-SCAN, postprocessing software filter technology; LS, Lynch syndrome.

screening for upper urinary tract carcinomas to identify LS was approved by a majority (73 per cent) but did not reach consensus. A summary of recommendations for patients (layperson summary) is presented in Table S2 (supporting information).

Introduction

LS (OMIM #120435) is the most common dominantly inherited cancer syndrome but is often not recognized^{2,3}. The prevalence of *path_MMR* carriers has been estimated to be around one in 300, that is 2.5 million people in Europe alone⁴.

Carriers are at increased risk of developing cancers, including colorectal, endometrial, ovarian, stomach, pancreatic, small bowel, biliary tract, urinary tract, brain and skin cancer. In LS, these cancers may occur much earlier in life than their sporadic counterparts, but older age of onset is not infrequent, and penetrance and expression vary by gene and gender from very high to immeasurable. The International Society for Gastrointestinal Hereditary Tumours (InSiGHT), through the use of its international database (<http://insight-database.org/>) and expertise, categorizes MMR gene variants as being pathogenic (class 5) or likely to be pathogenic (class 4) (or as being of uncertain significance,

likely not pathogenic or not pathogenic). This information can then be used to inform patient-centred counselling in consultation with the Prospective Lynch Syndrome Database (PLSD) (<http://www.plsd.eu>). Potentially modifiable factors include acetylsalicylic acid (aspirin) prophylaxis and lifestyle. Typically, LS-associated cancers have significantly better prognoses than sporadic cancers affecting the same organs, reflecting biological differences, including the marked immune responses that characterize LS cancers⁵. Patients with LS who are within cancer surveillance programmes benefit from a stage shift and earlier cancer diagnosis and usually survive their first cancers. Despite surveillance, those with LS can go on to develop metachronous cancers, with service planning implications⁶.

Carriers are identified by demonstration of a class 5 or 4 germline *path_MMR* variant. HNPCC refers to a family history indicating dominantly inherited colorectal cancer, which was later divided to specify several distinct, inherited, cancer syndromes that include colorectal cancer and other cancers (Fig. 2)⁷. Previously published guidelines^{8,9}, for clinical management of LS were based on retrospective studies and made uniform management recommendations, regardless of which gene was involved.

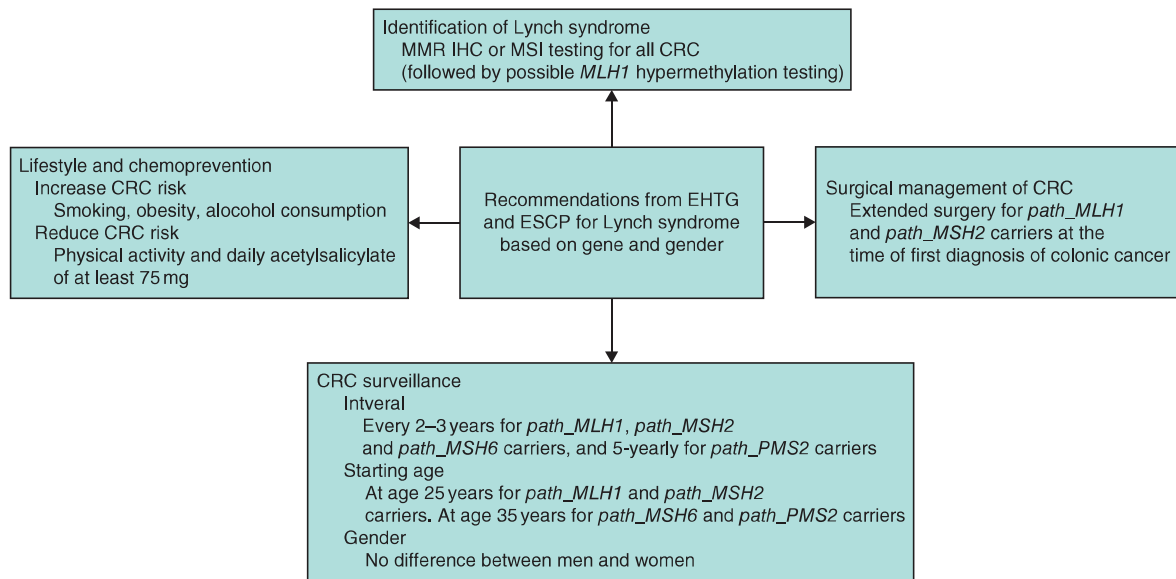


Fig. 1 Summary of core content of the recommendations

MMR, mismatch repair; IHC, immunohistochemical; MSI, microsatellite instability; CRC, colorectal cancer; EHTG, European Hereditary Tumour Group; ESCP, European Society of Coloproctology.

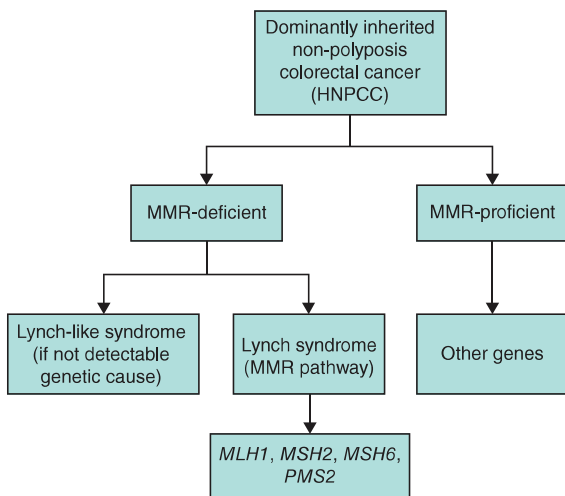


Fig. 2 Clinical classification of hereditary non-polyposis colorectal cancer and causal genes⁷

HNPCC, hereditary non-polyposis colorectal cancer; MMR, mismatch repair.

Methods

Guideline group

In 2007, a group of European experts (the Mallorca Group) published guidelines for the clinical management of LS¹⁰ that were revised in 2013⁸. The present second revision was conducted by a combined expert working group from the EHTG (former Mallorca Group) and ESCP, and was based on previously selected clinical questions. The group consisted of surgeons, clinical and molecular geneticists, pathologists, epidemiologists, gastroenterologists and a patient representative. If a particular specialty was not represented, specialists outside the group were consulted. It was decided that the update format of the manuscript would be via a continuous update process to be undertaken by the EHTG (living guidance).

Scope of updated guidelines

This update is based on the results from new prospective studies that reported the average risk of cancer in carriers by organ, by age, by gene and by gender. It covers the screening, diagnosis and management of LS, and is targeted for patients with this condition. Its aim is to gather the most up-to-date evidence on the management of LS. Furthermore, this guideline addresses the clinical questions raised in previous versions, and updates recommendations for the clinical management of carriers. Specifically, the guideline details the treatment and prevention of cancers based on gene and gender, and identifies areas requiring more research. This document is directed to patients of both genders and all age groups in which the diagnosis of LS is suspected or confirmed. The recommendations are directed to all patients with the condition, irrespective of severity or co-morbidities.

Literature search

A PICO (Patients, Intervention, Comparison, Outcome) model structure was created for each area of interest, based on previously published template questions⁸. A systematic literature search was performed using the PubMed database and the Cochrane Database of Systematic Reviews, and manual searches of relevant articles up until November 2018. The following Medical Subject Heading (MeSH) terms were used: 'hereditary nonpolyposis colorectal cancer'[All Fields] OR 'Lynch syndrome'[All Fields]; 3893 articles were identified. The titles were screened and relevant articles written in English were reviewed, and the level of evidence was graded as high, moderate, low or very low, according to GRADE (Grading of Recommendations, Assessment, Development and Evaluation) criteria (<http://www.gradeworkinggroup.org/>) (Table S3, supporting information).

Timeline and meetings

During the working group meetings (3 meetings and several teleconferences), the outcomes of the literature search were discussed in detail. PICOs are available in Appendix S1 (supporting information) and Delphi round results in Table S4 (supporting information).

Suggestions for guidance statements emerging from the literature review were formulated and tested through Delphi model-based voting rounds. The first Delphi round took place as an online questionnaire on SurveyMonkey® (<https://www.surveymonkey.co.uk>) in week 38 of 2018. The stakeholders were identified from the membership of the EHTG to provide multidisciplinary expertise. The statements were thereby revised for a second Delphi round via live voting which took place in week 39 of 2018, among participants at the Third Annual Meeting of the EHTG in Nice, France. The statements were revised again, and a third Delphi round was conducted by SurveyMonkey® with voting in weeks 32–34 of 2019, again among multidisciplinary stakeholders identified by the EHTG. The most recent results from the PLSD studies were disclosed to all participants before voting, but were only published later¹¹. The threshold for reaching consensus in the Delphi votes was set at 80 per cent.

The AGREE reporting checklist was used to guide the reporting of the process ([Appendix S1, supporting information](#)). An external review of the statements was undertaken before the third Delphi round, focusing mainly on the language of the statements communicating the strength of the recommendation based on the quality of evidence.

Question 1: how can the identification of Lynch syndrome be improved?

LS carcinomas of the large bowel are associated with a highly cellular, medullary or mucinous appearance, with a marked increase in the number of intratumoral and peritumoral lymphocytes, a pushing border with a low frequency of budding and low stromal content. They have a lower rate of nodal spread. Although these phenotypic features are in keeping with aberrant MMR protein expression, they are not specific for LS.

The clinical criteria for preselection of people for genetic testing (Amsterdam II¹² and revised Bethesda¹³ criteria) are insensitive and lack specificity in identifying carriers ([Table S5, supporting information](#)); testing of incident colorectal cancer cases has been recommended for over a decade. In parallel with the present work, a consensus guideline meeting on gynaecological cancer in LS recommended screening for LS in patients with endometrial and ovarian cancer (and also BRCA1/2 screening in ovarian cancer). Furthermore, identification of carriers provides the opportunity for cascade testing of relatives, which has the benefit of identifying healthy carriers. These approaches have been shown to be cost-effective^{14,15}.

Laboratory screening of patients with upper urinary tract cancer to identify LS was agreed by a majority (73 per cent) but did not reach consensus.

Conclusions and recommendations

- All colorectal cancers should be tested by MMR (MLH1, MSH2, MSH6, PMS2) immunohistochemistry or MSI testing (followed by possible MLH1 hypermethylation testing) to screen for LS.
- Patients with endometrial or ovarian cancer should be screened by immunohistochemistry or DNA testing as described in the Manchester consensus statement.

Question 2: what is the optimal colorectal surveillance protocol for Lynch syndrome?

Subquestion 1: should colonoscopic surveillance be performed?

Data from largely observational studies conducted since the 1990s have supported the role of colonoscopic surveillance in

patients with LS. Järvinen and colleagues^{16,17} reported on the outcomes of a cohort of patients with LS who underwent colonoscopic surveillance and compared them with a group who did not, and observed a 62 per cent reduction in colorectal cancer in the surveillance group. Similar observations were made in other studies^{18–20}. Altogether, colonoscopic surveillance seems to lead to a 60–72 per cent decrease in colorectal cancer mortality. More recent data from prospective observational studies have questioned the previously reported benefits in earlier studies^{16,17,20} of comparative colorectal cancer incidence. Specifically, nearly half of *path_MLH1* and *path_MSH2* carriers develop colorectal cancer under surveillance^{6,21–23}, and the benefits of colonoscopic surveillance are mainly to improve survival by earlier detection compared with no surveillance.

Conclusions and recommendations

- There was consensus agreement that for all *path_MMR* carriers colonoscopic surveillance should be performed to reduce mortality and incidence of colorectal cancer.

Subquestion 2: should chromoendoscopy/virtual chromoendoscopy be performed?

Chromoendoscopy (CE) uses contrast dyes (usually indigocarmine) to highlight the mucosal surface contours and enhance visualization. In virtual CE, filtering technology is built into the colonoscope system, which alters the white-light image to highlight mucosal surface architecture and capillary pattern. Results with use of CE and virtual CE are summarized in [Table 2](#)^{24–33}. These studies are largely methodologically flawed, which limits the conclusions that can be drawn. CE may be equivalent to high-quality white-light examination with prolonged withdrawal. However, given the conflicting results of studies, and the methodological flaws of most published studies, CE may still be a helpful adjunct to be considered in colonoscopic surveillance in LS.

Conclusions and recommendations

- Chromoendoscopy is equivalent to high-definition white-light endoscopy in specialist centres. It may be an adjunct to be considered in the absence of high-definition endoscopy or in centres with lower adenoma detection rates.

Subquestion 3: what is the appropriate colonoscopic surveillance interval?

In studies from the PLSD published by Møller and colleagues²¹, the interval between last surveillance colonoscopy and colorectal cancer was analysed. Of 145 colorectal cancers, 100 were diagnosed more 2 years after the last colonoscopy (interval after colonoscopy range 0–125 months). On the other hand, the high incidence of colorectal cancers in the PLSD despite colonoscopic surveillance was not due to the inclusion of a large cohort of Finnish *path_MLH1* carriers for whom a 2–3-year interval between colonoscopies had been recommended³⁴. The cumulative incidence of colorectal cancer or stage at detection did not differ between 1-yearly, 2-yearly and 2–3-yearly colonoscopic surveillance strategies in a study of 2747 *path_MLH1*, *path_MSH2* and *path_MSH6* carriers who were followed up for a total of 23 309 years by 16 327 colonoscopies²³.

Gathering evidence suggests that carcinogenesis in *path_PMS2* is predominantly via the adenomatous pathway³⁵, and that the cancer risk is substantially lower than that

for other LS genotypes, especially under colonoscopic surveillance⁶.

There is no reported substantial difference in lifetime incidence of colorectal cancer between that estimated by retrospective segregation analyses over three generations^{36–38} and that in the PLSD report⁶ on the effects of colonoscopy in preventing colorectal cancer as advocated by recent international guidelines (Table 3).

Table 3 Studies describing the cumulative incidence of colorectal cancer in patients with Lynch syndrome

Reference	Gender	70-year cumulative incidence (%)			
		MLH1	MSH2	MSH6	PMS2
Bonadona et al. ³⁸	Both	41	48	12	
Dowty et al. ³⁶	Men	34	47		
	Women	36	37		
ten Broeke et al. ³⁷	Men				13*
	Women				12*
PLSD ⁶	Men	53	42	18	10
	Women	44	46	20	10

*Cumulative risk at 80 years. PLSD, Prospective Lynch Syndrome Database.

Conclusions and recommendations

- For *path_MLH1*, *path_MSH2* and *path_MSH6* carriers, 2- or 3-yearly colonoscopic surveillance is recommended (consensus not reached between 2 and 3 years).
- For *path_PMS2* carriers, 5-yearly surveillance may be considered.
- For patients with LS with a history of colorectal cancer and segmental or subtotal colectomy, biennial colonoscopies should be performed.
- There is no evidence at the moment to support different surveillance colonoscopy intervals for men and women.
- If bowel preparation is not entirely adequate, a repeat procedure at 1 year is recommended.
- If the bowel preparation is completely inadequate or the examination incomplete, an immediate repeat colorectal surveillance procedure should be requested (within next 6 weeks).

Subquestion 4: at what age should surveillance colonoscopy be initiated?

A number of studies have confirmed that the risk of developing colorectal cancer before the age of 25 years is very low (Table 4)^{6,8,21,22,37,48}.

Table 4 Overview of studies about age and risk of developing colorectal cancer in Lynch syndrome

Reference	Study outcomes
de Jong et al. ³⁹	Only two of 246 patients (0.8%) with LS developed CRC before the age of 20 years and another two between age 20 and 25 years
Hendriks et al. ⁴⁰	These studies confirmed that the risk of developing CRC before the age of 25 years is very low
Quehenberger et al. ⁴¹	
Hampel et al. ⁴²	
Jenkins et al. ⁴³	
Vasen et al. ⁸	These previous guidelines recommended starting surveillance colonoscopy at age 20–25 years.
Cairns et al. ⁴⁴	
Rubenstein et al. ⁴⁵	
Jenkins et al. ⁴⁶	This meta-analysis for <i>path_MLH1</i> and <i>path_MSH2</i> carriers questioned whether the initiation of surveillance colonoscopy was justified before the age of 30 years
Giardiello et al. ⁴⁷	US multisociety task force guidelines recommended starting surveillance colonoscopy at 20–25 years (or 2–5 years younger than youngest affected if aged <25 years), but to consider starting at 30 and 35 years for <i>path_MSH6</i> and <i>path_PMS2</i> carriers respectively
ten Broeke et al. ^{37,48}	The study described a series of 377 patients with <i>path_PMS2</i> and the observed median age at first CRC was 52 (range 26–86) years. The authors also noted gender differences in CRC risk. The cumulative risk in men aged <40, 40–49, 50–59 and 60–69 years was 1.3, 4.6, 7.1 and 18.8% respectively. The corresponding cumulative risks by age in women were 0.5, 0.9, 4.7 and 10.5%. It was recommended that starting colonoscopy surveillance could be deferred until age 30 years for both genders.
	ten Broeke et al. also published a large series of patients with <i>path_PMS2</i> , and reported only a 2–3 times increased cumulative incidence of CRC under surveillance compared with the general population. This is about the same level of CRC risk as when there is a positive family history of the disease but genetic testing for LS (and other hereditary CRC syndromes) proves negative
Bonadona et al. ³⁸	This nationwide French study of patients with LS supports a genotype–phenotype correlation. There were no <i>path_PMS2</i> carriers in this cohort. Overall, the cumulative CRC risk by 70 years was 38% in men and 31% women. When analysed by genotype, the cumulative CRC risks were 46% for <i>path_MLH1</i> , 48% for <i>path_MSH2</i> and 12% for <i>path_MSH6</i> . Median age at diagnosis of CRC also varied by genotype: 45 (range 15–90) years for <i>path_MLH1</i> , 44 (16–95) years for <i>path_MSH2</i> and 54 (24–85) years for <i>path_MSH6</i>
Møller et al. ^{6,21,22}	In the 2017 PLSD report addressing incidence and survival of first cancers in patients with LS undergoing surveillance, the cumulative CRC incidence to age 70 years was 46% for <i>path_MLH1</i> , 35% for <i>path_MSH2</i> , 20% for <i>path_MSH6</i> and 0% for <i>path_PMS2</i> . Overall, when incidence was analysed by gender, no difference was observed between men and women. The recent report (2018) from the PLSD described cancer risks and survival up to age 75 years, analysing the data both by gene and gender. The cohort included 3119 patients with 24 475 observation years. The previously described genotype-dependent penetrance was confirmed; the cumulative CRC risk to age 75 years by genotype was: 46% for <i>path_MLH1</i> , 43% for <i>path_MSH2</i> , 15% for <i>path_MSH6</i> and 0% for <i>path_PMS2</i> (although there were only 124 <i>path_PMS2</i> carriers in this cohort, so no firm conclusions could be drawn regarding this subgroup). <i>Path_MSH6</i> has a lower risk of early-onset cancer; the cumulative CRC risk at age 40 years was 12% for <i>path_MLH1</i> , 9% for <i>path_MSH2</i> and 0% for <i>path_MSH6</i> . There were no consistent gender differences for CRC within each genotype group

LS, Lynch syndrome; CRC, colorectal cancer; PLSD, Prospective Lynch Syndrome Database.

The risk of a *path_PMS2* carrier developing cancer at young age is low, and the median age for *path_PMS2*-related first colorectal cancers is 52 years⁴⁷. Based on PLSD studies, *path_MSH6* carriers also have a lower risk of early-onset cancer; the cumulative colorectal cancer risk at age 40 years was 12 per cent for *path_MLH1*, 9 per cent for *path_MSH2* and 0 per cent for *path_MSH6*. There is no convincing evidence to show that the age of onset is different between men and women.

Conclusions and recommendations

- For *path_MLH1* or *path_MSH2* carriers, surveillance colonoscopies should be initiated at the age of 25 years.
- For *path_MSH6* or *path_PMS2* carriers, surveillance colonoscopies should be initiated at the age of 35 years.
- Age at onset of surveillance should not be stratified by gender.

Question 3: what is the effectiveness of surveillance for other cancers?

The individual cumulative risk of cancer in any organ for the remaining lifetime of a patient with LS may be obtained by indicating their age, gender and genetic variant using <http://www.plsd.eu/>.

There is no demonstrated benefit of surveillance for incidence or survival of gastric cancer, small bowel cancer, pancreatic cancer, urinary tract cancer, prostate cancer or breast cancer in *path_MMR* carriers (Table 5)^{6,49–56}.

Conclusions and recommendations

- Consensus was not achieved for the statement ‘Surveillance for other cancers (than colorectal, endometrial and ovarian) should not be offered’.

Question 4: what is the appropriate surgical treatment for colorectal cancer?

The risk of metachronous colorectal cancer after primary colonic cancer depends on which variant a carrier has and on the extent of surgery performed in managing the primary colonic cancer (how much colon is left to be at risk). There are no good data describing the risk of a second colonic cancer by gene and treatment of first cancer. Analyses in the PLSD²² suggested that the risk of a second colorectal cancer was determined stochastically: the risk of a second cancer was not substantially different from

Table 5 Studies describing cumulative risk and surveillance outcome for gastric, small bowel, pancreatic, urinary tract, prostate and breast cancer in Lynch syndrome

Reference	Study outcomes
Gastric	
Møller et al. ⁶	There is a relative increase in incidence of 8.9 for <i>path_MLH1</i> and 9.7 for <i>path_MSH2</i> carriers compared with the general population
Park et al. ⁴⁹	Geographical differences may be significant, with this report from Korea showing a higher lifetime risk
Capelle et al. ⁵⁰	The Dutch Gastric Cancer Registry study revealed that the majority of gastric cancers in this patient population is of the intestinal type (62%)
Renkonen-Sinisalo et al. ⁵¹	The study collected data on 73 mutation-positive patients with a mean age of 49 years. In this group, an upper endoscopy for surveillance did not identify any neoplastic changes
Small bowel	
Møller et al. ⁶	There is a relative increase in incidence of this type of cancer of 64.7 for <i>path_MLH1</i> carriers
ten Kate et al. ⁵²	The study reported distribution predominantly in the duodenum and jejunum
Saurin et al. ⁵³	The authors reported on 35 asymptomatic patients undergoing capsule endoscopy, which identified lesions in three patients. Of these, one had a jejunal adenocarcinoma and two had adenomas with low-grade dysplasia
Haanstra et al. ⁵⁴	The authors examined the effect of video capsule endoscopy in the detection of small bowel neoplasia in 200 asymptomatic patients. In this group, there were significant findings in two patients, who were diagnosed with adenocarcinoma (1 patient) and adenoma (1). An adenocarcinoma diagnosed 7 months after a negative capsule endoscopy was considered a missed lesion. Two years later, 155 of the initial 200 patients underwent a second video capsule endoscopy. Findings leading to further endoscopies with gastroduodenoscopy or balloon-assisted endoscopy were seen in 11% of patients but none proved to be neoplasia
Pancreatic	
Møller et al. ⁶	The relative risk of pancreatic cancer is 7.8 for <i>path_MLH1</i> carriers
Canto et al. ⁵⁵	In this large study of screening in 354 patients at high risk of pancreatic cancer, a survival benefit was identified for patients diagnosed during screening. This study used endoscopic ultrasonography, MRI and CT for screening. However, no patients with LS were diagnosed with a tumour
Urinary tract	
Møller et al. ⁶	There is a relative increase in incidence of bladder cancer of 4.1 for <i>path_MLH1</i> and 8.1 for <i>path_MSH2</i> carriers. There is also a relative increase in incidence of ureter and kidney cancer of 3.5 for <i>path_MLH1</i> and 13.7 for <i>path_MSH2</i> carriers
Myrthøj et al. ⁵⁶	The National Danish HNPCC registry assessed a strategy of screening with urinary cytology. In this study of 977 individuals, including 263 with confirmed <i>path_MMR</i> variants, urine cytology had a sensitivity of 29%, with a specificity of 96%. Five of 14 cancers that occurred were interval cancers not detected by screening
Prostate	
Møller et al. ⁶	There is a relative increase in incidence of this type of cancer of 3.2 for <i>path_MSH2</i> carriers
IMPACT study (http://impact.icr.ac.uk/)	The study is currently recruiting carriers of <i>path_MLH1</i> , <i>path_MSH2</i> and <i>path_MSH6</i> , and those who have tested negative for <i>path_MLH1</i> , <i>path_MSH2</i> or <i>path_MSH6</i> known to be present in their family. This study can be considered for patients undergoing surveillance for LS
Breast	
Møller et al. ⁶	In the PLSD, there is a relative incidence of breast cancer of 1.3 for <i>path_MLH1</i> , 1.2 for <i>path_MSH2</i> and 1.4 for <i>path_MSH6</i> carriers. In this cohort, the confidence intervals all include 1 and it is not possible to confirm a significant increase in breast cancer risk at this time

LS, Lynch syndrome; HNPCC, hereditary non-polyposis colorectal cancer; PLSD, Prospective Lynch Syndrome Database.

the risk of a first cancer by age, gene and gender. Without stratifying by gene and treatment of first colonic cancer (because numbers in the study did not allow substrata for analysis), a PLSD study²² reported that the risk of metachronous colorectal cancer by 70 years (starting from 40 years) after an earlier colonic cancer and despite regular colonoscopies was 36 (95 per cent c.i. 29 to 43.8) per cent. The numbers were likely to be conservative estimates for metachronous cancer, because a substantial proportion of these patients were treated at specialized centres and will have had extended colonic surgery. Three recent meta-analyses and several independent studies evaluated the risk of metachronous colorectal cancer after colectomy for colonic cancer (Table 6)^{57–65}. No studies have reported the risk of a third colorectal cancer after subsequent colonic cancer. However, third metachronous colorectal cancers have been described, as has survival after these subsequent cancers²². There are no studies addressing the more invasive surgical option of extending colorectal surgery to a proctocolectomy at the occurrence of a first or metachronous colonic or rectal cancer. It is essential to evaluate the role of extended surgery prospectively and provide recommendations stratified by MMR gene in order to reduce the incidence of metachronous colorectal cancer occurring in *path_MMR* carriers.

Extended surgery, either subtotal colectomy with ileosigmoidal anastomosis or total colectomy with ileorectal anastomosis,

for primary colonic cancer in *path_MLH1* and *path_MSH2* carriers is preferable to reduce the risk of subsequent colorectal cancer, even though extended surgery has not been shown to improve overall survival. There is no substantial evidence to support extended surgery for *path_MSH6* and *path_PMS2* carriers. All surgical decision-making should be personalized, based on the patient's age, gender, and expected functional outcome and priorities.

Subquestion 1: should extended surgery for Lynch syndrome-associated colonic cancer be recommended?

A largely retrospective body of evidence supports the extension of surgical resection in *path_MLH1* and *path_MSH2* carriers, but the risk of metachronous colorectal cancer in *path_MSH6* and *path_PMS2* carriers is not high enough to warrant an extended approach (Table 6).

Conclusions and recommendations

- For a *path_MLH1* or *path_MSH2* carrier with a first colonic cancer, extended surgery with ileosigmoidal/ileorectal anastomosis is preferable to standard resection to reduce the risk of metachronous colorectal cancer.

Table 6. Studies describing surgical treatment for colorectal cancer in Lynch syndrome

Reference	Study outcomes
Anele et al. ⁵⁷	This report included six studies involving 871 patients who met the inclusion criteria (705 had segmental colectomy and 166 extended colectomy). The weighted mean follow-up was 7.6 years. Patients with LS were four times more likely to develop metachronous CRC after segmental colectomy than those who had extended resection, despite regular endoscopic surveillance (1–2-yearly)
Heneghan et al. ⁵⁸	This review included eight studies and 948 patients (780 had segmental colectomy and 168 extended colectomy) followed up for 8–9 years, but they did not exclude studies based on clinical criteria only for diagnosis of LS. The authors calculated the risk of metachronous CRC to be 3.7 times higher after segmental colectomy than extended resection. There were limitations regarding morbidity and mortality data in most of the original studies
Malik et al. ⁵⁹	This meta-analysis identified 1389 patients with LS and HNPCC followed up for a mean of 8.4 years, with a mean age at onset of 45.5 years. A total of 1119 patients underwent segmental colectomies with an absolute risk of metachronous CRC of 22.4% at the end of follow-up. The 270 patients who underwent extended colectomies had a metachronous CRC risk of 4.7%. Segmental colectomy was significantly associated with an increased RR of metachronous CRC (RR 5.12, 95% c.i. 2.88 to 9.11), although no significant association with mortality was identified (RR 1.65, 0.90 to 3.02)
Renkonen-Sinisalo et al. ⁶⁰	The authors compared the outcomes of 242 genetically confirmed LS carriers who underwent either STC (98) or segmental colectomy (144), and were followed up for between 14.6 and 25 years. The cumulative risk of metachronous CRC after segmental colectomy was 47% compared with 7% after STC + ISA. Extended surgery also reduced the risk of subsequent abdominal surgery compared with segmental resection (10.9 versus 54.1%), but there was no difference in CRC-specific survival. However, the majority of patients were <i>path_MLH1</i> carriers. For patients undergoing STC, 10–20 cm of sigmoid was left and an ISA performed
Kim et al. ⁶¹	The cumulative risk of metachronous CRC was reported to be 20.4% in 10-year follow-up after segmental colectomy compared with 0% after extended surgery in this South-Korean study of 106 patients with LS. No survival benefit of extended surgery was established
Parry et al. ⁶²	The authors reported a decrease in metachronous CRC risk for every 10 cm of bowel removed. The cumulative risk of metachronous CRC in 322 patients undergoing segmental colectomy was 16 (95% c.i. 10 to 25)% at 10 years, 41 (30 to 52)% at 20 years and 62 (50 to 77)% at 30 years. Of the 50 patients who underwent extensive colonic resection (STC + ISA or IRA) for their first colonic cancer, none were diagnosed with metachronous CRC over 414 person-years of follow-up
Stupart et al. ⁶³ Natarajan et al. ⁶⁴	Other retrospective comparative studies have reported a high incidence of metachronous CRC after segmental colectomy and a lower incidence after extended colectomy. STC with IRA or ISA decreases the risk of metachronous colonic cancer and provides easy endoscopic surveillance
You et al. ⁶⁵	This study of 201 extended resections (STC + ISA or TC + IRA) and 321 segmental colectomies for indications other than inflammatory bowel diseases reported a median of four daily bowel movements after ISA and five after IRA, despite considerable dietary restrictions (reported by 55.6 per cent) and medication use (19.6 per cent reported daily use). STC + ISA resulted in significantly less daytime and night-time bowel movements than TC + IRA ($P = 0.002$) but no significant difference in quality-of-life measures ($P = 0.16$)

LS, Lynch syndrome; CRC, colorectal cancer; HNPCC, hereditary non-polyposis colorectal cancer; RR, relative risk; STC, subtotal colectomy; ISA, ileosigmoidal anastomosis; IRA, ileorectal anastomosis; TC, total colectomy.

- For a *path_MSH6* or *path_PMS2* pathogenic variant carrier with a first colonic cancer, standard/segmental colonic resection should be offered.
- For a *path_MMR* carrier with a metachronous colonic cancer, the surgical treatment can be extended surgery with ileorectal/ileosigmoidal anastomosis.
- A decision on extended surgery for colorectal cancer should not be based on deficient MMR immunohistochemistry (loss of MLH1, MSH2, MSH6 or PMS2) and BRAF staining/MLH1 hypermethylation from the preoperative endoscopic biopsy only.

Subquestion 2: how should surgery for rectal cancer in Lynch syndrome be performed?

Studies have reported metachronous cancer after rectal cancer in carriers^{66,67}. Because the cumulative risk of a subsequent colonic cancer developing during surveillance is significant, extended surgery may be a personal preference, considering the higher degree of surgical morbidity associated with the procedure. Quality of life of patients with an ileoanal pouch may be comparable to that of patients with familial adenomatous polyposis rather than those with inflammatory bowel disease (IBD), because the worse overall outcome in the latter group is due to the underlying inflammatory condition. There is clear evidence that surgeons performing a high volume of procedures in high-volume units (over 10 per year) achieve lower pouch failure rates as well as better pouch salvage than those with a lower throughput of these procedures^{68,69}. Preferred surgical options by gene are shown in Table 7.

Table 7 Surgical options for colorectal cancer in *path_MMR* carriers

	<i>Path_MLH1</i>	<i>Path_MSH2</i>	<i>Path_MSH6</i>	<i>Path_PMS2</i>	Additional risk factors
Primary colonic cancer of a known LS pathogenic variant carrier	Subtotal colectomy with ileosigmoidal (ileorectal) anastomosis	Subtotal colectomy with ileosigmoidal (ileorectal) anastomosis	Segmental colectomy (right, extended right or left colectomy)	Segmental colectomy (right, extended right or left colectomy)	Adenoma formation in a colonic segment other than the segment affected by colonic cancer Extended surgery such as colectomy with ileosigmoidal or ileorectal anastomosis. For young patients, consider more extensive surgery
Metachronous colonic cancer in a known LS pathogenic variant carrier who has undergone previous segmental colectomy	Subtotal colectomy with ileorectal anastomosis	Subtotal colectomy with ileorectal anastomosis	Subtotal colectomy with ileorectal anastomosis	Subtotal colectomy with ileorectal anastomosis	
Primary rectal cancer in a known LS pathogenic variant carrier	Anterior resection/APR	Anterior resection/APR	Anterior resection/APR	Anterior resection/APR	
Rectal cancer after previous colonic cancer surgery in a known LS pathogenic variant carrier	Proctectomy/proctocolectomy with ileoanal anastomosis with pouch or APR with permanent ileostomy	Proctectomy/proctocolectomy with ileoanal anastomosis with pouch or APR with permanent ileostomy	Proctectomy/proctocolectomy with ileoanal anastomosis with pouch or APR with permanent ileostomy		

LS, Lynch syndrome; APR, abdominoperineal resection.

Conclusions and recommendations

- For a *path_MMR* carrier, the surgical treatment of a primary rectal cancer (occurring as the first colorectal cancer) should be standard resection (anterior resection or abdominoperineal resection).
- In a young *path_MMR* carrier with a synchronous colorectal neoplasm or a personal preference, extended surgery can be considered.
- Ileoanal pouch surgery (in agreement with European CanCer Organisation guidelines for pouch surgery in ulcerative colitis) should be performed in highly specialized colorectal surgical units.

Subquestion 3: should prophylactic bowel surgery be performed?

It is acknowledged that, even with the more favourable stage at diagnosis in patients under surveillance, there is a 9 per cent overall mortality rate among patients with LS in the 10 years after diagnosis of colorectal cancer. There is no documented procedure to identify and separate carriers at higher risk of colorectal cancer than the average by using age, gene and gender, nor those who might be at risk of not surviving a future colorectal cancer. There is no evidence base to support prophylactic colorectal surgery in *path_MMR* carriers.

In a study⁷⁰ of patients with high-grade dysplasia in endoscopic biopsies and a polyp that was not amenable to endoscopic removal, 22 of 165 polyps (13.3 per cent) had an invasive cancer on final pathology. In another study at the Mayo Clinic⁷¹,

133 of 750 unresectable polyps (17.7 per cent) harboured a malignancy, of which 23 per cent were lymph node-positive. Although these studies were conducted without knowledge of the MMR status of the tumours, they indicate that high-grade dysplasia on biopsy is a strong predictor of tumours harbouring invasive malignancy.

In patients with LS and concurrent IBD, it is unclear whether colorectal cancer risks are sufficiently increased for prophylactic colectomy to be indicated. In a small series⁷² of 12 patients with LS and concurrent IBD, four developed colorectal cancer in an early age. However, the series did not demonstrate a sufficiently increased risk of colorectal cancer to recommend prophylactic surgery.

Conclusions and recommendations

- For endoscopically non-removable polyps with advanced histology, an oncological approach is recommended, as for gene-specific treatment for carcinoma.
- Prophylactic colorectal surgery in the absence of neoplastic lesions in the colorectum is not recommended for *path_MMR* carriers based on their pathogenic variant-related risk only.

Question 5: what is the influence of lifestyle factors on the development of adenoma or colorectal cancer in Lynch syndrome?

The majority of studies showed positive associations between BMI and smoking and colorectal cancer, whereas some studies reported that alcohol consumption was positively associated with colorectal cancer. One study reported an inverse association between physical activity and colorectal cancer in *path_MMR* carriers (Table 8)^{73–89}. No lifestyle factor has been demonstrated to

increase the risk of cancer specifically for one gender, or for carriers of pathogenic variants in a specific gene.

Conclusions and recommendations

- *Path_MMR* carriers should be advised that smoking and obesity increase the risk of colorectal cancer.
- *Path_MMR* carriers should be advised that alcohol consumption increases the risk of colorectal cancer.
- *Path_MMR* carriers should be advised that physical activity reduces the risk of colorectal cancer.

Question 6: what is the role of acetylsalicylic acid (aspirin) in the management of Lynch syndrome?

An RCT^{76,85,90} showed that 600 mg acetylsalicylic acid daily for 2–4 years was well tolerated and reduced colorectal cancer incidence after 5 years following initiation of the treatment. A recently published study⁹¹ has shown that the benefit of prevention with acetylsalicylic acid persists into the second decade. Observational data in the general population suggest that lower doses may also be effective^{92,93}. For bodyweight above average (70 kg), a higher dose than currently in clinical use for other indications may be required⁹⁴.

Conclusions and recommendations

- *Path_MMR* carriers should be advised that daily acetylsalicylic acid intake will reduce colorectal cancer risk.
- The recommended acetylsalicylic acid dose should be a minimum of 75–100 mg daily. This dose should be increased for people with above-average body mass.

Table 8 Association studies between BMI, smoking, alcohol consumption, physical activity and colorectal cancer in Lynch syndrome

Reference	Study outcomes
Dierraarde <i>et al.</i> ⁷³ Botma <i>et al.</i> ⁷⁴ Campbell <i>et al.</i> ⁷⁵ Movahedi <i>et al.</i> ⁷⁶ Win <i>et al.</i> ⁷⁷	These studies reported on the association between BMI and colorectal tumours in LS. A high BMI was associated with an increased risk of colorectal tumours in three publications ^{74,76,77} another ⁷⁵ indicated an association in the same direction, and one ⁷³ did not show an association
Dierraarde <i>et al.</i> ⁷³ Kamiza <i>et al.</i> ⁷⁸ Watson <i>et al.</i> ⁷⁹ Winkels <i>et al.</i> ⁸⁰ Dashti <i>et al.</i> ⁸¹ Kamiza <i>et al.</i> ⁷⁸	In analyses of alcohol consumption and colorectal tumour risk in LS, three studies ^{73,78,79} did not observe an association, one ⁸⁰ demonstrated a possible increased risk, and one ⁸¹ reported a significant increase in risk of colorectal tumours when alcohol consumption was high
Brand <i>et al.</i> ⁸² Dierraarde <i>et al.</i> ⁷³ Pande <i>et al.</i> ⁸³ Watson <i>et al.</i> ⁷⁹ Winkels <i>et al.</i> ⁸⁰	The influence of physical activity on colorectal tumour risk has been investigated in only one study, which showed that being physically active is significantly associated with a decreased colorectal tumour risk in those with LS The risk of colorectal tumours is significantly increased by smoking in LS
Dierraarde <i>et al.</i> ⁷³ Kamiza <i>et al.</i> ⁷⁸ Botma <i>et al.</i> ⁷⁴ Voskuil <i>et al.</i> ⁸⁴ Burn <i>et al.</i> ⁸⁵ Mathers <i>et al.</i> ⁸⁶ Jung <i>et al.</i> ⁸⁷ Chau <i>et al.</i> ⁸⁸ Heine-Bröring <i>et al.</i> ⁸⁹	Different aspects of diet, such as dietary patterns ⁷⁴ , and consumption of meat ^{73,78,84} , vegetables ^{73,78} , fruit ^{73,78} , fish ⁷³ , dairy products ⁷³ , dietary fibre ^{73,85,86} , dietary B vitamins ⁸⁷ , dietary supplements ^{88,89} , tea ⁷³ and coffee ⁷³ have been investigated in relation to colorectal tumour risk in people with LS. None of these dietary factors, however, were evaluated in more than three publications

LS, Lynch syndrome.

Final conclusion

The recommendations from the EHTG and ESCP for identification of patients with LS, colorectal surveillance, surgical management of colorectal cancer, lifestyle and chemoprevention in LS that reached a consensus (at least 80 per cent) are presented here. The joint statement also endorsed the Manchester International Consensus Group recommendations for the management of gynaecological cancers in LS.

Acknowledgements

Development of the guideline was supported by an educational grant from Promega (USA). EHTG is a charitable company registered in Scotland (registration number SC048407). ESCP is a charitable organization registered in Scotland (registration number SC205553). A grant from the ESCP guideline committee was awarded for this guideline development. The authors thank J. Kleijnen for valuable advice and help in streamlining the PICO in the external review.

T.T.S. is supported by grants from the Emil Aaltonen Foundation, Finnish Medical Foundation and Sigrid Juselius Foundation. D.G.E and E.J.C. are supported by the National Institute for Health Research (NIHR) Manchester Biomedical Research Centre (IS-BRC-1215-20007). N.R. was funded as a Medical Research Council Doctoral Research Fellow (MR/M018431/1). P.Q. is an NIHR senior investigator and supported by Yorkshire Cancer Research L386 and L394. J.R.S. was supported by Health and Care Research Wales via a grant to Wales Gene Park. None of the funding bodies influenced the content of the recommendation. T.T.S. is a Chief Executive Officer and co-owner of Healthfund Finland, outside the submitted work. D.G.E. reports consultancy from AstraZeneca, outside the submitted work.

Disclosure: The authors declare no other conflict of interest.

Supporting information

Additional [supporting information](#) can be found online in the Supporting Information section at the end of the article.

References

- Crosbie EJ, Ryan NAJ, Arends MJ, Bosse T, Burn J, Cornes JM *et al.* The Manchester International Consensus Group recommendations for the management of gynecological cancers in Lynch syndrome. *Genet Med* 2019; **21**: 2390–2400.
- Lynch HT, Snyder CL, Shaw TG, Heinen CD, Hitchins MP. Milestones of Lynch syndrome: 1895–2015. *Nat Rev Cancer* 2015; **15**: 181–194.
- Lynch HT, Lynch PM, Lanspa SJ, Snyder CL, Lynch JF, Boland CR. Review of the Lynch syndrome: history, molecular genetics, screening, differential diagnosis, and medicolegal ramifications. *Clin Genet* 2009; **76**: 1–18.
- Haraldsdottir S, Rafnar T, Frankel WL, Einarsdottir S, Sigurdsson A, Hampel H *et al.* Comprehensive population-wide analysis of Lynch syndrome in Iceland reveals founder mutations in *MSH6* and *PMS2*. *Nat Commun* 2017; **8**: 1–11.
- Llosa NJ, Cruise M, Tam A, Wicks EC, Hechenbleikner EM, Taube JM *et al.* The vigorous immune microenvironment of microsatellite instable colon cancer is balanced by multiple counter-inhibitory checkpoints. *Cancer Discov* 2015; **5**: 43–51.
- Møller P, Seppälä TT, Bernstein I, Holinski-Feder E, Sala P, Evans DG *et al.* Cancer risk and survival in path-MMR carriers by gene and gender up to 75 years of age: a report from the Prospective Lynch Syndrome Database. *Gut* 2018; **67**: 1306–1316.
- Valle L. Recent discoveries in the genetics of familial colorectal cancer and polyposis. *Clin Gastroenterol Hepatol* 2019; **15**: 809–819.
- Vasen HFA, Blanco I, Aktan-Collan K, Gopie JP, Alonso A, Aretz S *et al.* Revised guidelines for the clinical management of Lynch syndrome (HNPCC): recommendations by a group of European experts. *Gut* 2013; **62**: 812–823.
- Syngal S, Brand RE, Church JM, Giardiello FM, Hampel HL, Burt RW. ACG clinical guideline: genetic testing and management of hereditary gastrointestinal cancer syndromes. *Am J Gastroenterol* 2015; **110**: 223–262.
- Vasen HFA, Möslein G, Alonso A, Bernstein I, Bertario L, Blanco I *et al.* Guidelines for the clinical management of Lynch syndrome (hereditary non-polyposis cancer). *J Med Genet* 2007; **44**: 353–362.
- Dominguez-Valentin M, Sampson JR, Seppälä TT, ten Broeke SW, Plazzer JP, Nakken S *et al.* Cancer risks by gene, age, and gender in 6350 carriers of pathogenic mismatch repair variants: findings from the Prospective Lynch Syndrome Database. *Genet Med* 2020; **22**: 15–25.
- Vasen HF, Watson P, Mecklin JP, Lynch HT. New clinical criteria for hereditary nonpolyposis colorectal cancer (HNPCC, Lynch syndrome) proposed by the International Collaborative group on HNPCC. *Gastroenterology* 1999; **116**: 1453–1456.
- Umar A, Boland CR, Terdiman JP, Syngal S, de la Chapelle A, Rüschoff J *et al.* Revised Bethesda guidelines for hereditary non-polyposis colorectal cancer (Lynch syndrome) and microsatellite instability. *J Natl Cancer Inst* 2004; **96**: 261–268.
- Snowhill T, Coelho H, Huxley N, Jones-Hughes T, Briscoe S, Frayling IM *et al.* Molecular testing for Lynch syndrome in people with colorectal cancer: systematic reviews and economic evaluation. *Health Technol Assess Rockv* 2017; **21**: 1–238.
- Pujol P, Lyonnet DS, Frebourg T, Blin J, Picot MC, Lasset C *et al.* Lack of referral for genetic counseling and testing in BRCA1/2 and Lynch syndromes: a nationwide study based on 240 134 consultations and 134 652 genetic tests. *Breast Cancer Res Treat* 2013; **141**: 135–144.
- Järvinen HJ, Mecklin JP, Sistonen P. Screening reduces colorectal cancer rate in families with hereditary nonpolyposis colorectal cancer. *Gastroenterology* 1995; **108**: 1405–1411.
- Järvinen HJ, Aarnio M, Mustonen H, Aktan-Collan K, Aaltonen LA, Peltomäki P *et al.* Controlled 15-year trial on screening for colorectal cancer in families with hereditary nonpolyposis colorectal cancer. *Gastroenterology* 2000; **118**: 829–834.
- Newton K, Green K, Lalloo F, Evans DG, Hill J. Colonoscopy screening compliance and outcomes in patients with Lynch syndrome. *Colorectal Dis* 2015; **17**: 38–46.
- Stuckless S, Green JS, Morgenstern M, Kennedy C, Green RC, Woods MO *et al.* Impact of colonoscopic screening in male and female Lynch syndrome carriers with an *MSH2* mutation. *Clin Genet* 2012; **82**: 439–445.
- Dove-Edwin I, Sasieni P, Adams J, Thomas HJW. Prevention of colorectal cancer by colonoscopic surveillance in individuals with a family history of colorectal cancer: 16 year, prospective, follow-up study. *BMJ* 2005; **331**: 1047–1049.
- Møller P, Seppälä T, Bernstein I, Holinski-Feder E, Sala P, Evans DGG *et al.* Cancer incidence and survival in Lynch syndrome patients receiving colonoscopic and gynaecological surveillance: first report from the prospective Lynch syndrome database. *Gut* 2017; **66**: 464–472.
- Møller P, Seppälä T, Bernstein I, Holinski-Feder E, Sala P, Evans DG *et al.* Incidence of and survival after subsequent cancers in

- carriers of pathogenic MMR variants with previous cancer: a report from the prospective Lynch syndrome database. *Gut* 2017; **66**: 1657–1664.
23. Engel C, Vasen HF, Seppälä T, Aretz S, Bigirwamungu-Bargeman M, de Boer SY et al. No difference in colorectal cancer incidence or stage at detection by colonoscopy among 3 countries with different Lynch syndrome surveillance policies. *Gastroenterology* 2018; **155**: 1400–1409.e2.
 24. Brown SR, Baraza W, Din S, Riley S. Chromoscopy versus conventional endoscopy for the detection of polyps in the colon and rectum. *Cochrane Database Syst Rev* 2016; (4)CD006439.
 25. Kamiński MF, Hassan C, Bisschops R, Pohl J, Pellisé M, Dekker E et al. Advanced imaging for detection and differentiation of colorectal neoplasia: European Society of Gastrointestinal Endoscopy (ESGE) guideline. *Endoscopy* 2014; **46**: 435–449.
 26. Lecomte T, Cellier C, Meatchi T, Barbier JP, Cugnenc PH, Jian R et al. Chromoendoscopic colonoscopy for detecting preneoplastic lesions in hereditary nonpolyposis colorectal cancer syndrome. *Clin Gastroenterol Hepatol* 2005; **3**: 897–902.
 27. Stoffel EM, Turgeon DK, Stockwell DH, Zhao L, Normolle DP, Tuck MK et al. Missed adenomas during colonoscopic surveillance in individuals with Lynch syndrome (hereditary nonpolyposis colorectal cancer). *Cancer Prev Res* 2008; **1**: 470–475.
 28. Rahmi G, Lecomte T, Malka D, Maniere T, Le Rhun M, Guimbaud R et al. Impact of chromoscopy on adenoma detection in patients with Lynch syndrome: a prospective, multicenter, blinded, tandem colonoscopy study. *Am J Gastroenterol* 2015; **110**: 288–298.
 29. van Rijn JC, Reitsma JB, Stoker J, Bossuyt PM, Van Deventer SJ, Dekker E. Polyp miss rate determined by tandem colonoscopy: a systematic review. *Am J Gastroenterol* 2006; **101**: 343–350.
 30. East JE, Suzuki N, Stavrinidis M, Guenther T, Thomas HJW, Saunders BP. Narrow band imaging for colonoscopic surveillance in hereditary non-polyposis colorectal cancer. *Gut* 2008; **57**: 65–70.
 31. Bisschops R, Tejpar S, Willekens H, De Hertogh G, Van Cutsem E. Virtual chromoendoscopy (I-SCAN) detects more polyps in patients with Lynch syndrome: a randomized controlled crossover trial. *Endoscopy* 2017; **49**: 342–350.
 32. Hüneburg R, Lammert F, Rabe C, Rahner N, Kahl P, Büttner R et al. Chromocolonoscopy detects more adenomas than white light colonoscopy or narrow band imaging colonoscopy in hereditary nonpolyposis colorectal cancer screening. *Endoscopy* 2009; **41**: 316–322.
 33. Rondagh EJA, Gulikers S, Gómez-García EB, Vanlingen Y, Detisch Y, Winkens B et al. Nonpolypoid colorectal neoplasms: a challenge in endoscopic surveillance of patients with Lynch syndrome. *Endoscopy* 2013; **45**: 257–264.
 34. Seppälä T, Pylvänäinen K, Evans DG, Järvinen H, Renkonen-Sinisalo L, Bernstein I et al. Colorectal cancer incidence in path_MLH1 carriers subjected to different follow-up protocols: a prospective Lynch syndrome database report. *Hered Cancer Clin Pract* 2017; **15**: 18.
 35. ten Broeke SW, van Bavel TC, Jansen AML, Gómez-García E, Hes FJ, van Hest LP et al. Molecular background of colorectal tumors from patients with Lynch syndrome associated with germline variants in PMS2. *Gastroenterology* 2018; **155**: 844–851.
 36. Dowty JG, Win AK, Buchanan DD, Lindor NM, Macrae FA, Clendenning M et al. Cancer risks for MLH1 and MSH2 mutation carriers. *Hum Mutat* 2013; **34**: 490–497.
 37. ten Broeke SW, Klift HMV, Tops CMJ, Aretz S, Bernstein I, Buchanan DD et al. Cancer risks for PMS2-associated Lynch syndrome. *J Clin Oncol* 2018; **36**: 2961–2968.
 38. Bonadona V, Bonaïti B, Olschwang S, Grandjouan S, Huiart L, Longy M et al. Cancer risks associated with germline mutations in MLH1, MSH2, and MSH6 genes in Lynch syndrome. *JAMA* 2011; **305**: 2304–2310.
 39. de Jong AE, Nagengast FM, Kleibeuker JH, van de Meeberg PC, van Wijk HJ, Cats A et al. What is the appropriate screening protocol in Lynch syndrome? *Fam Cancer* 2006; **5**: 373–378.
 40. Hendriks YMC, Wagner A, Morreau H, Menko F, Stormorken A, Quehenberger F et al. Cancer risk in hereditary nonpolyposis colorectal cancer due to MSH6 mutations: impact on counseling and surveillance. *Gastroenterology* 2004; **127**: 17–25.
 41. Quehenberger F, Vasen HFA, Van Houwelingen HC. Risk of colorectal and endometrial cancer for carriers of mutations of the hMLH1 and hMSH2 gene: correction for ascertainment. *J Med Genet* 2005; **42**: 491–496.
 42. Hampel H, Frankel W, Panescu J, Lockman J, Sotamaa K, Fix D et al. Screening for Lynch syndrome (hereditary nonpolyposis colorectal cancer) among endometrial cancer patients. *Cancer Res* 2006; **66**: 7810–7817.
 43. Jenkins MA, Baglietto L, Dowty JG, Van Vliet CM, Smith L, Mead LJ et al. Cancer risks for mismatch repair gene mutation carriers: a population-based early onset case-family study. *Clin Gastroenterol Hepatol* 2006; **4**: 489–498.
 44. Cairns SR, Scholefield JH, Steele RJ, Dunlop MG, Thomas HJW, Evans GD et al. Guidelines for colorectal cancer screening and surveillance in moderate and high risk groups (update from 2002). *Gut* 2010; **59**: 666–689.
 45. Rubenstein JH, Enns R, Heidelbaugh J, Barkun A, Adams MA, Dorn SD et al. American Gastroenterological Association Institute Guideline on the diagnosis and management of Lynch syndrome. *Gastroenterology* 2015; **149**: 777–782.
 46. Jenkins MA, Dowty JG, Ait Ouakrim D, Mathews JD, Hopper JL, Drouet Y et al. Short-term risk of colorectal cancer in individuals with Lynch syndrome: a meta-analysis. *J Clin Oncol* 2015; **33**: 326–331.
 47. Giardiello FM, Allen JI, Axilbund JE, Boland CR, Burke CA, Burt RW et al. Guidelines on genetic evaluation and management of Lynch syndrome: a consensus statement by the US multi-society task force on colorectal cancer. *Am J Gastroenterol* 2014; **109**: 1159–1179.
 48. ten Broeke SW, Brohet RM, Tops CM, van der Klift HM, Velthuizen ME, Bernstein I et al. Lynch syndrome caused by germline PMS2 mutations: delineating the cancer risk. *J Clin Oncol* 2015; **33**: 319–325.
 49. Park YJ, Shin KH, Park JG. Risk of gastric cancer in hereditary nonpolyposis colorectal cancer in Korea. *Clin Cancer Res* 2000; **6**: 2994–2998.
 50. Capelle LG, Van Grieken NCT, Lingsma HF, Steyerberg EW, Klokman WJ, Bruno MJ et al. Risk and epidemiological time trends of gastric cancer in Lynch syndrome carriers in the Netherlands. *Gastroenterology* 2010; **138**: 487–492.
 51. Renkonen-Sinisalo L, Sipponen P, Aarmio M, Julkunen R, Aaltonen LA, Sarna S et al. No support for endoscopic surveillance for gastric cancer in hereditary non-polyposis colorectal cancer. *Scand J Gastroenterol* 2002; **37**: 574–577.
 52. Ten Kate GL, Kleibeuker JH, Nagengast FM, Craanen M, Cats A, Menko FH et al. Is surveillance of the small bowel indicated for Lynch syndrome families? *Gut* 2007; **56**: 1198–1201.
 53. Saurin JC, Pilleul F, Soussan EB, Manire T, Dhalluin PN, Gaudric M et al. Small-bowel capsule endoscopy diagnoses early and advanced neoplasms in asymptomatic patients with Lynch syndrome. *Endoscopy* 2010; **42**: 1057–1062.

54. Haanstra J, Al-Toma A, Dekker E, Vanhoutvin S, Nagengast F, Mathus-Vliegen E et al. Incidence of small bowel neoplasia in Lynch syndrome assessed by video capsule endoscopy. *Endosc Int Open* 2017; **05**: E622–E626.
55. Canto MI, Almario JA, Schulick RD, Yeo CJ, Klein A, Blackford A et al. Risk of neoplastic progression in individuals at high risk for pancreatic cancer undergoing long-term surveillance. *Gastroenterology* 2018; **155**: 740–751.e2.
56. Myrthøj T, Andersen MB, Bernstein I. Screening for urinary tract cancer with urine cytology in Lynch syndrome and familial colorectal cancer. *Fam Cancer* 2008; **7**: 303–307.
57. Anele CC, Adegbola SO, Askari A, Rajendran A, Clark SK, Latchford A et al. Risk of metachronous colorectal cancer following colectomy in Lynch syndrome: a systematic review and meta-analysis. *Colorectal Dis* 2017; **19**: 528–536.
58. Heneghan HM, Martin ST, Winter DC. Segmental vs extended colectomy in the management of hereditary nonpolyposis colorectal cancer: a systematic review and meta-analysis. *Colorectal Dis* 2015; **17**: 382–389.
59. Malik SS, Lythgoe MP, McPhail M, Monahan KJ. Metachronous colorectal cancer following segmental or extended colectomy in Lynch syndrome: a systematic review and meta-analysis. *Fam Cancer* 2018; **17**: 557–564.
60. Renkonen-Sinisalo L, Seppälä TTTT, Järvinen HJHJ, Mecklin JPJ-P. Subtotal colectomy for colon cancer reduces the need for subsequent surgery in Lynch syndrome. *Dis Colon Rectum* 2017; **60**: 792–799.
61. Kim TJ, Kim ER, Hong SN, Kim YH, Huh JW, Park YA et al. Survival outcome and risk of metachronous colorectal cancer after surgery in Lynch syndrome. *Ann Surg Oncol* 2017; **24**: 1085–1092.
62. Parry S, Win AK, Parry B, Macrae FA, Gurrin LC, Church JM et al. Metachronous colorectal cancer risk for mismatch repair gene mutation carriers: the advantage of more extensive colon surgery. *Gut* 2011; **60**: 950–957.
63. Stupart DA, Goldberg PA, Baigrie RJ, Algar U, Ramesar R. Surgery for colonic cancer in HNPCC: total vs segmental colectomy. *Colorectal Dis* 2011; **13**: 1395–1399.
64. Natarajan N, Watson P, Silva-Lopez E, Lynch HT. Comparison of extended colectomy and limited resection in patients with Lynch syndrome. *Dis Colon Rectum* 2010; **53**: 77–82.
65. You YN, Chua HK, Nelson H, Hassan I, Barnes SA, Harrington J. Segmental vs. extended colectomy: measurable differences in morbidity, function, and quality of life. *Dis Colon Rectum* 2008; **51**: 1036–1043.
66. Kalady MF, Lipman J, McGannon E, Church JM. Risk of colonic neoplasia after proctectomy for rectal cancer in hereditary nonpolyposis colorectal cancer. *Ann Surg* 2012; **255**: 1121–1125.
67. Win AK, Parry S, Parry B, Kalady MF, Macrae FA, Ahnen DJ et al. Risk of metachronous colon cancer following surgery for rectal cancer in mismatch repair gene mutation carriers. *Ann Surg Oncol* 2013; **20**: 1829–1836.
68. Burns EM, Bottle A, Aylin P, Clark SK, Tekkis PP, Darzi A et al. Volume analysis of outcome following restorative proctocolectomy. *Br J Surg* 2011; **98**: 408–417.
69. Raval MJ, Schnitzler M, O'Connor BI, Cohen Z, McLeod RS. Improved outcome due to increased experience and individualized management of leaks after ileal pouch–anal anastomosis. *Ann Surg* 2007; **246**: 763–770.
70. Loungnarath R, Mutch MG, Birnbaum EH, Read TE, Fleshman JW. Laparoscopic colectomy using cancer principles is appropriate for colonoscopically unresectable adenomas of the colon. *Dis Colon Rectum* 2010; **53**: 1017–1022.
71. Bertelson NL. Colectomy for endoscopically unresectable polyps: how often is it cancer. *Dis Colon Rectum* 2012; **55**: 1111–1116.
72. McNamara KL, Aronson MD, Cohen Z. Is there a role for prophylactic colectomy in Lynch syndrome patients with inflammatory bowel disease? *Int J Colorectal Dis* 2016; **31**: 9–13.
73. Diergaarde B, Braam H, Vasen HF, Nagengast FM, van Muijen GNP, Kok FJ et al. Environmental factors and colorectal tumor risk in individuals with hereditary nonpolyposis colorectal cancer. *Clin Gastroenterol Hepatol* 2007; **5**: 736–742.e1.
74. Botma A, Nagengast FM, Braem MGM, Hendriks JCM, Kleibeuker JH, Vasen HFA et al. Body mass index increases risk of colorectal adenomas in men with Lynch syndrome: the GEOLynch cohort study. *J Clin Oncol* 2010; **28**: 4346–4353.
75. Campbell PT, Jacobs ET, Ulrich CM, Figueiredo JC, Poynter JN, McLaughlin JR et al. Case–control study of overweight, obesity, and colorectal cancer risk, overall and by tumor microsatellite instability status. *J Natl Cancer Inst* 2010; **102**: 391–400.
76. Movahedi M, Bishop DT, Macrae F, Mecklin JP, Moeslein G, Olschwang S et al. Obesity, aspirin, and risk of colorectal cancer in carriers of hereditary colorectal cancer: a prospective investigation in the CAPP2 study. *J Clin Oncol* 2015; **33**: 3591–3597.
77. Win AK, Dowty JG, English DR, Campbell PT, Young JP, Winship I et al. Body mass index in early adulthood and colorectal cancer risk for carriers and non-carriers of germline mutations in DNA mismatch repair genes. *Br J Cancer* 2011; **105**: 162–169.
78. Kamiza AB, Hsieh LL, Tang R, Chien HT, Lai CH, Chiu LL et al. Risk factors associated with colorectal cancer in a subset of patients with mutations in *MLH1* and *MSH2* in Taiwan fulfilling the Amsterdam II criteria for Lynch syndrome. *PLoS One* 2015; **10**: 1–14.
79. Watson P, Ashwathnarayan R, Lynch HT, Roy HK. Tobacco use and increased colorectal cancer risk in patients with hereditary nonpolyposis colorectal cancer (Lynch syndrome). *Arch Intern Med* 2004; **164**: 2429–2431.
80. Winkels RM, Botma A, Van Duijnhoven FJB, Nagengast FM, Kleibeuker JH, Vasen HFA et al. Smoking increases the risk for colorectal adenomas in patients with Lynch syndrome. *Gastroenterology* 2012; **142**: 241–247.
81. Dashti SG, Buchanan DD, Jayasekara H, Ouakrim DA, Clendenning M, Rosty C et al. Alcohol consumption and the risk of colorectal cancer for mismatch repair gene mutation carriers. *Cancer Epidemiol Biomarkers Prev* 2017; **26**: 366–375.
82. Brand RM, Jones DD, Lynch HT, Brand RE, Watson P, Ashwathnarayan R et al. Risk of colon cancer in hereditary nonpolyposis colorectal cancer patients as predicted by fuzzy modeling: influence of smoking. *World J Gastroenterol* 2006; **12**: 4485–4491.
83. Pande M, Lynch PM, Hopper JL, Jenkins MA, Gallinger S, Haile RW et al. Smoking and colorectal cancer in Lynch syndrome: results from the Colon Cancer Family Registry and the University of Texas M.D. Anderson Cancer Center. *Clin Cancer Res* 2010; **16**: 1331–1339.
84. Voskuil D, Kampman E, Grubben MJA, Kok F, Nagengast F, Vasen HF et al. Meat consumption and meat preparation in relation to colorectal adenomas among sporadic and HNPCC family patients in the Netherlands. *Eur J Cancer* 2002; **38**: 2300–2308.
85. Burn J, Gerdes AM, MacRae F, Mecklin JP, Moeslein G, Olschwang S et al. Long-term effect of aspirin on cancer risk in carriers of hereditary colorectal cancer: an analysis from the CAPP2 randomised controlled trial. *Lancet* 2011; **378**: 2081–2087.
86. Mathers JC, Movahedi M, Macrae F, Mecklin JP, Moeslein G, Olschwang S et al. Long-term effect of resistant starch on cancer risk in carriers of hereditary colorectal cancer: an analysis from

- the CAPP2 randomised controlled trial. *Lancet Oncol* 2012; **13**: 1242–1249.
87. Jung AY, van Duijnhoven FJB, Nagengast FM, Botma A, Heine-Bröring RC, Kleibeuker JH *et al*. Dietary B vitamin and methionine intake and MTHFR C677T genotype on risk of colorectal tumors in Lynch syndrome: the GEOLynch cohort study. *Cancer Causes Control* 2014; **25**: 1119–1129.
 88. Chau R, Dashti SG, Ait Ouakrim D, Buchanan DD, Clendenning M, Rosty C *et al*. Multivitamin, calcium and folic acid supplements and the risk of colorectal cancer in Lynch syndrome. *Int J Epidemiol* 2016; **45**: 940–953.
 89. Heine-Bröring RC, Winkels RM, Botma A, van Duijnhoven FJB, Jung AY, Kleibeuker JH *et al*. Dietary supplement use and colorectal adenoma risk in individuals with Lynch syndrome: the GEOLynch Cohort Study. *PLoS One* 2013; **8**: 1–8.
 90. Burn J, Bishop DT, Mecklin JP, Macrae F, Möslein G, Olschwang S *et al*. Effect of aspirin or resistant starch on colorectal neoplasia in the Lynch syndrome. *N Engl J Med* 2008; **359**: 2567–2578.
 91. Burn J, Sheth H, Elliott F, Reed L, Macrae F, Mecklin JP *et al*.; CAPP2 Investigators. 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. *Lancet* 2020; **395**: 1855–1863.
 92. Algra AM, Rothwell PM. Effects of regular aspirin on long-term cancer incidence and metastasis: a systematic comparison of evidence from observational studies *versus* randomised trials. *Lancet Oncol* 2012; **13**: 518–527.
 93. Cook NR, Lee IM, Zhang SM, Moorthy MV, Buring JE. Alternate-day, low-dose aspirin and cancer risk: long-term observational follow-up of a randomized trial. *Ann Intern Med* 2013; **159**: 77–85.
 94. Rothwell PM, Cook NR, Gaziano JM, Price JF, Belch JFF, Roncaglioni MC *et al*. Effects of aspirin on risks of vascular events and cancer according to bodyweight and dose: analysis of individual patient data from randomised trials. *Lancet* 2018; **392**: 387–399.