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COMPREHENSIVE SYSTEMATIC REVIEW OF THE ROLE OF ARTIFICIAL INTELLIGENCE-BASED COMPUTER-AIDED DETECTION ENDOSCOPY IN COLON POLYPS: A SYSTEMATIC REVIEW AND META-ANALYSIS OF RANDOMIZED CONTROLLED TRIALS AND PRIMARY STUDIES

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ABSTRACT

Background and aims: Adenoma detection rate (ADR) is the principal quality indicator of colonoscopy and is inversely associated with post-colonoscopy colorectal cancer (PCCRC). Artificial intelligence (AI)-based computer-aided detection (CADe) systems built on deep convolutional neural networks provide real-time visual alerts for suspected polyps. We aimed to comprehensively synthesise randomised and primary non-randomised evidence published in the last 15 years on the efficacy, effectiveness and diagnostic performance of CADe-assisted colonoscopy for colorectal polyp detection.

Methods: The study strictly adhered to the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) 2020 guidelines. Eligible designs were randomised controlled trials (RCTs), comparative studies, cohorts and case series; systematic reviews and meta-analyses were excluded from the evidence base and considered only in the discussion. Risk of bias was assessed with RoB 2, ROBINS-I and the JBI case-series checklist. Random-effects meta-analyses used restricted maximum-likelihood heterogeneity estimation with Hartung–Knapp–Sidik–

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Jonkman (HKSJ) confidence intervals and 95% prediction intervals (PI). Certainty of evidence was rated with GRADE.

Results: Sixty-three studies were included (43 RCTs, 12 non-randomised comparative studies and 8 case/validation series; more than 79,000 colonoscopies). In 34 parallel-group RCTs (n = 34,010), CADe increased ADR from 41.4% to 47.4% (risk ratio [RR] 1.16 (95% CI 1.11–1.22); I^2 = 66%; 95% PI 0.94–1.43; low certainty). CADe halved the adenoma miss rate in tandem RCTs (RR 0.49 (95% CI 0.32–0.75); moderate certainty), increased polyp detection (RR 1.21 (95% CI 1.08–1.35)) and adenomas per colonoscopy (mean difference 0.27 (95% CI 0.15–0.38)), but did not increase detection of advanced adenoma/advanced neoplasia (RR 1.04 (95% CI 0.95–1.14)) or, with statistical certainty, serrated lesions (RR 1.48 (95% CI 0.80–2.73)). The relative benefit declined with higher control-arm ADR (meta-regression P < 0.001; R^2 = 67%), from RR 1.45 when baseline ADR was below 30% to RR 1.08 when it was 45% or higher, and attenuated in more recent and FIT-positive trials. In non-randomised real-world cohorts the pooled effect was smaller and non-significant (odds ratio 1.20 (95% CI 0.98–1.46); very low certainty). Small-study effects were present (Egger P = 0.004), although the trim-and-fill-adjusted estimate remained favourable (RR 1.11). Stand-alone validation series reported per-lesion or per-image sensitivities of approximately 87–100%.

Conclusions: CADe-assisted colonoscopy consistently increases the detection of predominantly diminutive, non-advanced adenomas and reduces miss rates, with the greatest gains among lower-performing endoscopists. Its effect on advanced neoplasia, serrated lesions and, ultimately, PCCRC incidence remains unproven, and benefits are attenuated in high-performing and real-

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world settings. Implementation should be targeted, monitored and coupled with strategies that mitigate automation bias and deskilling.

Keywords: artificial intelligence; computer-aided detection; deep learning; colonoscopy; colorectal polyp; adenoma detection rate; adenoma miss rate; meta-analysis

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INTRODUCTION

Colorectal cancer remains one of the most frequently diagnosed malignancies and a leading cause of cancer-related death worldwide. The most recent GLOBOCAN estimates attribute approximately one in ten incident cancers and more than nine per cent of all cancer deaths to colorectal cancer, and its burden is projected to rise substantially by 2040–2050 as populations age and westernised lifestyles spread to transitioning economies, including those of Southeast Asia.[1–3]

Most colorectal cancers arise through the adenoma–carcinoma sequence or the serrated neoplasia pathway, which provides a long window for secondary prevention through colonoscopic detection and resection of precancerous polyps. The adenoma detection rate (ADR), defined as the proportion of screening colonoscopies in which at least one histologically confirmed adenoma is detected, is the best-validated surrogate of colonoscopy quality. Large cohorts have shown that each 1% absolute increase in ADR is associated with an approximately 3% reduction in the risk of PCCRC, and that improving an endoscopist's ADR over time is associated with reduced interval cancer and cancer death, particularly among endoscopists whose baseline ADR is below approximately 25–28%.[4–7]

The protective association of ADR extends to faecal immunochemical test (FIT)-based screening programmes, in which median ADRs are considerably higher, and complementary metrics such as the proximal serrated polyp detection rate, the sessile serrated lesion detection rate (SSLDR) and adenomas per colonoscopy (APC) independently predict PCCRC. Nonetheless, pooled analyses suggest that the incremental protective benefit of ADR may plateau above approximately 34% in primary screening, a finding with direct implications for technologies whose principal effect is to increase ADR.[8–13]

Despite quality-improvement initiatives, inter-endoscopist variability in ADR remains wide, and a substantial proportion of adenomas, particularly diminutive, flat and proximal lesions, are missed. Missed lesions arise from two broad mechanisms: lesions that never appear in the endoscopic field (exposure errors) and lesions that appear on screen but are not recognised (perceptual or recognition errors). Real-time computer-aided detection (CADe) systems, based on deep convolutional neural networks (CNNs) trained on large annotated image and video libraries, specifically target recognition errors by overlaying bounding boxes, often with an acoustic signal, on suspected lesions.[14–16]

Following early validation work demonstrating per-image accuracies above 95% and per-lesion sensitivities approaching 100%, several CADe platforms (including GI Genius, ENDO-AID, CAD EYE, EndoScreener and others) received regulatory approval and were evaluated in randomised trials. Early single-centre trials, predominantly from China and Italy, reported relative ADR increases of 30–50%. In contrast, more recent pragmatic, community-based and FIT-positive trials, as well as real-world implementation cohorts, have reported smaller or null effects, raising concerns about an efficacy–effectiveness gap, observer (Hawthorne) effects, alert fatigue and potential deskilling.[17–23]

These divergent findings are reflected in clinical guidance: the American Gastroenterological Association living guideline made no recommendation for or against CADe because of very low certainty of evidence for patient-important outcomes, whereas a BMJ Rapid Recommendation suggested against its routine use, and commentators have emphasised the need to balance detection metrics against surveillance burden and clinical impact. Most previous meta-analyses pooled only RCTs, did not systematically integrate real-world and validation evidence, and rarely explored baseline performance as a quantitative effect modifier.[24–27]

We therefore conducted a comprehensive systematic review and meta-analysis restricted to the last 15 years, integrating RCTs, comparative studies, cohorts and case series, to (i) estimate the effect of AI-based CADe on ADR, adenoma miss rate (AMR), polyp detection rate (PDR), advanced neoplasia, serrated lesions and APC; (ii) explore sources of heterogeneity, including baseline ADR, platform, clinical setting and endoscopist experience; (iii) contrast efficacy in RCTs with effectiveness in routine practice; and (iv) appraise the certainty of the evidence.[28–30]

METHODS

Protocol and reporting

This review was designed and reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement and its explanation and elaboration document. [28,31]

Eligibility criteria

Eligibility was defined using the PICOS framework. We included studies in adults undergoing colonoscopy for any indication (screening, surveillance, FIT positivity or symptoms) that evaluated a real-time AI-based CADe system. Eligible designs were RCTs (parallel-group or tandem), non-randomised comparative studies (prospective or retrospective

cohorts, before–after, propensity-matched or historically controlled studies) and case series or prospective clinical validation series reporting stand-alone detection performance on clinical colonoscopy data. Systematic reviews and meta-analyses were not included in the evidence base or the characteristics tables but were retrieved for citation chasing and discussed comparatively. Only peer-reviewed full reports published between January 2011 and October 2026 were eligible.[28,32,33]

Table 1. Eligibility criteria according to the PICOS framework

Domain	Inclusion criteria	Exclusion criteria
Population	Adults (≥18 years) undergoing colonoscopy for screening, surveillance, FIT positivity or diagnostic indications; IBD surveillance and high-risk populations accepted	Paediatric populations; capsule endoscopy, CT colonography or upper GI endoscopy only
Intervention	Real-time AI/deep-learning-based computer-aided detection (CADe) of colorectal polyps, alone or integrated with quality-assurance (CAQ) modules	Computer-aided diagnosis/characterisation (CADx) only; offline image-only algorithm development without clinical colonoscopy data
Comparator	Standard high-definition white-light colonoscopy without CADe (RCTs and comparative studies); reference standard (histology/expert review) for case/validation series	CADe plus co-intervention compared with CADe alone (no CADe-free comparator)
Outcomes	Primary: ADR. Secondary: AMR (tandem), PDR, advanced adenoma/ACN detection rate, SSL/serrated lesion detection rate, APC, withdrawal time, non-neoplastic resection; stand-alone sensitivity/specificity	Engineering metrics only (e.g., segmentation Dice, frames per second) without clinical detection outcomes
Study design	RCTs (parallel, tandem); comparative/cohort studies; case	Systematic reviews/meta-analyses (discussion only), narrative

	series and clinical validation series	reviews, editorials, letters, conference abstracts, modelling/cost-effectiveness studies
Time frame/language	Published 1 January 2011 – 19 October 2026 (last 15 years); English language	Publications before 2011

Search Strategy

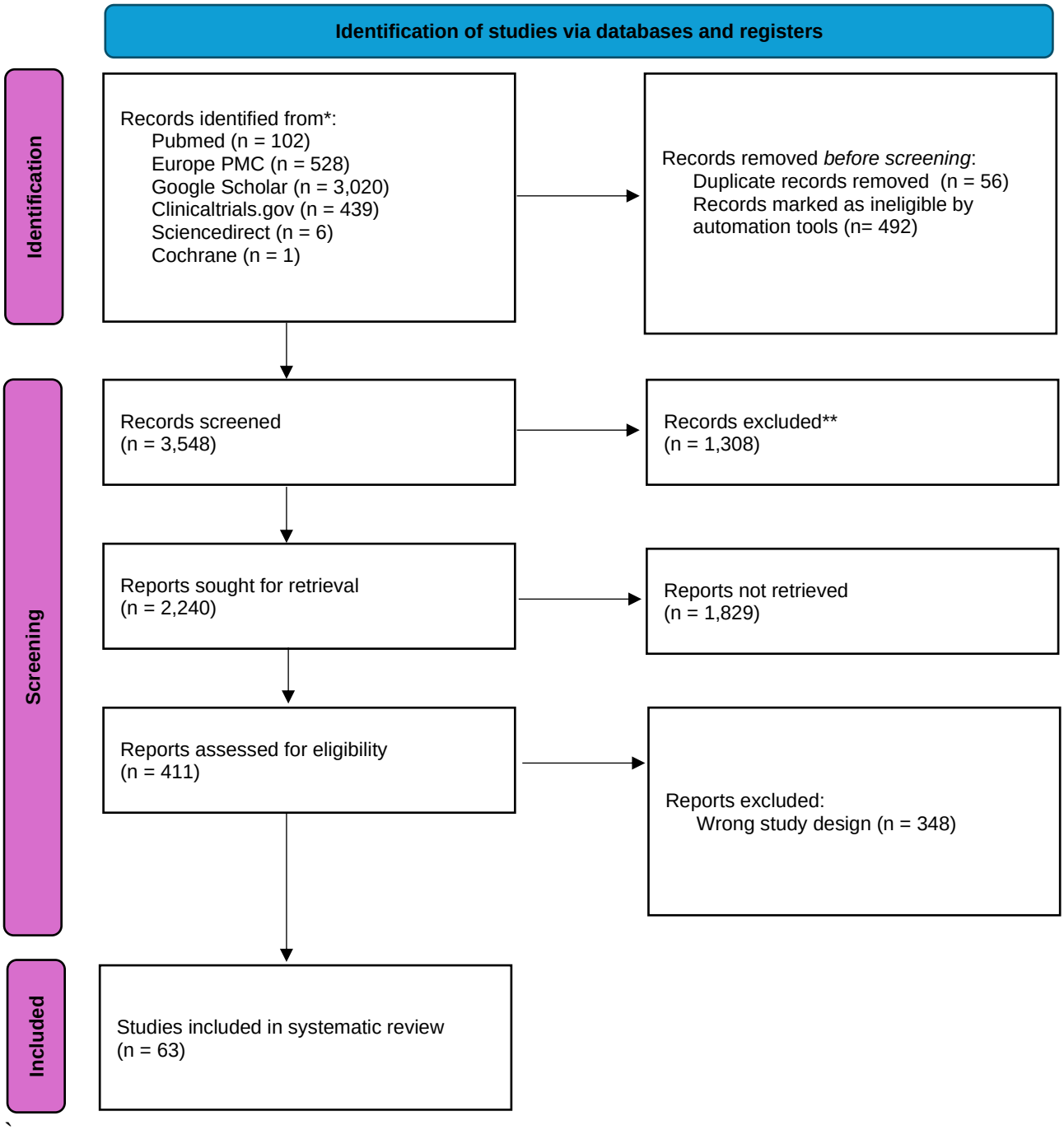
The keywords used for this research based PICO :

PICO Element	Keyword 1	Keyword 2	Keyword 3
P (Population)	Colon Polyps	Colorectal Adenoma	Colonoscopy
I (Intervention)	Artificial Intelligence	Computer-Aided Detection	Endoscopy
C (Comparison)	Standard Colonoscopy	Conventional Endoscopy	Non-CADe Colonoscopy
O (Outcome)	Adenoma Detection Rate	Polyp Detection Rate	Adenoma Miss Rate

The Boolean MeSH keywords inputted on databases for this research are: *("Colon Polyps" OR "Colorectal Adenoma" OR "Colonoscopy") AND ("Artificial Intelligence" OR "Computer-Aided Detection" OR "Endoscopy") AND ("Standard Colonoscopy" OR "Conventional Endoscopy" OR "Non-CADe Colonoscopy") AND ("Adenoma Detection Rate" OR "Polyp Detection Rate" OR "Adenoma Miss Rate")*

Article Search Strategy

Database	Keywords	Hits
Pubmed	*("Colon Polyps" OR "Colorectal Adenoma" OR "Colonoscopy") AND ("Artificial Intelligence" OR "Computer-Aided Detection" OR "Endoscopy") AND ("Standard Colonoscopy" OR "Conventional Endoscopy" OR "Non-CADe Colonoscopy") AND ("Adenoma Detection Rate" OR "Polyp Detection Rate" OR "Adenoma Miss Rate")*	102
Europe PMC	*("Colon Polyps" OR "Colorectal Adenoma" OR "Colonoscopy") AND ("Artificial Intelligence" OR "Computer-Aided Detection" OR "Endoscopy") AND ("Standard Colonoscopy" OR "Conventional Endoscopy" OR "Non-CADe Colonoscopy") AND ("Adenoma Detection Rate" OR "Polyp Detection Rate" OR "Adenoma Miss Rate")*	528
Google Scholar	*("Colon Polyps" OR "Colorectal Adenoma" OR "Colonoscopy") AND ("Artificial Intelligence" OR "Computer-Aided Detection" OR "Endoscopy") AND ("Standard Colonoscopy" OR "Conventional Endoscopy" OR "Non-CADe Colonoscopy") AND ("Adenoma Detection Rate" OR "Polyp Detection Rate" OR "Adenoma Miss Rate")*	3,020
Clinicaltrials.gov	*(“Colon Polyps” OR “Colorectal Adenoma” OR “Colonoscopy”) AND (“Artificial Intelligence” OR “Computer-Aided Detection” OR “Endoscopy”) AND (“Adenoma Detection Rate” OR “Polyp Detection Rate” OR “Adenoma Miss Rate”)*	439
Elsevier	*(“Colon Polyps” OR “Colorectal Adenoma” OR “Colonoscopy”) AND (“Artificial Intelligence” OR “Computer-Aided Detection” OR “Endoscopy”) AND (“Adenoma Detection Rate” OR “Polyp Detection Rate” OR “Adenoma Miss Rate”)*	6
Cochrane	*(“Colon Polyps” OR “Colorectal Adenoma” OR “Colonoscopy”) AND (“Artificial Intelligence” OR “Computer-Aided Detection” OR “Endoscopy”) AND (“Adenoma Detection Rate” OR “Polyp Detection Rate” OR “Adenoma Miss Rate”)*	1



Article search flowchart

Study selection

Records were de-duplicated and screened at title/abstract level by two reviewers independently; potentially eligible reports were then assessed in full. Disagreements were resolved by consensus or adjudication by a third reviewer. When several reports described the same trial or cohort, the most complete peer-reviewed report was retained and companion reports were used only for supplementary data. Trials comparing CADe plus a mucosal

exposure device with CADe alone were excluded from quantitative synthesis because they lacked a CADe-free comparator, but were considered in the discussion.[28,34,35]

Data extraction and outcome definitions

A standardised extraction form captured bibliographic data, country, design (parallel or tandem; single- or multicentre; blinding/concealment), clinical setting and indication, endoscopist experience, CADe platform, sample size per arm and outcome data. ADR was defined as the proportion of patients with at least one histologically confirmed adenoma (or carcinoma); AMR as the number of adenomas detected at the second pass divided by all adenomas detected in both passes of a tandem procedure; PDR as the proportion of patients with at least one polyp; advanced adenoma detection rate (AADR) as the proportion with at least one adenoma ≥10 mm or with high-grade dysplasia or villous histology (advanced colorectal neoplasia, ACN, additionally included advanced serrated lesions when so reported); SSLDR as the proportion with at least one sessile serrated or serrated lesion; and APC as the total number of adenomas divided by the number of colonoscopies.[36–38]

Handling of derived and missing data

Event counts were extracted directly whenever reported. When only proportions and arm sizes were available, counts were back-calculated and rounded to the nearest integer. For ten 1:1 randomised trials in which the accessible report provided the total analysed population and arm-specific percentages but not arm-specific denominators, equal allocation of the analysed population was assumed (flagged with † in tables and figures), and a pre-specified sensitivity analysis excluded these trials. For one tandem trial reporting AMR as proportions with 95% CIs only, counts were derived by inverting the Wald interval (flagged with ‡). Adjusted or propensity-matched effect estimates were preferred for non-randomised studies.[32,39,40]

Risk-of-bias and quality assessment

Risk of bias in RCTs was assessed for the ADR (or primary) result with the revised Cochrane tool (RoB 2) across five domains, following Cochrane implementation guidance; because endoscopists cannot be blinded to visual CADe alerts, bias due to deviations from intended interventions was judged at least “some concerns” unless a sham or concealed design was used. Non-randomised comparative studies were assessed with ROBINS-I across seven domains, with particular attention to confounding by secular trends in before–after designs. Case series and clinical validation series were appraised with the 10-item JBI critical appraisal checklist for case series.[29,30,33,41,42]

Risk of bias and methodological quality

Of 39 RCT results assessed with RoB 2, 1 was judged at low overall risk of bias, 31 (79%) raised some concerns and 7 (18%) were at high risk. The dominant source of concern was domain 2 (deviations from intended interventions), because endoscopists could not be masked to visual alerts and may have altered withdrawal behaviour; histopathological outcome assessment was generally masked and objective. High risk resulted from combinations of unclear allocation concealment, post-randomisation exclusions, absent pathologist masking or retrospective registration in small single-centre trials.[29,41,54,55,68,71,74,82,89]



Figure 1 legend. Domain-level and overall RoB 2 judgements for each randomised trial. Green (+), low risk; yellow (–), some concerns; red (×), high risk.

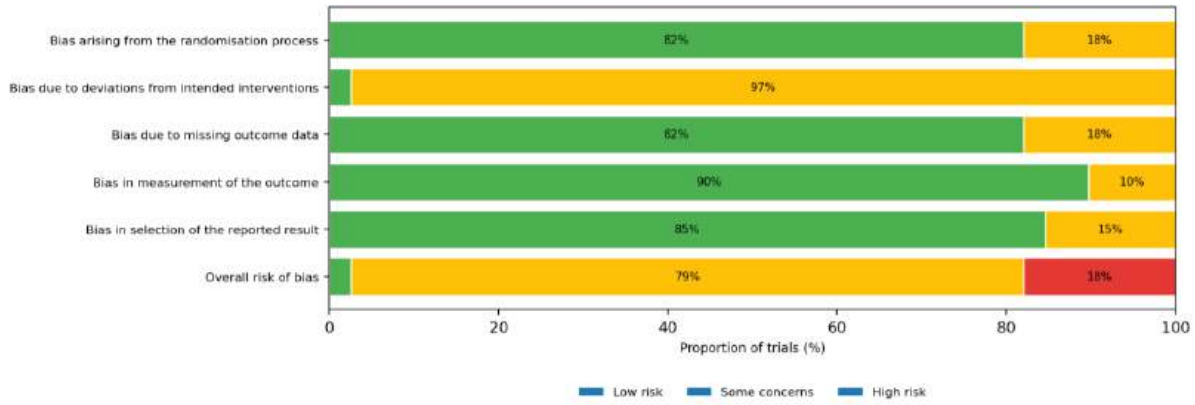


Figure 2 legend. Proportion of randomised trials judged at low risk, some concerns or high risk in each RoB 2 domain and overall.

Among the nine non-randomised studies pooled for ADR, four were at moderate and five at serious overall risk of bias according to ROBINS-I, driven principally by confounding from secular trends, case-mix and operator changes in before–after and historically controlled designs. Case series and validation series met a median of 7 of 10 JBI items (range 6–9), with common limitations in consecutive inclusion and reporting of site and demographic information.[21,30,33,42,98,108]

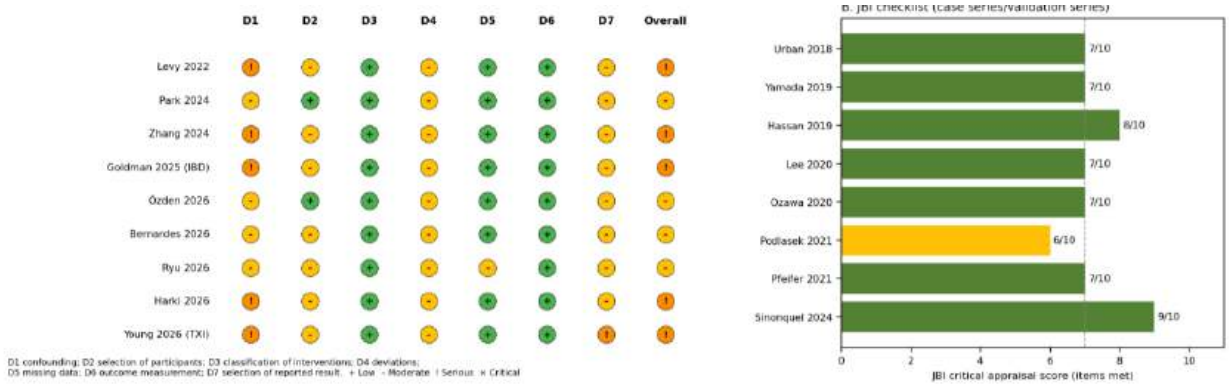


Figure 3 legend. (A) ROBINS-I domain-level and overall judgements for the non-randomised comparative studies pooled in the ADR meta-analysis. (B) JBI case-series checklist scores (number of 10 items fulfilled); dashed line marks 7/10.

Effect measures and synthesis methods

Dichotomous outcomes from RCTs were pooled as risk ratios (RRs) and continuous outcomes (APC) as mean differences (MDs). For non-randomised studies, ADR was pooled as odds ratios (ORs) to accommodate adjusted estimates. All meta-analyses used random-effects models with the between-study variance (τ^2) estimated by restricted maximum likelihood (REML) and 95% CIs computed with the (modified) Hartung–Knapp–Sidik–Jonkman (HKSJ) method, which maintains nominal error rates better than the DerSimonian–

Laird approach; 95% prediction intervals (PIs) were calculated to express the expected range of effects in a new setting. For syntheses including fewer than three studies, Wald-type intervals were used because HKSJ intervals are unstable when very few studies are available.[39,43–45]

Heterogeneity, subgroup analyses and meta-regression

Statistical heterogeneity was quantified using Cochran's Q, I^2 and τ^2. Pre-specified subgroup analyses for ADR examined geographical region, CADe platform, clinical setting/indication (FIT-positive or organised programme versus screening/surveillance versus diagnostic/mixed), endoscopist experience (trainee/non-expert versus expert/mixed), number of centres, publication period, baseline (control-arm) ADR category (<30%, 30–45%, ≥45%) and trial size; between-subgroup differences were tested with the Q-between statistic. Mixed-effects meta-regression explored control-arm ADR, publication year and log-transformed sample size as continuous moderators, with the proportion of between-study variance explained reported as R^2.[39,44,46]

Sensitivity analyses

Robustness of the primary result was assessed by excluding trials with equal-allocation imputation, CAQ-integrated systems, high overall risk of bias or fewer than 300 participants; by restricting to trials at low overall risk of bias and to trials published from 2023 onwards; by applying alternative models (Wald-type random effects without HKSJ, common-effect inverse-variance) and an alternative effect measure (OR); and by leave-one-out and cumulative meta-analyses ordered by publication year. Empirical evidence that unblinded trials may exaggerate intervention effects motivated these analyses.[43,47,48]

Assessment of reporting bias

Small-study effects and publication bias were explored for outcomes with at least eight studies using contour-enhanced funnel plots, Egger's regression test, Begg's rank-correlation test, Galbraith (radial) plots and the Duval–Tweedie trim-and-fill method (L_0 estimator). Risk of bias due to missing evidence was considered qualitatively following the ROB-ME framework.[28,49]

Certainty of evidence and absolute effects

Certainty of evidence for each outcome was rated with GRADE (high, moderate, low, very low), considering risk of bias, inconsistency, indirectness, imprecision and publication bias; bodies of non-randomised evidence assessed with ROBINS-I started at high certainty and were rated down accordingly. Absolute effects per 1,000 patients were derived by applying the pooled RR to the pooled control-arm risk, and the number needed to treat (NNT;

colonoscopies performed with CADe to detect one additional adenoma-positive patient) was modelled across baseline ADR levels using both the constant pooled RR and the meta-regression-predicted RR.[24,40]

Software

Analyses were performed in Python 3 (NumPy, SciPy) using purpose-written, validated routines for REML estimation, HKSJ adjustment, prediction intervals, Egger and Begg tests, trim-and-fill and mixed-effects meta-regression; forest, funnel, Galbraith, L'Abbé, bubble, cumulative and influence plots were produced with Matplotlib. A two-sided $P < 0.05$ was considered statistically significant; for interaction tests $P < 0.10$ was considered suggestive.[39,43,44]

RESULTS

Characteristics of included studies

The 43 included RCTs comprised 34 parallel-group trials contributing to the primary ADR analysis, six tandem (back-to-back) trials and three additional parallel trials reporting non-ADR outcomes. The 34 parallel-group trials were published between 2019 and 2026 and enrolled 34,010 participants (16,994 CADe; 17,016 standard colonoscopy), with individual trial sizes ranging from 102 to 3,213. Fourteen trials were conducted in Asia, fourteen in Europe, 5 in North America and one in the Middle East; 19 were single-centre. Control-arm ADR ranged widely, from 7.7% to 70.0%, reflecting heterogeneous indications, populations and baseline endoscopist performance.[18–20,53–83]

Platforms evaluated included GI Genius (five trials), EndoScreener/Wision AI-based systems (three), ENDO-AID (two), CAD EYE (two), quality-assurance-integrated systems combining detection with withdrawal-speed or blind-spot monitoring (ENDOANGEL and AQCS; two) and a range of other commercial or investigational platforms (Eagle-Eye, SKOUT, EndoVigilant, DEEP2 and unspecified or nationally developed systems). Six trials were conducted in FIT-positive or organised screening programmes, four in asymptomatic screening/surveillance populations and the remainder in mixed or diagnostic populations; three trials specifically enrolled endoscopists-in-training or non-experts. Only one trial used a sham-controlled double-blind design, in which CADe output was displayed on a second monitor visible to an observer. The conceptual framework linking the CADe pipeline, human–AI interaction modifiers and the histology-based endpoints analysed in this review is summarised in Figure.[18,53,55–57,61,62,65–67,72,75,82]

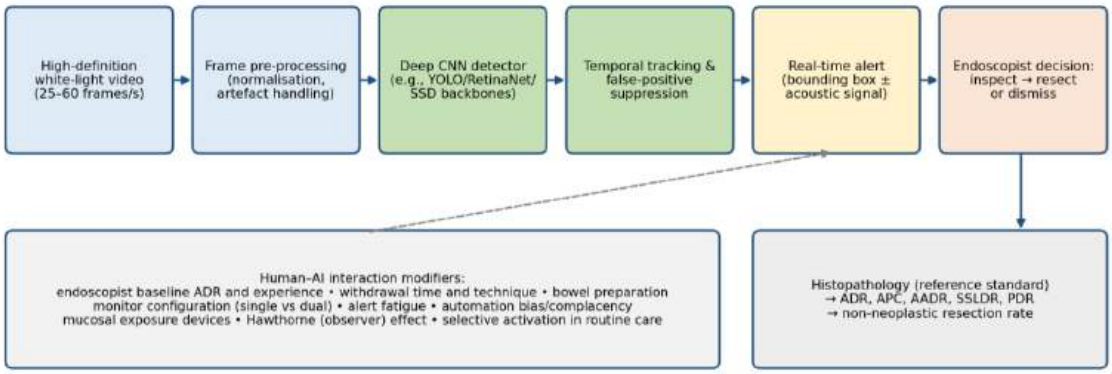


Figure 4 legend. Schematic of real-time CADe during colonoscopy: video frames are processed by a deep convolutional neural network with temporal tracking to generate on-screen alerts; the endoscopist decides whether to inspect and resect, and histopathology defines the outcome measures. Human–AI interaction factors modify the translation of algorithmic sensitivity into clinical detection.

Table 2. Characteristics and adenoma detection outcomes of the parallel-group randomised controlled trials included in the primary meta-analysis

Study	Country	Centres; masking	Setting / indication	Endoscopists	CADe platform	n CADe / control	ADR CADe, % (events)	ADR control, % (events)	RR (95% CI)	RoB 2 overall
Wang 2019[19]	China	Single-centre; open	Diagnostic / mixed	Expert/mixed	EndoScreener (Wision AI)	522 / 536	29.1 (152)	20.3 (109)	1.43 (1.16 – 1.77)	Some concerns
Gong 2020[53]	China	Single-centre; open	Diagnostic / mixed	Expert/mixed	ENDOANGEL (CAQ)	355 / 349	16.3 (58)	7.7 (27)	2.11 (1.37 – 3.25)	Some concerns
Liu 2020[54]	China	Single-centre; open	Diagnostic / mixed	Expert/mixed	Embedded single-monitor CADe	393 / 397	29.0 (114)	20.9 (83)	1.39 (1.08 – 1.77)	High
Repici 2020[18]	Italy	Multicentre; open	Diagnostic / mixed	Expert/mixed	GI Genius	341 / 344	54.8 (187)	40.4 (139)	1.36 (1.16	Some concern

									– 1.59)	s
Su 2020[55]	China	Single-centre; open	Diagnostic / mixed	Expert/mixed	AQCS (CAQ + CADe)	308 / 315	28.9 (89)	16.5 (52)	1.75 (1.29 – 2.37)	High
Wang 2020 (CADe-DB)[56]	China	Single-centre; double-blind (sham)	Diagnostic / mixed	Expert/mixed	EndoScreener vs sham	484 / 478	34.1 (165)	27.6 (132)	1.23 (1.02 – 1.49)	Low
Repici 2021 (AID-2)[57]	Italy/Europe	Multicentre; open	Diagnostic / mixed	Trainee/non-expert	GI Genius	330 / 330	53.3 (176)	44.5 (147)	1.20 (1.02 – 1.40)	Some concerns
Yao 2021[58]	China	Single-centre; open	Diagnostic / mixed	Expert/mixed	CADe arm (4-arm trial)	268 / 271	21.3 (57)	14.8 (40)	1.44 (1.00 – 2.08)	Some concerns
Ahmad 2022 (AI-	UK	Single-centre;	FIT-positive /	Expert/mixed	Commercial CADe	308 / 306	71.4 (220)	65.0 (199)	1.10 (0.99	Some concern

DETECT)[59]		open	programme						– 1.22)	s
Aniwan 2022†[60]	Thailand	Single-centre; open	Screening / surveillance	Expert/mixed	Commercial CADe (CADe arm)	311 / 311	52.1 (162)	41.8 (130)	1.25 (1.05 – 1.48)	Some concerns
Gimeno-García 2022[61]	Spain	Single-centre; open	Diagnostic / mixed	Expert/mixed	ENDO-AID	185 / 185	55.1 (102)	43.8 (81)	1.26 (1.02 – 1.55)	Some concerns
Rondonotti 2022[62]	Italy	Multicentre; open	FIT-positive / programme	Expert/mixed	CAD EYE	405 / 395	53.6 (217)	45.3 (179)	1.18 (1.03 – 1.36)	Some concerns
Shaukat 2022[63]	USA	Multicentre; open	Screening / surveillance	Expert/mixed	SKOUT	682 / 677	47.8 (326)	43.9 (297)	1.09 (0.97 – 1.22)	Some concerns
Xu 2022[64]	China/Hong Kong	Multicentre; open	Screening / surveillance	Expert/mixed	Eagle-Eye	1,519 / 1,540	39.9 (606)	32.4 (499)	1.23 (1.12 –	Some concerns

									1.35)	
Karsenti 2023[65]	France	Single-centre; open	Diagnostic / mixed	Expert/mixed	GI Genius	1,003 / 1,012	37.5 (376)	33.7 (341)	1.11 (0.99 – 1.25)	Some concerns
Lau 2023[66]	Hong Kong	Single-centre; open	Diagnostic / mixed	Trainee/non-expert	ENDO-AID	386 / 380	57.5 (222)	44.5 (169)	1.29 (1.12 – 1.49)	Some concerns
Mangas-Sanjuán 2023†[67]	Spain	Multicentre; open	FIT-positive / programme	Expert/mixed	GI Genius	1,607 / 1,606	64.2 (1032)	62.0 (996)	1.04 (0.98 – 1.09)	Some concerns
Nakashima 2023[68]	Japan	Single-centre; open	Diagnostic / mixed	Expert/mixed	Novel CNN-based CADe	207 / 208	59.4 (123)	47.6 (99)	1.25 (1.04 – 1.50)	High
Wei 2023[20]	USA	Multicentre; open	Diagnostic / mixed	Expert/mixed	EndoVigilant	387 / 382	35.9 (139)	37.2 (142)	0.97 (0.80 – 1.16)	Some concerns

Liu KS 2024†[69]	Hong Kong	Single-centre; open	Diagnostic / mixed	Expert/mixed	Commercial CADe (AI arm)	227 / 227	53.7 (122)	46.3 (105)	1.16 (0.97 – 1.40)	Some concerns
Maas 2024[70]	Europe/Canada	Multicentre; open	Diagnostic / mixed	Expert/mixed	Commercial CADe	250 / 247	38.4 (96)	37.7 (93)	1.02 (0.81 – 1.28)	Some concerns
Schöler 2024†[71]	Sweden	Single-centre; open	Diagnostic / mixed	Expert/mixed	CAD EYE / GI Genius	120 / 120	40.8 (49)	43.3 (52)	0.94 (0.70 – 1.27)	High
Seager 2024 (COLO-DETECT)[72]	UK	Multicentre; open	Diagnostic / mixed	Expert/mixed	GI Genius	980 / 986	56.6 (555)	48.4 (477)	1.17 (1.08 – 1.27)	Some concerns
Thiruvengadam 2024†[73]	USA	Single-centre; open	Diagnostic / mixed	Expert/mixed	Commercial CADe	550 / 550	42.5 (234)	34.4 (189)	1.24 (1.06 – 1.44)	Some concerns
Alali 2025[74]	Kuwait	Single-	Screening /	Expert/mixe	Commercial	51 / 51	47.1	37.3	1.26	High

		centre; open	surveillance	d	CADe		(24)	(19)	(0.80 – 2.00)	
Chang 2025†[75]	USA	Single-centre; open	Diagnostic / mixed	Trainee/non-expert	Commercial CADe	523 / 522	40.5 (212)	35.1 (183)	1.16 (0.99 – 1.35)	Some concerns
Jeon 2025[76]	South Korea	Multicentre; open	Diagnostic / mixed	Expert/mixed	Commercial CADe	497 / 501	52.3 (260)	36.1 (181)	1.45 (1.25 – 1.67)	Some concerns
Yabuuchi 2025[77]	Japan	Single-centre; open	Diagnostic / mixed	Expert/mixed	Commercial CADe	501 / 497	50.7 (254)	54.5 (271)	0.93 (0.83 – 1.05)	Some concerns
Zimmermann-Fraedrich 2025†[78]	Germany	Multicentre; open	Diagnostic / mixed	Expert/mixed	Commercial CADe	814 / 813	40.5 (330)	38.3 (311)	1.06 (0.94 – 1.20)	Some concerns
Dávila-Piñón 2026†[79]	Spain	Multicentre; open	FIT-positive /	Expert/mixed	Commercial CADe	414 / 413	60.9 (252)	57.6 (238)	1.06 (0.94	Some concern

			programme						– 1.18)	s
Hsu 2026[80]	Taiwan	Multicentre; open	Diagnostic / mixed	Expert/mixed	Commercial CADe	675 / 681	58.5 (395)	53.3 (363)	1.10 (1.00 – 1.21)	Some concerns
Leggett 2026 (GAIN)†[81]	USA/international	Multicentre; open	Diagnostic / mixed	Expert/mixed	DEEP2	704 / 703	42.9 (302)	38.8 (273)	1.10 (0.97 – 1.25)	Some concerns
Robles de la Osa 2026†[82]	Spain	Single-centre; open	FIT-positive / programme	Expert/mixed	CAD EYE	181 / 180	61.3 (111)	70.0 (126)	0.88 (0.75 – 1.02)	High
Spada 2026[83]	Italy	Multicentre; open	FIT-positive / programme	Expert/mixed	Commercial CADe	506 / 503	67.6 (342)	59.8 (301)	1.13 (1.03 – 1.24)	Some concerns

† Arm-specific denominators derived assuming equal 1:1 allocation of the analysed population (see Methods 2.6). ADR, adenoma detection rate; CAQ, computer-aided quality assurance; CADe, computer-aided detection; FIT, faecal immunochemical test; RoB 2, revised Cochrane risk-of-bias tool; RR, risk ratio (CADe vs control).

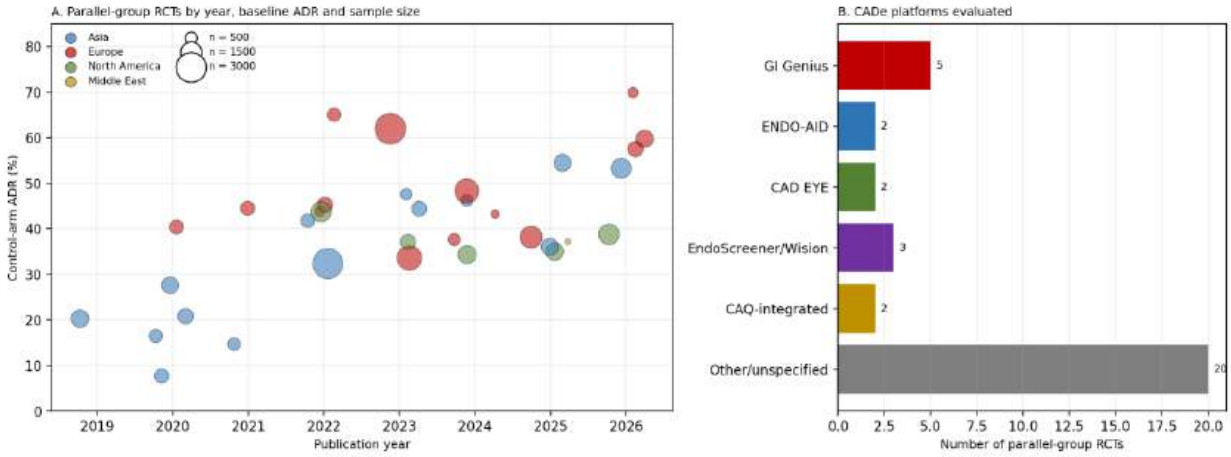


Figure 5 legend. (A) Each bubble represents one parallel-group RCT positioned by publication year (jittered) and control-arm ADR; bubble area is proportional to sample size and colour denotes region. (B) Number of trials by CADe platform. CAQ, computer-aided quality assurance.

The six tandem RCTs enrolled patients undergoing same-day back-to-back colonoscopy in randomised order; four reported AMR as counts suitable for pooling, whereas one reported proportions only and one used a three-arm novice/expert design. Three further parallel RCTs reported polyp detection rate or endoscopist sensitivity without extractable ADR.[38,84–91]

Table 3. Characteristics of tandem RCTs and additional RCTs not contributing to the ADR meta-analysis

Study	Country / setting	Design	CADe platform	n	Principal findings	Use in synthesis
Wang 2020 (tandem)[84]	China; single-centre	Tandem RCT, CADe-first vs routine-first	EndoScreener	369	AMR 13.89% vs 40.00%; polyp miss rate 12.98% vs 45.90%	AMR meta-analysis‡
Glissen	USA; 4	Tandem	EndoScreener	223	AMR	AMR

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Brown 2021 (CADeT-CS)[85]	academic centres	RCT			20.12% (34/169) vs 31.25% (45/144); SSL miss rate 7.14% vs 42.11%; first-pass APC 1.19 vs 0.90	meta-analysis
Wallace 2022[38]	Italy, UK, USA; 8 centres	Tandem RCT	GI Genius (deep-learning CADe)	230	AMR 15.5% (38/246) vs 32.4% (80/247); adjusted OR 0.38; false-negative patients 6.8% vs 29.6%	AMR meta-analysis
Maas 2024 (tandem subset)[86]	Europe, USA, Israel; 10 hospitals	RCT with randomised tandem subset	Commercial CADe	916 (127 tandem)	APC 0.70 vs 0.51; AMR 19% (11/59) vs 36% (16/45)	AMR meta-analysis
Kamba 2021[87]	Japan; 4 sites	Tandem RCT	Original CNN-based CADe	358	AMR 13.8% vs 36.7%;	Qualitative (counts not

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					SSL miss rate 13.0% vs 38.5%; ADR 64.5% vs 53.6%	extractable)
Yao 2023[88]	China; 3 hospitals	Three-arm tandem RCT (novice, AI-assisted novice, expert)	ENDOANGEL-based CADe	685	AMR 18.82% (AI-assisted novices) vs 43.69% (novices) vs 26.97% (experts; non-inferior)	Qualitative
Xu X 2025[89]	China; multicentre	Parallel RCT	Real-time CADe software	390	PDR 67.18% vs 56.92%; CADe sensitivity 95.19%, specificity 98.44%	PDR meta-analysis
Zhang H 2024[90]	China; 3 centres	Parallel RCT	CADe with ileocaecal recognition and speed	1,293	Endoscopist sensitivity 84.97% vs 72.07%;	Qualitative

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			monitoring		higher 6–9 mm PDR	
Park D 2024[91]	South Korea; 6 institutions	Parallel RCT	RetinaNet-based CADe	805	Higher PDR and ADR with AI; OR 1.50 for polyp detection	Qualitative

‡ Counts back-calculated from reported proportions and 95% CIs. ADR, adenoma detection rate; AMR, adenoma miss rate; APC, adenomas per colonoscopy; OR, odds ratio; PDR, polyp detection rate; SSL, sessile serrated lesion.

Twelve non-randomised comparative studies evaluated CADe in routine practice, including before–after implementation cohorts, propensity-matched cohorts, room- or week-allocated prospective designs, a within-endoscopist comparison and historically controlled studies; nine provided ADR data suitable for pooling.[21,92–102]

Table 4. Characteristics of non-randomised comparative (cohort) studies

Study	Country / setting	Design	CADe	n CADe / non-CADe	Principal findings	ROBINS-I overall
Levy 2022[21]	Israel; large-volume centre	Retrospective before–after (6 months each)	GI Genius	1,969 / 2,175	ADR 30.3% vs 35.2%; PDR 36.5% vs 40.9%; shorter procedure time	Serious

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Park 2024[92]	South Korea; tertiary centre	Prospective, room-allocated, sex/age-matched	ENAD	879 / 879	ADR 45.1% vs 38.8%; SSLDR 5.7% vs 2.5%; APC 0.78 vs 0.61; WT 9.0 vs 8.3 min	Moderate
Zhang 2024[93]	China; tertiary centre	Retrospective PSM before–after (single vs dual monitor)	CADe	12,214 / 5,390	ADR OR 1.141 (1.047–1.243) for CADe period; no monitor-configuration difference	Serious
Goldman 2025[94]	Single centre; IBD surveillance	Retrospective before–after	CADe	750 / 225	Neoplasia 3.6% vs 5.8%; adjusted ADR 3.8% vs 5.2% (NS)	Serious
Özden 2026[95]	Türkiye; tertiary centre	Prospective, weekly alternation	Deep-learning CADe	1,061 / 1,061	ADR 19.0% vs 13.0%; aOR 1.56 (1.22–1.99); PDR 35.4% vs 28.7%;	Moderate

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					WT unchanged	
Bernardes 2026[96]	13 units	Prospective within-endoscopist comparison	CADe	947 / 2,026	ADR 34.4% vs 30.7%; aOR 1.31 (1.11–1.55); attenuated after endoscopist adjustment	Moderate
Ryu 2026[97]	Tertiary centre	Retrospective, 1:1 PSM	CADe	362 / 362	ADR 40.6% vs 30.4%; PDR 60.2% vs 50.6%; benefit in experts and trainees	Moderate
Harki 2026[98]	High-volume centre	Prospective vs historical controls	CADe	2,622 / 4,822	ADR OR 1.26 (1.13–1.41); AdvADR OR 1.25; no change in SSL detection or WT	Serious
Young	Australia	Prospective	CADe + TXI	100 /	ADR 62.0%	Serious

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2026[99]		TXI + CADe vs historical TXI		163	vs 55.8% (NS); +1 min WT; more non-neoplastic resections	
Takasu 2025[100]	Single facility	Retrospective (3 of 4 rooms equipped)	CAD	1,314 (total)	ADR 49.3% vs 31.6%; ADR of non-CAD procedures fell to 13.5% after introduction	Serious (not pooled)
Nehme 2023[101]	USA; tertiary centre	Retrospective vs historical; discretionary activation	GI Genius	CADe active in 52.1%	APC 1.08 vs 1.04 (NS); no ADR difference; staff concerns about false positives	Serious (not pooled)
Quan 2022[102]	USA; 2 centres	Prospective single-arm vs historical	Investigational CADe	300 / 300	APC 1.35 vs 1.07 (P = 0.099); more non-neoplastic polyps	Serious (not pooled)

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ADR, adenoma detection rate; AdvADR, advanced ADR; aOR, adjusted odds ratio; APC, adenomas per colonoscopy; IBD, inflammatory bowel disease; NS, not significant; PDR, polyp detection rate; PSM, propensity score matching; SSLDR, sessile serrated lesion detection rate; TXI, texture and colour enhancement imaging; WT, withdrawal time.

Eight case series or clinical validation series reported stand-alone detection performance of CNN-based CADe on clinical colonoscopy images or videos, including two prospective in vivo series[14,17,103–108]

Table 5. Characteristics of case series and clinical validation series (stand-alone CADe performance)

Study	Data source	Architecture / system	Unit of analysis	Reported performance	JBI score
Urban 2018[14]	8,641 labelled images (>2,000 patients); 20 videos	Deep CNN	Per image; per polyp (video)	Accuracy 96.4%; AUC 0.991; all removed polyps detected; false-positive rate 7%	7/10
Yamada 2019[103]	Validation image set	Deep-learning real-time system	Per image	Sensitivity 97.3%, specificity 99.0%, AUC 0.975; non-polypoid sensitivity 93.7%	7/10
Hassan 2019[17]	338 polyps from 105 patients (RCT video library)	GI Genius	Per lesion	Sensitivity 99.7% (337/338); false-positive frames <1%; faster reaction than endoscopists in 82%	8/10
Lee 2020[104]	Four independent	YOLOv2	Per image	Sensitivity 96.7%,	7/10

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	datasets incl. 15 unaltered videos			90.2%, 87.7% and 89.3%; detected all 38 endoscopist-detected polyps plus 7 additional	
Ozawa 2020[105]	7,077 images incl. 309 polyps	Single Shot MultiBox Detector	Per image	Sensitivity 92%, PPV 86% (WLI 90%/83%; NBI 97%/98%)	7/10
Podlasek 2021[106]	42 full colonoscopy recordings	CNN with post-processing	Per polyp (video)	Detected 94% of endoscopist-found polyps; false-positive rate 3%	6/10
Pfeifer 2021[107]	15,534 frames ex vivo; 42 patients in vivo	Deep CNN	Per frame; per patient	Sensitivity 90%, specificity 80%, AUC 0.92; in vivo ADR 26% → 36%	7/10
Sinonquel 2024[108]	946 patients; 2,141 polyps (prospective, second observer)	CNN + recurrent neural network	Per polyp (in vivo)	CADe sensitivity 94.6% vs endoscopists 96.0%; +86 true-positive polyps; ADR +1.1%; procedure time +6.6 min	9/10

AUC, area under the receiver operating characteristic curve; CNN, convolutional neural network; JBI, Joanna Briggs Institute; NBI, narrow-band imaging; PPV, positive predictive value; WLI, white-light imaging.

Primary outcome: adenoma detection rate

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Across 34 parallel-group RCTs (34,010 participants), ADR was 47.4% (8,061/16,994) with CADe and 41.4% (7,043/17,016) with standard colonoscopy, corresponding to a pooled RR of 1.16 (95% CI 1.11–1.22) ($P < 0.001$) under the REML–HKSJ random-effects model. Heterogeneity was substantial ($Q = 96.44$, $df = 33$, $P < 0.001$; $I^2 = 66\%$; $\tau^2 = 0.010$), and the 95% PI (0.94–1.43) included the null, indicating that a future trial could plausibly observe no benefit. Trial-level RRs ranged from 0.88 (Robles de la Osa 2026) to 2.11 (Gong 2020); 17 of 34 trials individually demonstrated a statistically significant increase. Expressed as an OR, the pooled effect was 1.32 (95% CI 1.22–1.43).[19,53,64,67,72,77,82]

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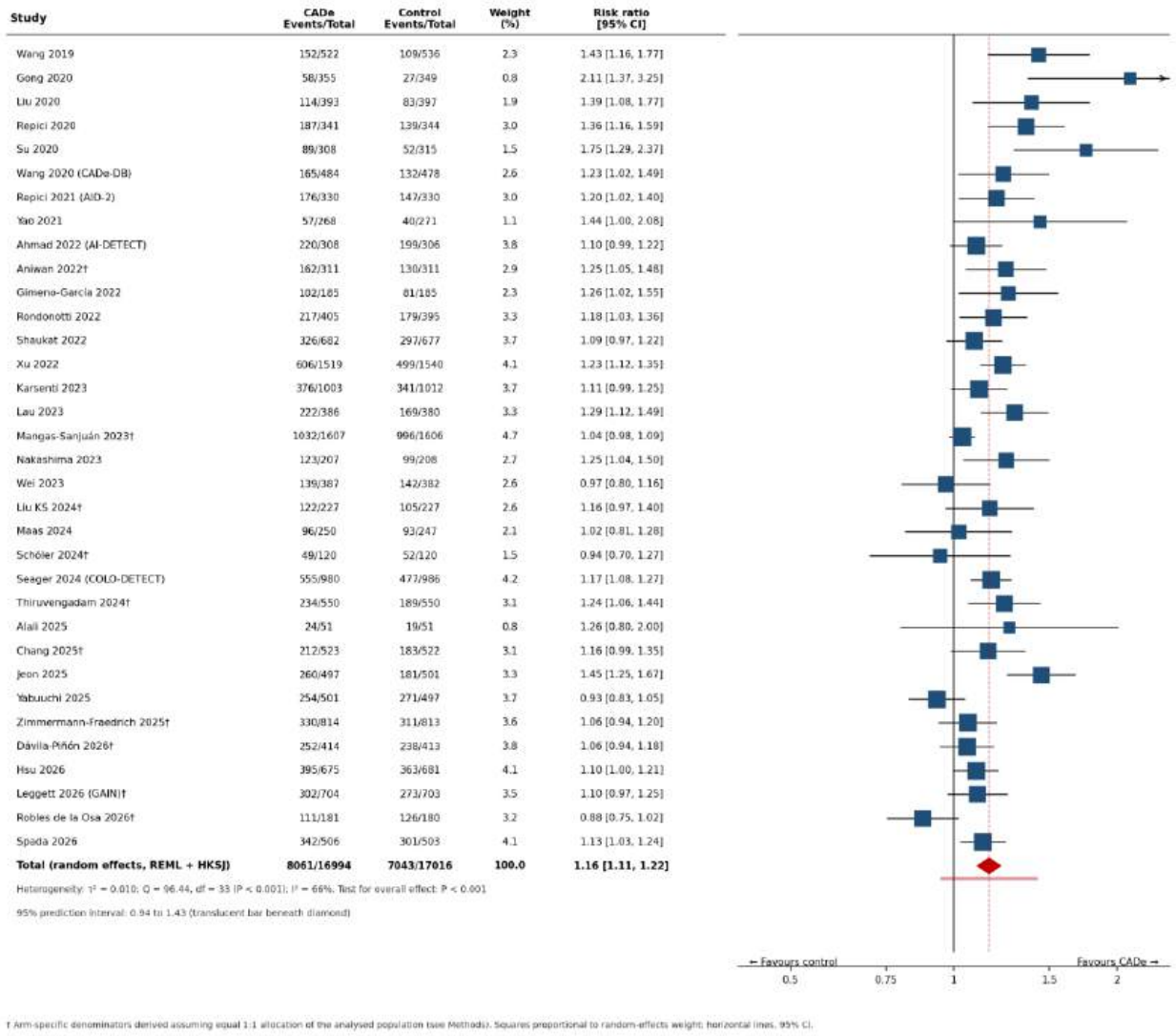


Figure 6 legend. Risk ratios (squares, proportional to random-effects weight) with 95% CIs (horizontal lines). The red diamond shows the pooled REML–HKSJ estimate; the translucent bar beneath it shows the 95% prediction interval. † Equal-allocation denominators.

Subgroup analyses

The ADR benefit was larger in Asian trials (RR 1.27 (1.15–1.41; k = 14; I^2 = 72%)) than in European (RR 1.10 (1.04–1.17; k = 14; I^2 = 55%)) and North American trials (RR 1.11 (1.01–1.22; k = 5; I^2 = 11%)); P-interaction = 0.048. Effects varied by platform (P-interaction < 0.001), with the largest estimates for quality-assurance-integrated systems that additionally monitored withdrawal

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speed and blind spots (RR 1.86 (1.45–2.39; k = 2; I^2 = 0%)) and EndoScreener-based systems (RR 1.34 (1.02–1.75; k = 3; I^2 = 0%)), intermediate effects for ENDO-AID (RR 1.28 (1.14–1.44; k = 2; I^2 = 0%)) and GI Genius (RR 1.15 (1.02–1.30; k = 5; I^2 = 73%)), and no significant effect for CAD EYE in two FIT-related trials (RR 1.02 (0.76–1.37; k = 2; I^2 = 88%)).[18,19,53–55,61,62,66,82]

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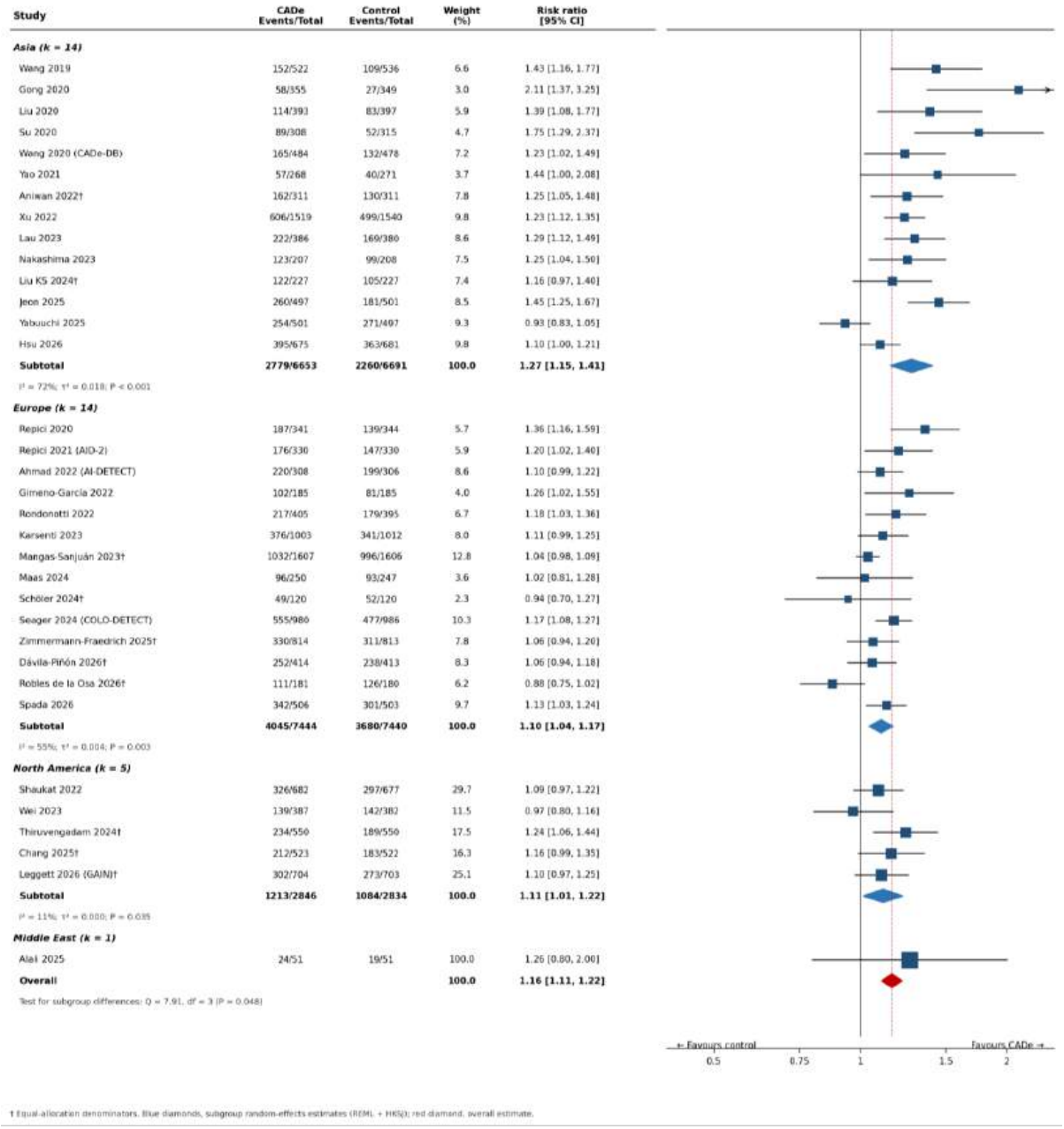
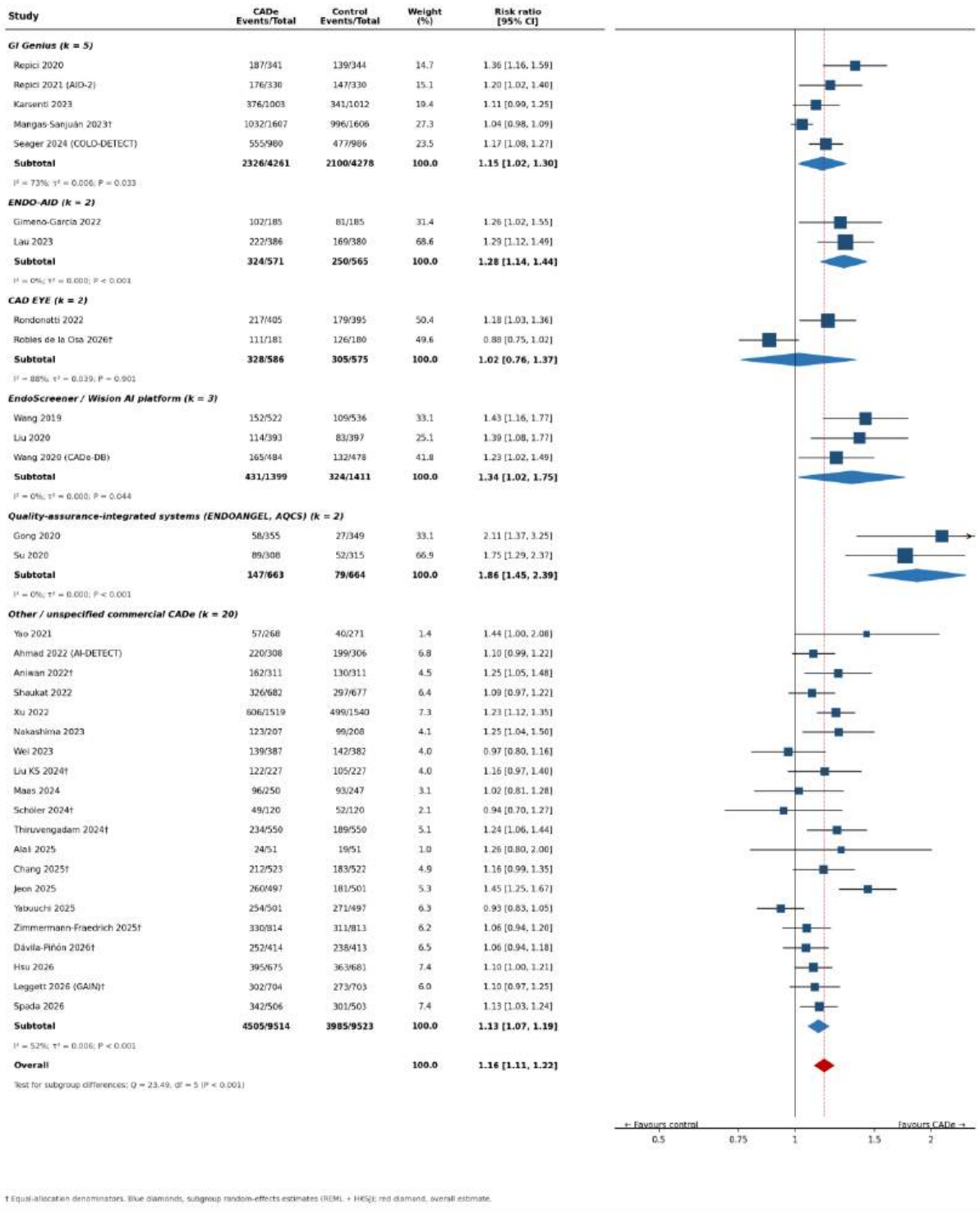


Figure 7 legend. ADR subgroup forest plot by region. Blue diamonds, subgroup estimates; red diamond, overall estimate. † Equal-allocation denominators.

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† Equal-allocation denominators. Blue diamonds, subgroup random-effects estimates (REML + HKSJ); red diamond, overall estimate.

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Figure 8 legend. ADR subgroup forest plot by CADe platform. For subgroups with two trials, Wald-type intervals were used (see Methods 2.8).

Clinical setting modified the effect (P-interaction = 0.037): CADe did not significantly increase ADR in FIT-positive or organised screening programmes (RR 1.06 (0.97–1.17; k = 6; I^2 = 56%)), where control-arm ADRs were high, whereas benefits were evident in screening/surveillance (RR 1.18 (1.03–1.36; k = 4; I^2 = 2%)) and diagnostic/mixed populations (RR 1.19 (1.12–1.28; k = 24; I^2 = 64%)). Trials enrolling trainees or non-experts showed a numerically larger effect (RR 1.22 (1.01–1.48; k = 3; I^2 = 0%)) than those enrolling experts or mixed operators (RR 1.16 (1.10–1.22; k = 31; I^2 = 67%); P-interaction = 0.309). Single-centre trials yielded somewhat larger effects than multicentre trials (P-interaction = 0.245), and small and large trials did not differ significantly (P-interaction = 0.246).[57,59,62,66,67,75,79,82,83]

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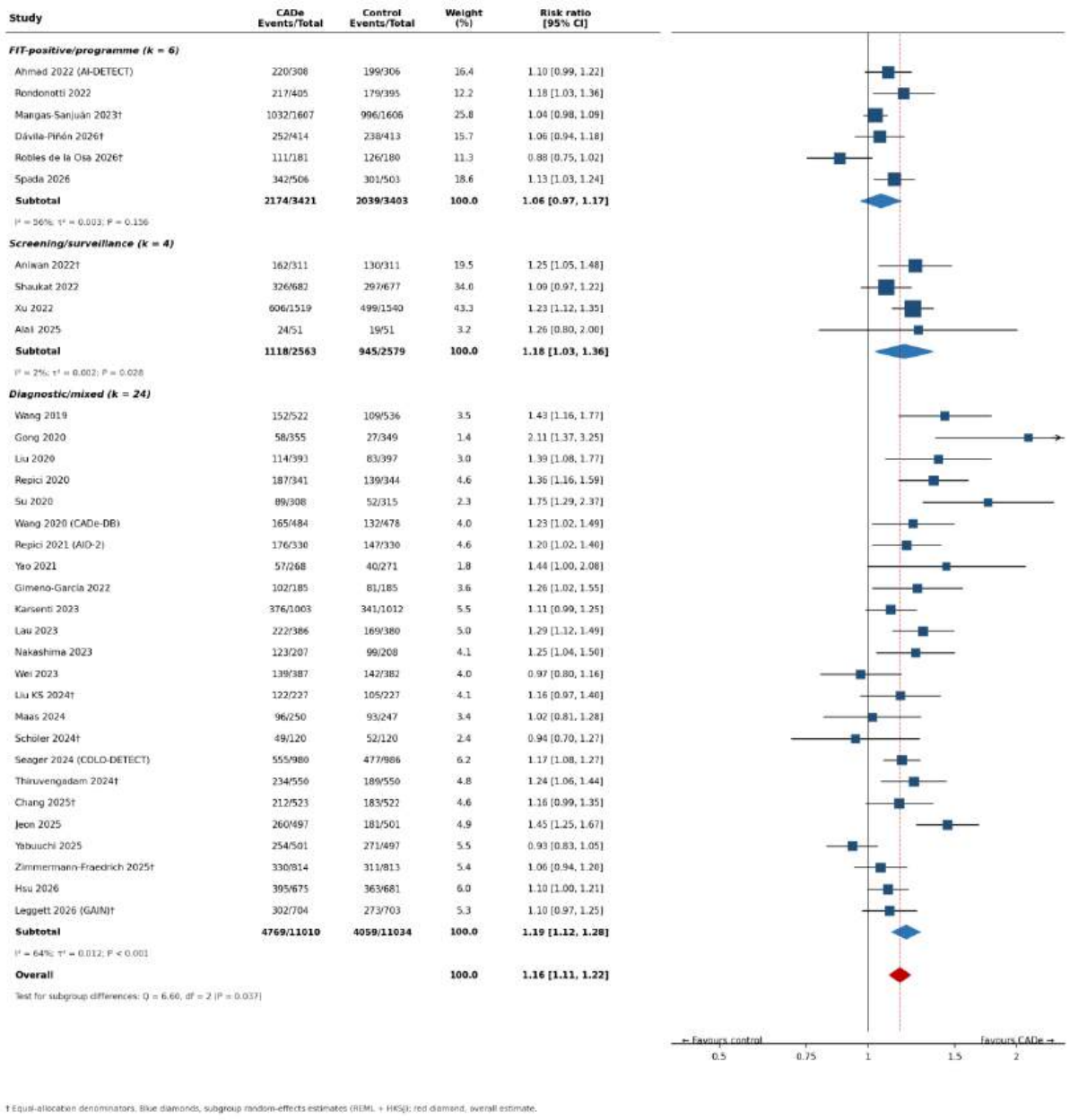


Figure 9 legend. ADR subgroup forest plot by clinical setting/indication. FIT, faecal immunochemical test.

Two temporal and performance-related moderators were particularly influential. The pooled effect declined from RR 1.37 (1.21–1.55; k = 8; I^2 = 33%) in trials published in 2019–2021 to RR 1.14 (1.07–1.22; k = 11; I^2 = 57%) in 2022–2023 and RR 1.10 (1.03–1.18; k = 15; I^2 = 64%) in

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2024–2026 (P-interaction = 0.001). Similarly, the relative gain was greatest when control-arm ADR was below 30% (RR 1.45 (1.22–1.73; k = 6; I^2 = 30%)), intermediate at 30–45% (RR 1.18 (1.11–1.24; k = 17; I^2 = 46%)) and smallest at 45% or higher (RR 1.08 (1.01–1.15; k = 11; I^2 = 60%); P-interaction < 0.001).[9,53,67,72,77,80]

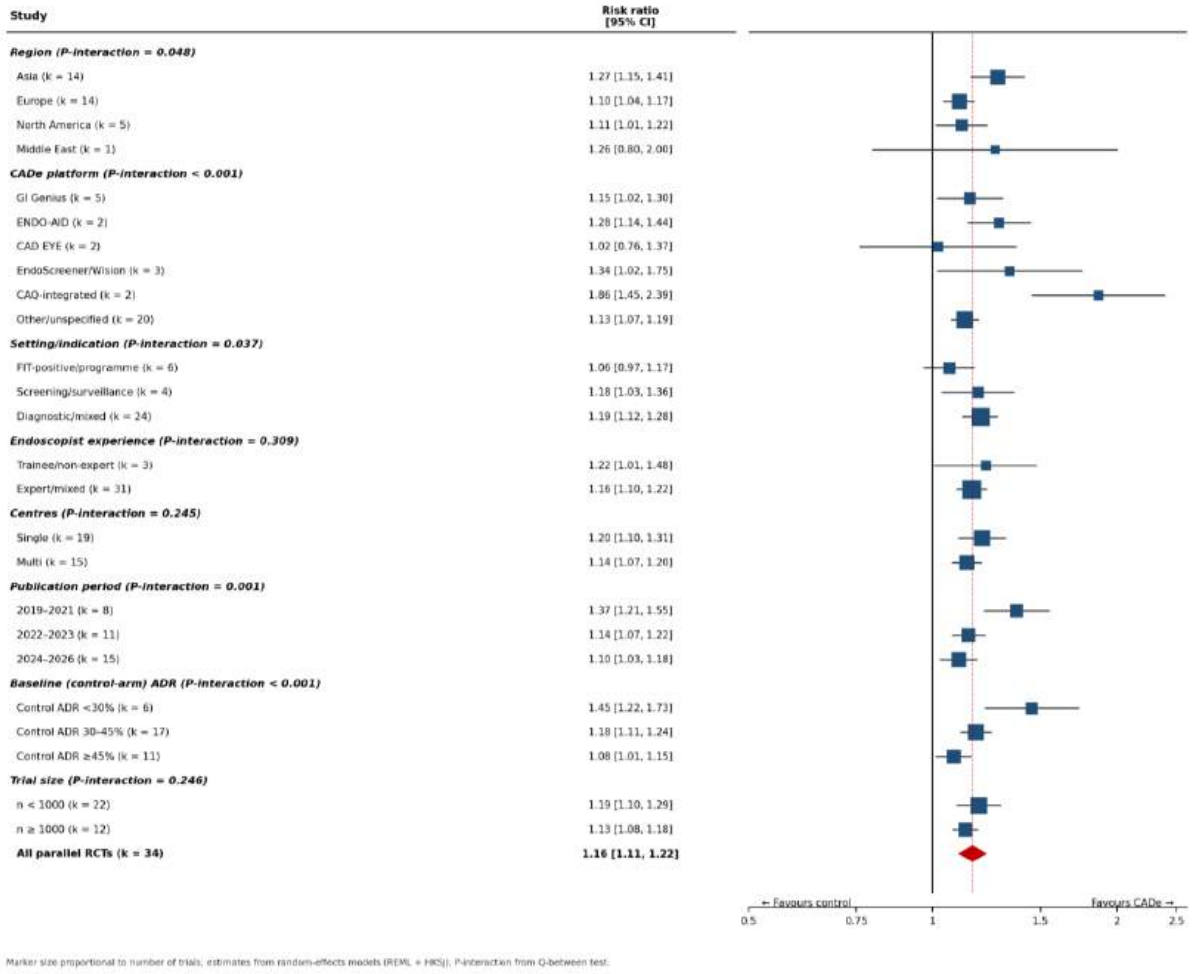


Figure 10 legend. Summary of pre-specified subgroup analyses for ADR. Marker size is proportional to the number of trials; P-interaction from the Q-between test.

Table 6. Subgroup analyses and meta-regression for the adenoma detection rate (parallel-group RCTs)

Subgroup / moderator	k	RR (95% CI)	I^2 / R^2	P

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Region — test for subgroup differences: Q = 7.91, df = 3, P = 0.048				
Asia	14	1.27 (1.15–1.41)	72%	P < 0.001
Europe	14	1.10 (1.04–1.17)	55%	P = 0.003
North America	5	1.11 (1.01–1.22)	11%	P = 0.035
Middle East	1	1.26 (0.80–2.00)	0%	P = 0.320
CADe platform — test for subgroup differences: Q = 23.49, df = 5, P < 0.001				
GI Genius	5	1.15 (1.02–1.30)	73%	P = 0.033
ENDO-AID	2	1.28 (1.14–1.44)	0%	P < 0.001
CAD EYE	2	1.02 (0.76–1.37)	88%	P = 0.901
EndoScreener/Wision	3	1.34 (1.02–1.75)	0%	P = 0.044
CAQ-integrated (ENDOANGEL, AQCS)	2	1.86 (1.45–2.39)	0%	P < 0.001
Other/unspecified	20	1.13 (1.07–1.19)	52%	P < 0.001
Setting / indication — test for subgroup differences: Q = 6.60, df = 2, P = 0.037				
FIT-positive/programme	6	1.06 (0.97–1.17)	56%	P = 0.156
Screening/surveillance	4	1.18 (1.03–1.36)	2%	P = 0.028
Diagnostic/mixed	24	1.19 (1.12–1.28)	64%	P < 0.001
Endoscopist experience — test for subgroup differences: Q = 1.04, df = 1, P = 0.309				
Trainee/non-expert	3	1.22 (1.01–1.48)	0%	P = 0.047
Expert/mixed	31	1.16 (1.10–1.22)	67%	P < 0.001
Number of centres — test for subgroup differences: Q = 1.35, df = 1, P = 0.245				
Single-centre	19	1.20 (1.10–1.31)	68%	P < 0.001
Multicentre	15	1.14 (1.07–1.20)	63%	P < 0.001
Publication period — test for subgroup differences: Q = 13.42, df = 2, P = 0.001				
2019–2021	8	1.37 (1.21–1.55)	33%	P < 0.001
2022–2023	11	1.14 (1.07–1.22)	57%	P < 0.001
2024–2026	15	1.10 (1.03–1.18)	64%	P = 0.010

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Baseline (control-arm) ADR — test for subgroup differences: Q = 16.96, df = 2, P < 0.001				
Control ADR <30%	6	1.45 (1.22–1.73)	30%	P = 0.003
Control ADR 30–45%	17	1.18 (1.11–1.24)	46%	P < 0.001
Control ADR ≥45%	11	1.08 (1.01–1.15)	60%	P = 0.024
Trial size — test for subgroup differences: Q = 1.35, df = 1, P = 0.246				
n < 1000	22	1.19 (1.10–1.29)	71%	P < 0.001
n ≥ 1000	12	1.13 (1.08–1.18)	48%	P < 0.001
Mixed-effects meta-regression (continuous moderators)				
Control-arm ADR (per 10 percentage points)	34	Ratio of RRs 0.935	R^2 = 67%	P < 0.001
Publication year (per year)	34	Ratio of RRs 0.963	R^2 = 30%	P < 0.001
$\log_{10}$ sample size (per 10-fold increase)	34	Ratio of RRs 0.968	R^2 = 2%	P = 0.691

CAQ, computer-aided quality assurance; RR, risk ratio. Subgroup estimates from REML random-effects models with HKSJ intervals (Wald-type intervals when k < 3).

Adenoma miss rate (tandem RCTs)

Four tandem RCTs (949 patients; 1,174 adenomas) contributed to the AMR analysis. The AMR was 16.7% (103/618) when CADe was used first and 34.0% (189/556) when standard colonoscopy was used first, a pooled RR of 0.49 (95% CI 0.32–0.75) (P = 0.013; I^2 = 27%), corresponding to an approximately 51% relative reduction in missed adenomas. Two additional tandem trials not amenable to pooling showed concordant reductions (13.8% vs 36.7% in a Japanese multicentre trial; 18.82% vs 43.69% among AI-assisted versus unassisted novices). Reductions were most marked for diminutive, non-polypoid and proximal lesions, and sessile serrated lesion miss rates were also lower in two trials.[38,84–88]

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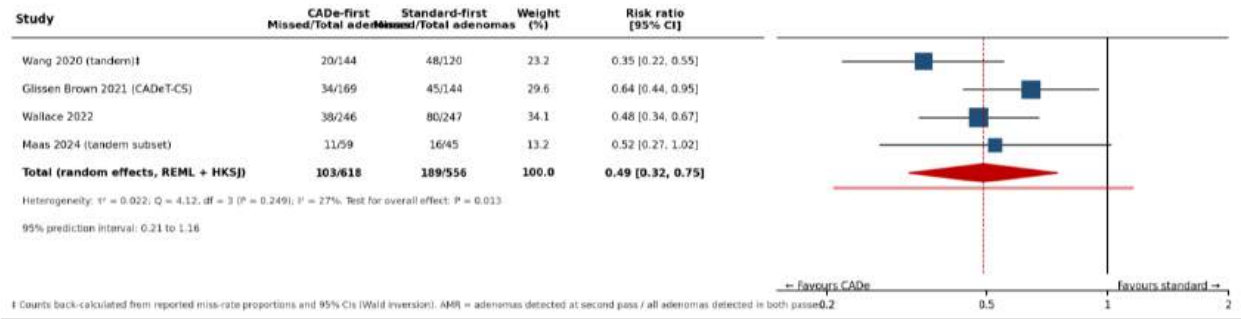


Figure 11 legend. AMR = adenomas detected at the second pass divided by all adenomas detected in both passes. RR < 1 favours CADe. ‡ Counts back-calculated from proportions and 95% CIs.

Polyp detection rate

In eight RCTs (4,378 participants), PDR was 68.3% with CADe versus 57.2% with standard colonoscopy (RR 1.21 (95% CI 1.08–1.35); P = 0.005), with considerable heterogeneity (I^2 = 76%; 95% PI 0.91–1.62) (Figure 13). The proportional increase in PDR exceeded that in ADR, consistent with additional detection of non-neoplastic (predominantly hyperplastic) polyps.[55,59,61,69,74,76,79,89]

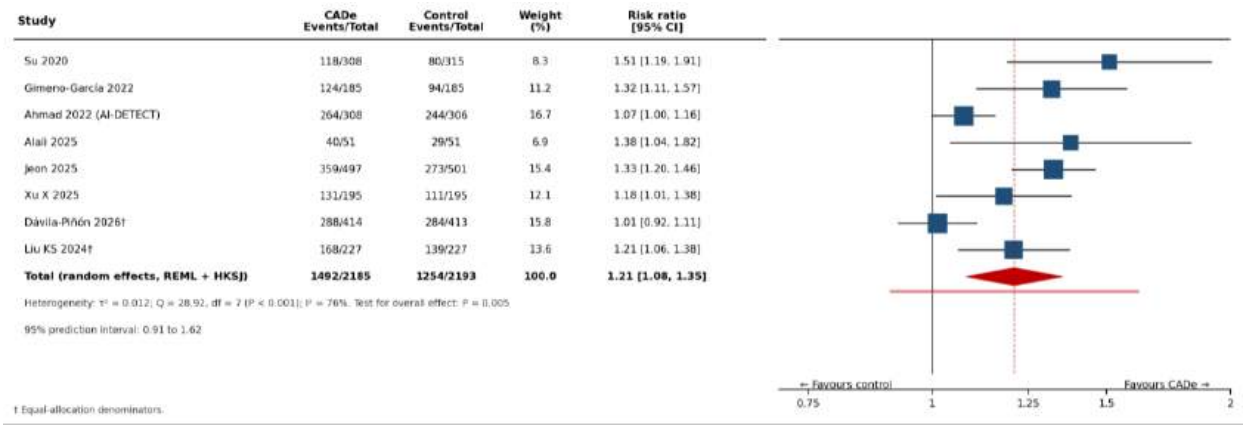


Figure 12 legend. Polyp detection rate, CADe vs standard colonoscopy. † Equal-allocation denominators.

Advanced adenoma and advanced colorectal neoplasia

Seven RCTs (9,891 participants), five of them in FIT-positive or organised screening populations, reported detection of advanced adenoma or advanced colorectal neoplasia. Detection rates were 20.9% with CADe and 19.9% without (RR 1.04 (95% CI 0.95–1.14); P = 0.359; I^2 = 0%), indicating no detectable benefit. The largest trial in this setting, powered for advanced

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neoplasia, found nearly identical detection rates (34.8% vs 34.6%) despite increased detection of non-polypoid, proximal and diminutive lesions.[60,62,64,67,79,82,83]

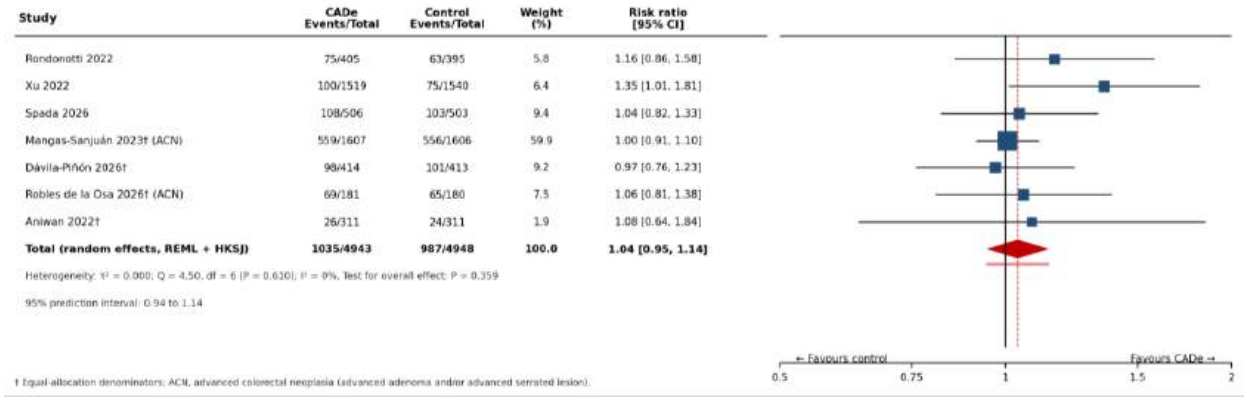


Figure 13 legend. Advanced adenoma or advanced colorectal neoplasia (ACN) detection rate. † Equal-allocation denominators.

Sessile serrated and serrated lesions

Four RCTs (2,936 participants) reported serrated lesion detection. The pooled estimate favoured CADe numerically (7.7% vs 5.3%; RR 1.48 (95% CI 0.80–2.73); P = 0.138; I^2 = 42%) but was imprecise. A prospective room-allocated cohort reported a significantly higher SSLDR with CADe (5.7% vs 2.5%), whereas a large community trial found identical serrated polyp detection rates (6.5% vs 6.3%).[20,71,73,79,92]

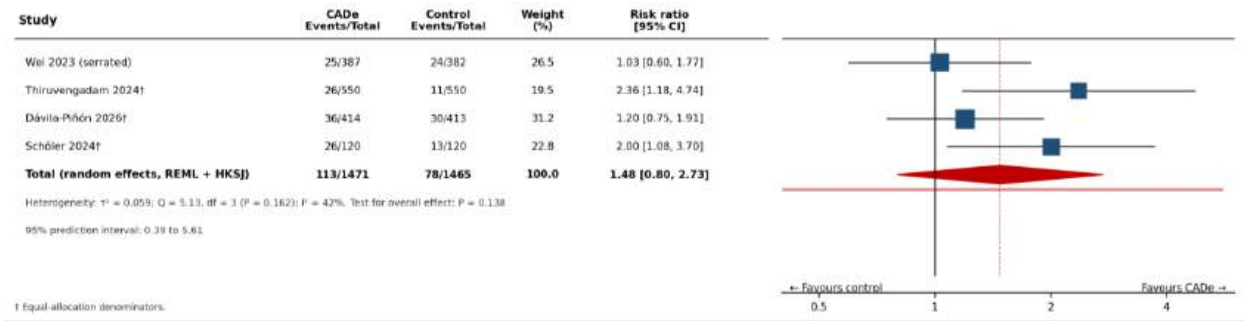


Figure 14 legend. Sessile serrated/serrated lesion detection rate. † Equal-allocation denominators.

Adenomas per colonoscopy

Seven RCTs (11,019 participants) reported APC with dispersion measures. CADe increased APC by 0.27 (95% CI 0.15–0.38) adenomas per colonoscopy (P = 0.001; I^2 = 58%; 95% PI 0.02–

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0.52). Trials reporting APC without dispersion showed consistent directions (e.g., 1.05 vs 0.83 and 0.70 vs 0.51 adenomas per colonoscopy), with the gain driven predominantly by adenomas of 5 mm or smaller; one Japanese community trial reported lower APC with CADe.[18,62–64,72,73,77,80,83,86]

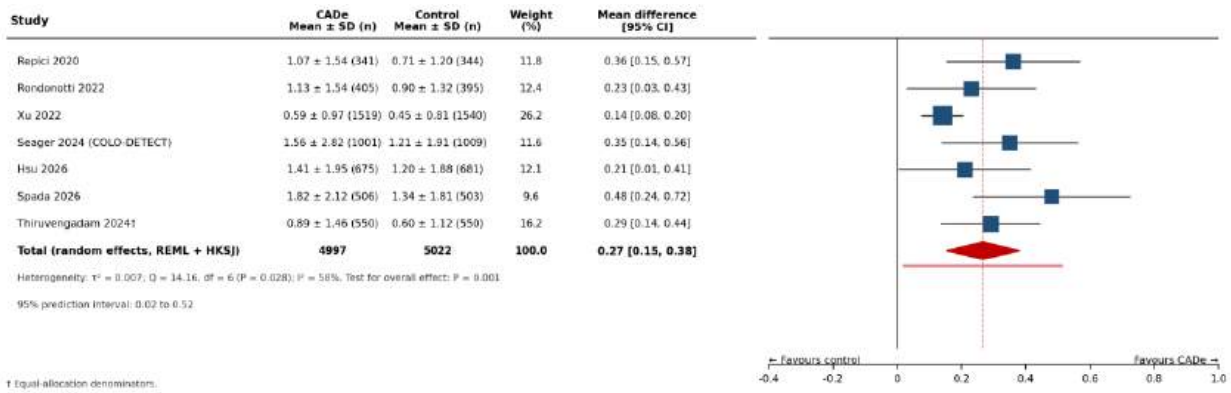


Figure 15 legend. Mean difference in adenomas per colonoscopy (APC); values > 0 favour CADe. † Equal-allocation denominators.

Non-randomised comparative studies

Nine non-randomised studies (38,007 colonoscopies) contributed to the real-world ADR analysis. The pooled OR was 1.20 (95% CI 0.98–1.46) (P = 0.071), with very high heterogeneity (I^2 = 84%) and a 95% PI of 0.70–2.04. Results ranged from a significant decrease in ADR after GI Genius introduction in a large Israeli centre and a non-significant decline in IBD surveillance, to significant increases in prospective room- or week-allocated designs, propensity-matched cohorts and a within-endoscopist comparison. Studies not pooled showed similarly divergent findings, including discretionary activation in only half of eligible procedures and a marked decline in unassisted ADR after CADe introduction.[21,92–102]

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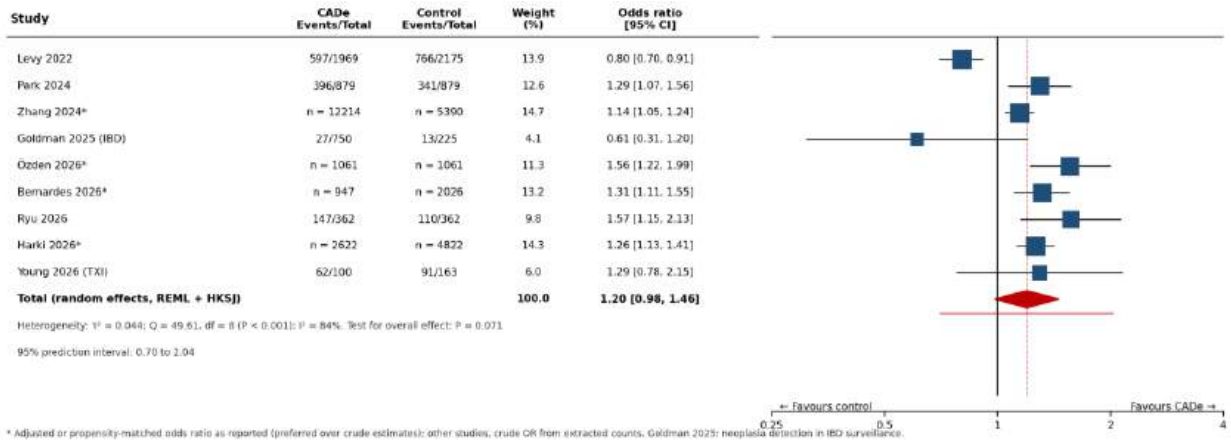


Figure 16 legend. ADR in non-randomised comparative studies (odds ratios). Adjusted or propensity-matched estimates were used where reported.

Meta-regression and baseline-risk relationship

In mixed-effects meta-regression, control-arm ADR was a strong inverse moderator of the CADe effect (slope -0.0068 log-RR per percentage point; $P < 0.001$), explaining 67% of between-trial variance: each 10-percentage-point higher baseline ADR reduced the RR by a factor of 0.935. The model-predicted RR was approximately 1.36 at a baseline ADR of 20%, 1.19 at 40% and 1.04 at 60%. Publication year was also inversely associated with effect size ($P < 0.001$; $R^2 = 30\%$), whereas sample size was not ($P = 0.691$). The L'Abbé plot shows convergence of CADe and control ADRs toward the line of no effect as baseline ADR increases.[19,53,55,67,77,82]

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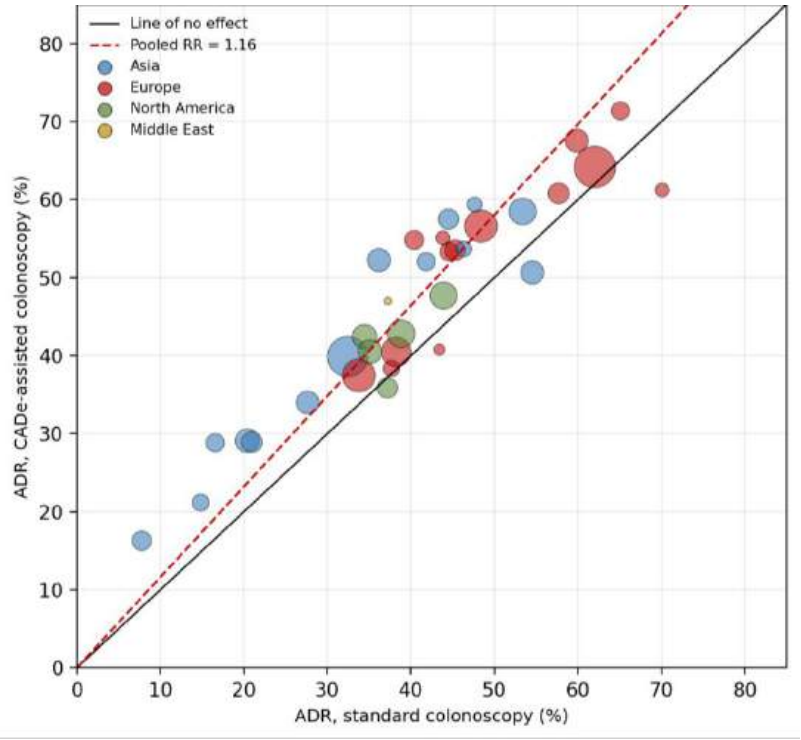


Figure 17 legend. L'Abbé plot. Each bubble represents one trial (area proportional to sample size); the solid line indicates no effect and the dashed line the pooled RR.

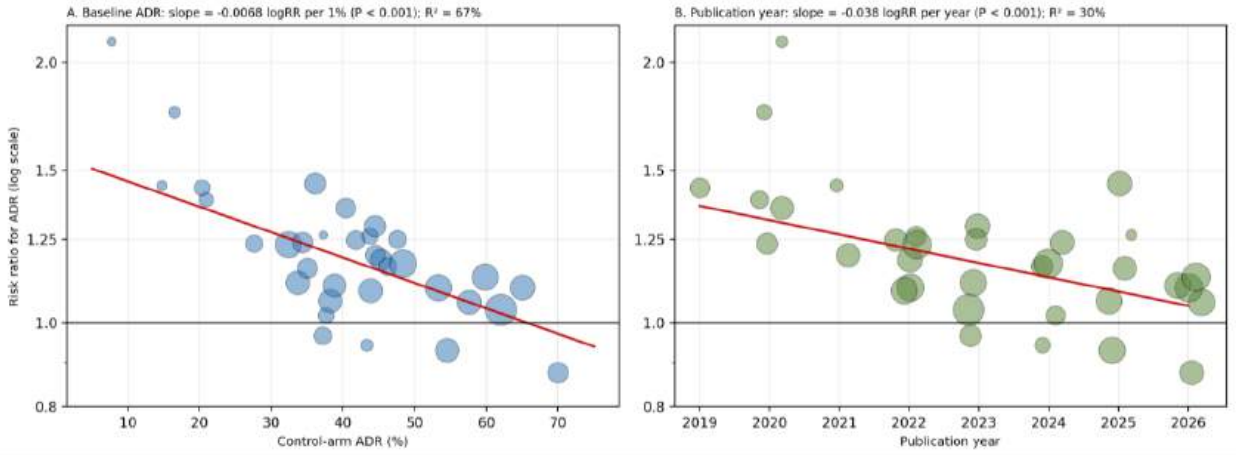


Figure 18 legend. Bubble plots of mixed-effects meta-regression of log RR for ADR on (A) control-arm ADR and (B) publication year; bubble size is proportional to inverse-variance weight and the red line shows the fitted regression.

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Sensitivity, influence and cumulative analyses

The primary result was robust across sensitivity analyses. Excluding the ten trials with equal-allocation imputation yielded RR 1.20 (95% CI 1.13–1.28); excluding high-risk-of-bias trials, CAQ-integrated systems or small trials altered the estimate by less than 0.02, whereas restricting to trials published from 2023 onwards attenuated it to RR 1.11. In leave-one-out analysis, the pooled RR ranged from 1.150 to 1.168, with no single trial driving the result. Cumulative meta-analysis showed that the effect estimate was largest when only early trials were available (RR 1.37 after the first eight trials, 2019–2021) and progressively declined and stabilised as larger pragmatic trials accrued.[43,47,56,67,72]

Table 7. Sensitivity, influence and small-study analyses for the adenoma detection rate

Analysis	k	RR (95% CI)	I^2
Primary analysis (REML + HKSJ)	34	1.16 (1.11–1.22)	66%
Excluding equal-allocation (imputed) trials	24	1.20 (1.13–1.28)	63%
Excluding CAQ-integrated systems (Gong 2020, Su 2020)	32	1.15 (1.10–1.20)	61%
Excluding high risk-of-bias trials	28	1.16 (1.10–1.21)	62%
Low overall risk of bias only (double-blind sham-controlled trial)	1	1.23 (1.02–1.49)	0%
Excluding trials with n < 300	32	1.16 (1.11–1.22)	67%
Trials published 2023–2026 only	20	1.11 (1.05–1.17)	64%
DerSimonian–Laird-type Wald CI (no HKSJ)	34	1.16 (1.11–1.21)	66%
Common-effect (inverse-variance) model	34	1.13 (1.10–1.15)	66%
ADR expressed as odds ratio	34	1.32 (1.22–1.43)	57%
Leave-one-out (range of pooled RR)	33	1.150 to 1.168	—
Trim-and-fill (8 imputed trials)	42	1.11 (1.05–1.18)	—

CAQ, computer-aided quality assurance; HKSJ, Hartung–Knapp–Sidik–Jonkman; REML, restricted maximum likelihood; RR, risk ratio. For the odds-ratio analysis the estimate shown is an OR.

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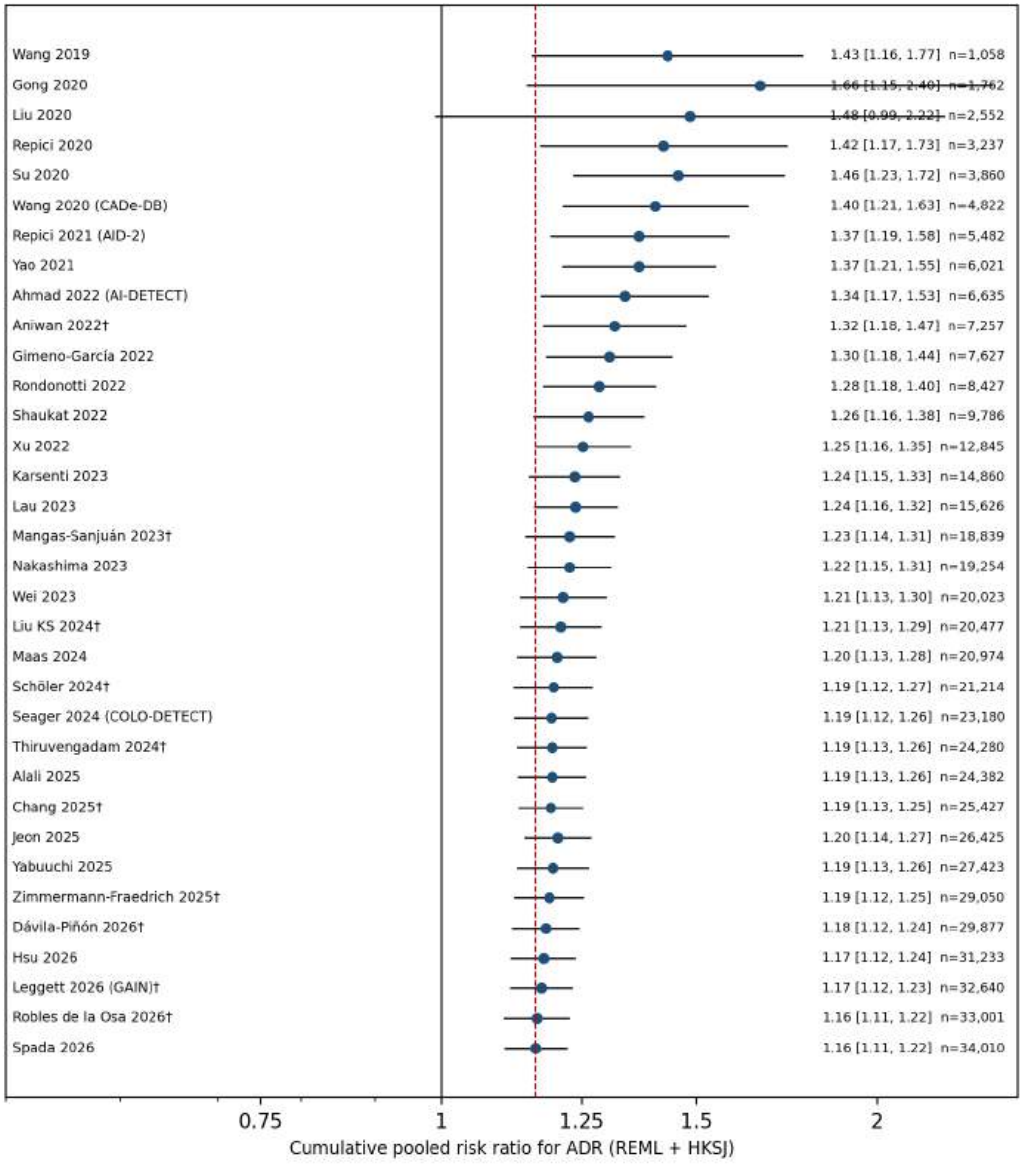


Figure 19 legend. Cumulative random-effects meta-analysis of ADR with trials added in order of publication year; n denotes cumulative participants.

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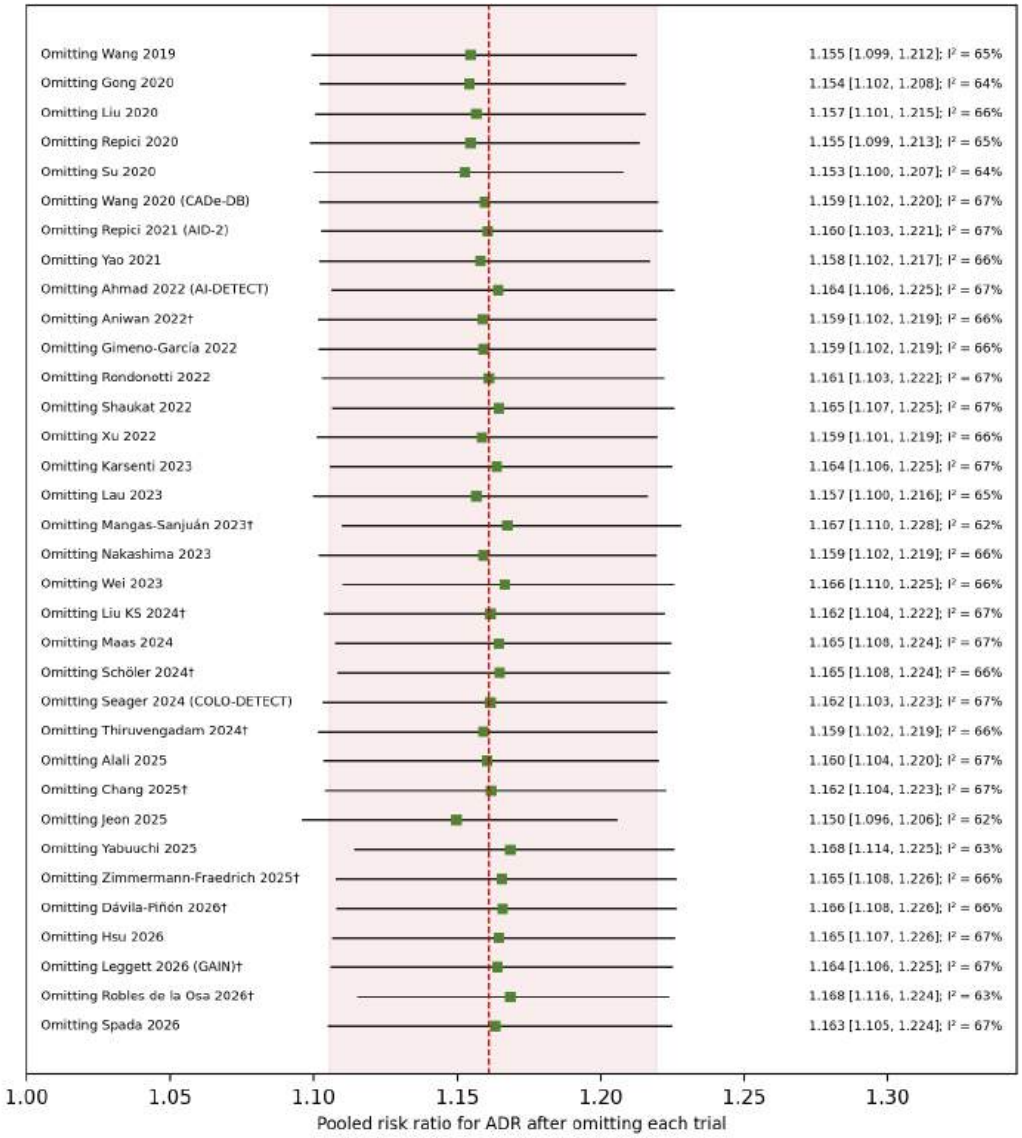


Figure 20 legend. Leave-one-out analysis; shaded band shows the 95% CI of the primary estimate (dashed line).

Small-study effects and publication bias

The contour-enhanced funnel plot for ADR was asymmetrical, with an excess of smaller trials reporting large effects in regions of statistical significance (Egger intercept 1.92, P = 0.004; Begg P = 0.022). Trim-and-fill imputed 8 trials on the left of the funnel, yielding an adjusted RR of 1.11 (95% CI 1.05–1.18), which remained favourable to CADe. Eight trials lay outside the ±2 band

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of the Galbraith plot, predominantly early single-centre Chinese trials with large effects and recent FIT-positive or high-ADR trials with null effects. No significant asymmetry was detected for PDR (Egger P = 0.079) or for the non-randomised ADR analysis (Egger P = 0.685).[19,49,53,55,67,77,82]

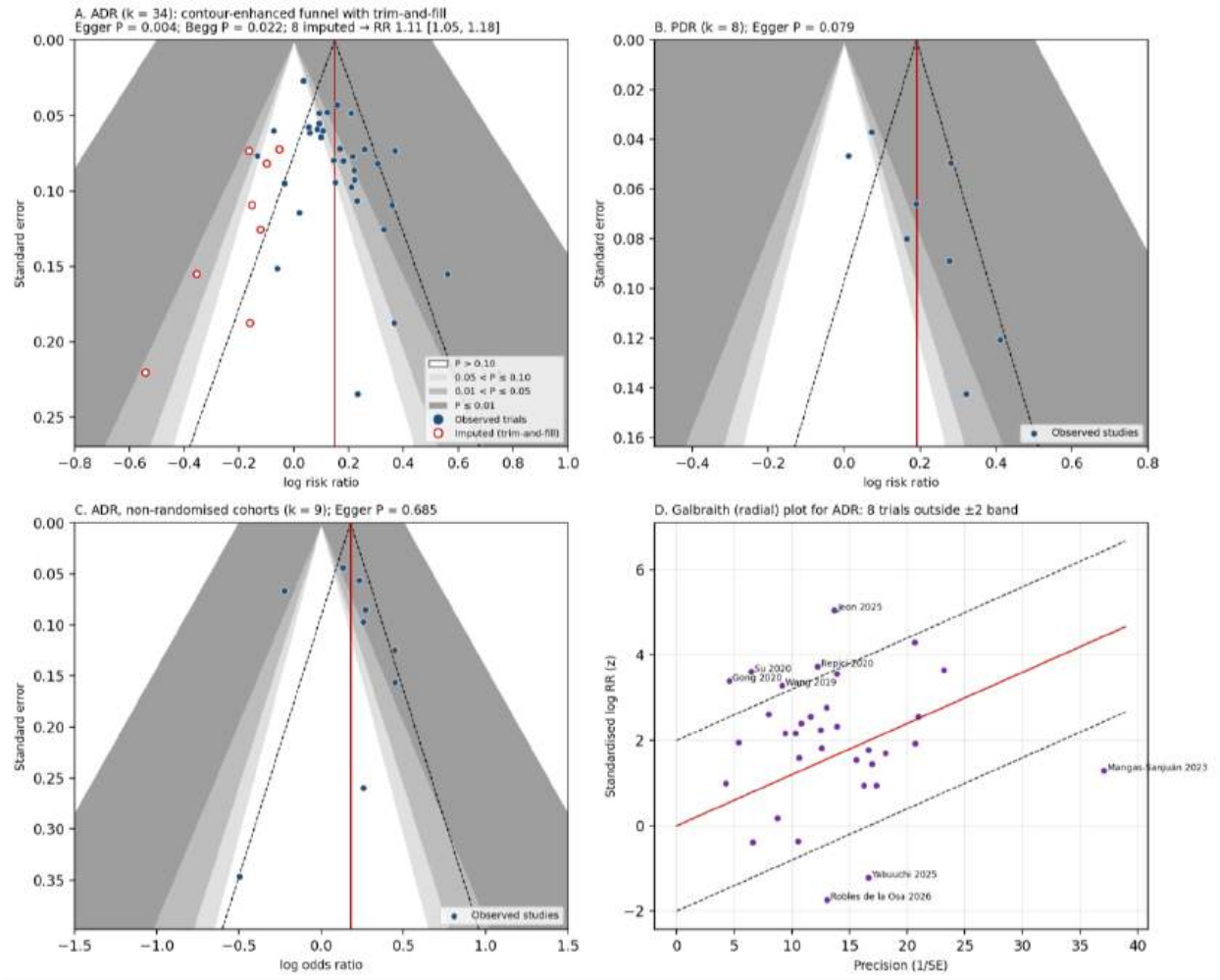


Figure 21 legend. (A) Contour-enhanced funnel plot for ADR with trim-and-fill (open red circles, imputed trials); shaded contours indicate conventional significance regions. (B) Funnel plot for PDR. (C) Funnel plot for ADR in non-randomised studies. (D) Galbraith radial plot for ADR.

Withdrawal time, non-neoplastic resection and safety

Reported mean withdrawal times were generally similar or modestly longer with CADe, with differences ranging from −0.3 to +1.35 minutes; the largest prolongation occurred with a

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quality-assurance-integrated system that actively regulated withdrawal speed (Figure 23). Increases in withdrawal time were largely confined to procedures in which additional polyps were found and resected. CADe increased detection or resection of non-neoplastic lesions in several trials (for example, non-adenomatous non-serrated polyps per colonoscopy 0.90 vs 0.51; non-neoplastic resection rate 52.1% vs 35.0% among trainees; hyperplastic polyps 114 vs 52), although others found no increase and one trial demonstrated non-inferiority of the true histology rate. No CADe-related adverse events were reported; in the largest pragmatic trial adverse events were similar between arms.[18–20,55,63–66,68,72,77,83]

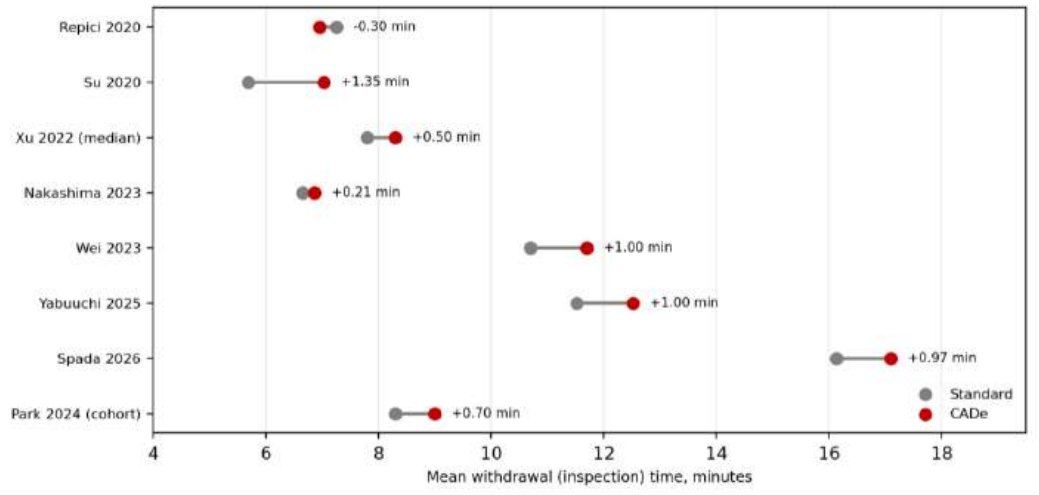


Figure 22 legend. Dumbbell plot of mean (or median, where indicated) withdrawal time with CADe (red) and standard colonoscopy (grey); labels show the CADe minus control difference.

Stand-alone performance in case series and validation series

Stand-alone CADe performance was high across validation series, with per-image or per-lesion sensitivities ranging from approximately 87% to 99.7% and specificities of 80–99% where reported. Performance was lower in unaltered full-length videos and for non-polypoid lesions than in curated still images. In the largest prospective in vivo series, in which blinded endoscopists were monitored by a second observer with access to CADe, the system was not superior to endoscopists for overall polyp detection (94.6% vs 96.0%), and unblinding added only 1.1% to the per-patient

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ADR, predominantly through lesions smaller than 5 mm, while prolonging procedure time.[14,17,103–108]

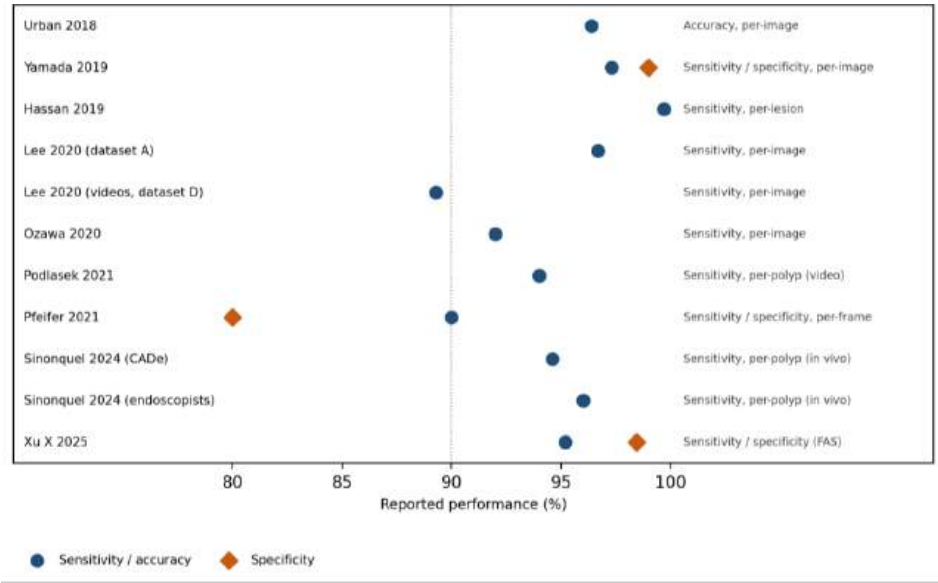


Figure 23 legend. Reported sensitivity/accuracy (circles) and specificity (diamonds) of CADe in clinical validation series; estimates were not pooled because of heterogeneous units of analysis (per image, per frame, per lesion, per patient).

Summary of pooled estimates, certainty of evidence and absolute effects

The certainty of evidence was moderate for the reduction in AMR and for the absence of an effect on advanced neoplasia, low for ADR, PDR, serrated lesions and APC (downgraded for risk of bias related to unmasked endoscopists and for inconsistency or imprecision), and very low for ADR in non-randomised studies. Applying the pooled RR to the pooled control-arm ADR of 41.4%, CADe would yield 67 additional adenoma-positive patients per 1,000 colonoscopies (95% CI 44–91; NNT ≈ 15). Because the relative effect declines with baseline performance, the meta-regression-predicted gain was 72 per 1,000 at a baseline ADR of 20% but only 24 per 1,000 at 60%, corresponding to NNTs of approximately 14 and 42, respectively.[24,25,40]

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Table 8. Summary of pooled estimates for all outcomes (random-effects REML with HKSJ confidence intervals)

Outcome	Studies (participants)	Pooled effect (95% CI)	95% PI	I^2 (τ^2)	P
ADR – parallel RCTs	34 (34,010)	RR 1.16 (1.11–1.22)	0.94–1.43	66% (0.010)	P < 0.001
AMR – tandem RCTs	4 (949 patients; 1,174 adenomas)	RR 0.49 (0.32–0.75)	0.21–1.16	27% (0.022)	P = 0.013
PDR – RCTs	8 (4,378)	RR 1.21 (1.08–1.35)	0.91–1.62	76% (0.012)	P = 0.005
AADR / ACN – RCTs	7 (9,891)	RR 1.04 (0.95–1.14)	0.94–1.14	0% (0.000)	P = 0.359
SSL / serrated – RCTs	4 (2,936)	RR 1.48 (0.80–2.73)	0.39–5.61	42% (0.059)	P = 0.138
APC – RCTs	7 (11,019)	MD 0.27 (0.15–0.38)	0.02–0.52	58% (0.007)	P = 0.001
ADR – non-randomised studies	9 (38,007)	OR 1.20 (0.98–1.46)	0.70–2.04	84% (0.044)	P = 0.071

AADR, advanced adenoma detection rate; ACN, advanced colorectal neoplasia; ADR, adenoma detection rate; AMR, adenoma miss rate; APC, adenomas per colonoscopy; MD, mean difference; OR, odds ratio; PDR, polyp detection rate; PI, prediction interval; RR, risk ratio; SSL, sessile serrated lesion.

Table 9. GRADE summary of findings: CADe-assisted versus standard colonoscopy

Outcome	Studies (participants)	Relative effect (95% CI)	Risk without CADe (per	Risk with CADe (per	Absolute difference per 1,000 (95% CI)	Certainty	Reasons for rating

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			1,000)	**1,000)**			
ADR	34 RCTs (34,010)	RR 1.16 (1.11–1.22)	414	481	67 more (44 more to 91 more)	⨁⨁◯◯ Low	Risk of bias (unmasked endoscopists, −1); inconsistency (I^2 66%, PI crosses 1, −1); small-study effects noted but adjusted estimate favourable
AMR (per 1,000 adenomas)	4 tandem RCTs (949)	RR 0.49 (0.32–0.75)	340	167	173 fewer (231 fewer to 85 fewer)	⨁⨁⨁◯ Moderate	Risk of bias (−1); consistent direction across trials
PDR	8 RCTs (4,378)	RR 1.21 (1.08–1.35)	572	692	120 more (47 more to 201 more)	⨁⨁◯◯ Low	Risk of bias (−1); inconsistency (I^2 76%, −1)
Advanced adenoma / ACN	7 RCTs (9,891)	RR 1.04 (0.95–1.14)	199	207	8 more (11 fewer to 27 more)	⨁⨁⨁◯ Moderate	Risk of bias (−1); probably little or no difference
SSL /	4 RCTs	RR 1.48	53	79	25 more (11	⨁⨁◯◯	Risk of bias

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serrated lesions	(2,936)	(0.80–2.73)			fewer to 92 more)	Low	(−1); imprecision (wide CI including null, −1)
APC	7 RCTs (11,019)	MD 0.27 (0.15–0.38)	—	—	0.27 more adenomas per colonoscopy	⨁⨁◯◯ Low	Risk of bias (−1); inconsistency (I^2 58%, −1)
ADR – real-world	9 cohorts (38,007)	OR 1.20 (0.98–1.46)	—	—	Uncertain	⨁◯◯◯ Very low	Serious risk of bias (confounding); serious inconsistency (I^2 84%); imprecision

Patient-important outcomes (colorectal cancer incidence, PCCRC and colorectal cancer mortality) were not reported by any included study. ACN, advanced colorectal neoplasia; ADR, adenoma detection rate; AMR, adenoma miss rate; APC, adenomas per colonoscopy; MD, mean difference; OR, odds ratio; PDR, polyp detection rate; RR, risk ratio; SSL, sessile serrated lesion.

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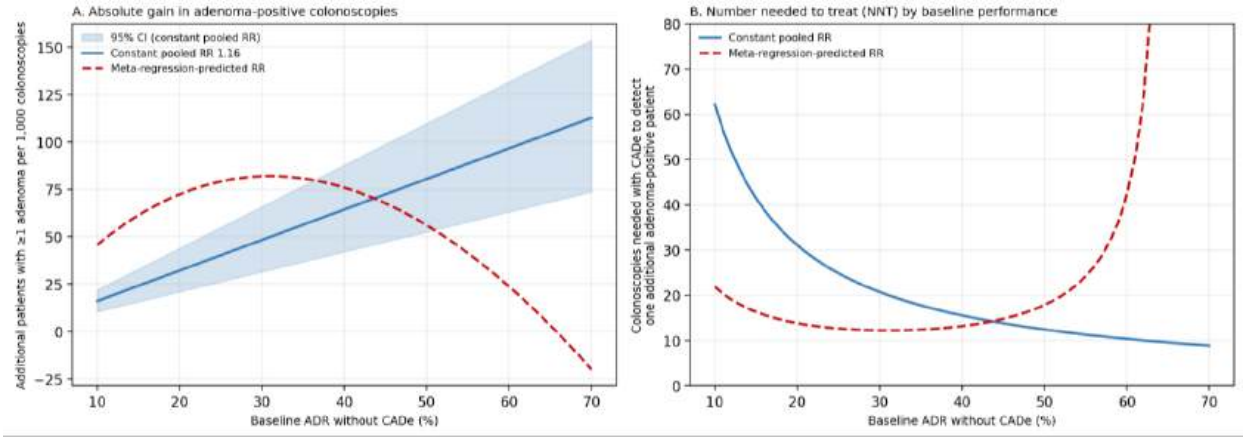


Figure 24 legend. (A) Additional adenoma-positive colonoscopies per 1,000 procedures and (B) number needed to treat across baseline ADR, assuming either a constant pooled RR (blue; shaded 95% CI) or the meta-regression-predicted RR (red dashed).

DISCUSSION

Principal findings

This comprehensive systematic review integrated 63 primary studies published over the last 15 years, comprising 34 parallel-group RCTs with 34,010 participants, six tandem RCTs, twelve real-world comparative studies and eight clinical validation series. Real-time AI-based CADe increased ADR by a relative 16% (absolute increase of approximately 6 percentage points), halved the adenoma miss rate, increased PDR and APC, and did not increase the detection of advanced adenomas or advanced colorectal neoplasia. The gain was concentrated in diminutive, non-polypoid and proximal adenomas, consistent with the design objective of CADe to reduce recognition errors for subtle lesions that appear transiently in the endoscopic field.[18,19,38,67,108]

Three further findings temper this overall benefit. First, the effect was strongly dependent on baseline performance: control-arm ADR explained approximately two-thirds of between-trial heterogeneity, and the relative gain fell from about 45% when baseline ADR was below 30% to about 8% when it was 45% or higher. Second, effect sizes declined with publication year and in FIT-positive programmes, and small-study effects were evident. Third, in non-randomised real-world cohorts the pooled effect was smaller, highly heterogeneous and not statistically significant,

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providing quantitative evidence of an efficacy–effectiveness gap between controlled trials and routine care.[21,67,77,82,109,110]

Comparison with previous systematic reviews and meta-analyses

Our pooled ADR estimate (RR 1.16) is lower than those of the first meta-analyses, which included five to ten predominantly early, single-centre trials and reported RRs of 1.43–1.52, and is slightly lower than those of more recent syntheses of 21–46 RCTs (RRs of 1.20–1.24). This progressive attenuation mirrors the cumulative meta-analysis in the present review and reflects the accrual of large pragmatic, community-based and FIT-positive trials with high baseline ADRs. Our AMR estimate (RR 0.49) closely matches previous estimates from tandem-trial syntheses (RR 0.45–0.53), indicating that the miss-rate effect is more stable than the ADR effect.[36,37,46,111–118]

Two meta-analyses of non-randomised studies previously reported pooled RRs of 1.11 (non-significant) and 1.13 (borderline), with no effect in the subgroup of GI Genius implementation studies; our larger, updated synthesis of nine cohorts yielded a comparable OR of 1.20 with a prediction interval spanning harm and substantial benefit. Network meta-analyses have suggested platform-specific differences, with ENDO-AID, ENDOANGEL and CAD EYE ranking above GI Genius; however, these rankings derive almost entirely from indirect comparisons in star-shaped networks, are confounded by geography and baseline ADR, and should not be over-interpreted. Our platform subgroup differences were likewise intertwined with region, era and baseline performance.[109,110,119–122]

Table 10. Comparison of the present findings with previously published systematic reviews and meta-analyses (discussion only; not part of the evidence base)

Review	Scope / design	Studies (participants)	ADR estimate	Other key findings
Hassan 2020[111]	MA of RCTs (to March 2020)	5 (4,354)	RR 1.44 (1.27–1.62)	APC RR 1.70; SSL per colonoscopy RR 1.52; advanced ADR NS

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Barua 2020[112]	SR/MA of RCTs	5	RR 1.52 (1.31–1.77)	PDR RR 1.48; no difference in advanced adenomas
Huang 2021[113]	MA of RCTs	10 (6,629)	RR 1.43	PDR RR 1.44; APC WMD 0.25
Hassan 2023[36]	SR/MA of RCTs with GRADE	21 (18,232)	RR 1.24 (1.16–1.33); low certainty	AMR RR 0.45; +0.18 non-neoplastic polypectomies per colonoscopy; WT +0.47 min
Lou 2023[114]	SR/MA of RCTs (HKSJ)	33 (27,404)	RR 1.24 (1.16–1.33)	AMR RR 0.50; APC IRR 1.39
Lee 2024[46]	SR/MA by trial design	24 (17,413)	RR 1.24 (1.17–1.31)	Tandem RR 1.18 vs parallel RR 1.26; larger effect in Asia
Makar 2024[115]	SR/MA of RCTs	28 (23,861)	RR 1.20 (1.14–1.27)	AMR RR 0.45; no SSL benefit; non-neoplastic resection RR 1.39
Soleymanjahi 2024[37]	SR/MA of RCTs	44 (36,201)	RR 1.21 (1.15–1.28)	ACN detection RR 1.16 but no difference in ACN per colonoscopy; WT +0.53 min
Maida 2024[117]	MA of tandem RCTs	6 (1,718)	—	AMR RR 0.46 (0.38–0.55); polyp miss rate RR 0.44

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Spadaccini 2025[122]	MA of FIT-positive RCTs	10 (5,421)	RR 1.19 (1.08–1.31)	No advanced adenoma benefit; more non-neoplastic resections
Bananzadeh 2026[116]	SR/MA of RCTs	46 (37,206)	RR 1.22 (1.17–1.27)	SSLDR RR 1.25; AMR RR 0.53
Shinozaki 2026[119]	Bayesian network MA	48 (38,986)	ENDO-AID RR 1.26; CAD EYE 1.18; GI Genius 1.15	Low-to-moderate certainty (CINeMA)
Patel 2023[109]	SR/MA of non-randomised studies	8 (9,782)	RR 1.11 (0.97–1.28)	Very low certainty; no increase in burden
Wei 2023[110]	SR/MA of real-world studies	12	RR 1.13 (1.01–1.28)	GI Genius subgroup RR 0.96
Present review	RCTs, cohorts and case series; 2011–2026	34 RCTs (34,010) for ADR; 63 studies overall	RR 1.16 (1.11–1.22)	AMR RR 0.49; AADR RR 1.04 (NS); cohorts OR 1.20 (NS); strong baseline-ADR modification

ACN, advanced colorectal neoplasia; ADR, adenoma detection rate; AMR, adenoma miss rate; APC, adenomas per colonoscopy; CINeMA, Confidence in Network Meta-Analysis; FIT, faecal immunochemical test; IRR, incidence rate ratio; MA, meta-analysis; NS, not significant; PDR, polyp detection rate; RR, risk ratio; SR, systematic review; SSL, sessile serrated lesion; WMD, weighted mean difference; WT, withdrawal time.

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Mechanistic interpretation

Missed adenomas result from failure to expose mucosa behind folds and flexures and from failure to recognise lesions that are displayed on screen. Detection-only CADe acts on the second mechanism; accordingly, its benefits in tandem trials were largest for diminutive and non-polypoid lesions and for lesions at the edge of the visual field, and stand-alone systems already approach the sensitivity of experienced endoscopists for overt polyps. The larger effects of systems that additionally monitored withdrawal speed, blind spots and inspection time suggest that addressing exposure errors, through computer-aided quality assurance or mucosal exposure devices, may yield complementary gains; trials combining CADe with Endocuff have shown incremental ADR increases, although a ceiling effect was observed when a balloon-based device was added in a high-ADR FIT-positive population.[34,35,38,53,55,56,58,60,69,108]

The efficacy–effectiveness gap

Several mechanisms may explain why randomised efficacy has not consistently translated into routine effectiveness. In open-label trials, endoscopists aware of being studied may improve their behaviour in both arms or preferentially in the CADe arm (observer or Hawthorne effects), and meta-epidemiological evidence shows that lack of blinding can exaggerate intervention effects. In routine practice, CADe may be activated selectively: it was used in only about half of eligible procedures in a US tertiary centre and in 57.5% of eligible colonoscopies in a concealed multicentre randomised trial in which the intention-to-treat effect was non-significant while procedures in which CADe was actually used showed a higher ADR. Before–after implementation cohorts are additionally susceptible to secular trends, changes in case-mix and staffing, and possible alterations in withdrawal behaviour.[21,47,48,50,93,101]

Conversely, the most rigorous designs available argue against a purely artefactual effect: the double-blind sham-controlled trial demonstrated a significant ADR increase, and prospective non-randomised designs that minimised selection bias, such as weekly alternation, random room allocation and within-endoscopist comparison, generally showed benefits of a magnitude similar to that observed in recent RCTs. Taken together, CADe appears to have a genuine but modest effect

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whose realisation in practice depends on consistent use, endoscopist engagement with alerts and the baseline quality of the service.[23,56,92,95,96]

Baseline performance, ceiling effects and clinical settings

The strong inverse relationship between control-arm ADR and the relative effect of CADe (approximately 7% smaller relative effect per 10-percentage-point higher baseline ADR) is clinically intuitive: when endoscopists already detect most adenomas, fewer missed lesions remain to be found. This pattern was seen in FIT-positive programmes, where ADRs commonly exceed 55–65% and CADe did not increase ADR or advanced neoplasia detection, and in high-performing Japanese and European community or tertiary settings. Importantly, epidemiological data suggest that the protective value of increasing ADR is greatest below approximately 26–34% and plateaus at higher levels, implying that the populations in which CADe yields the largest relative gains are also those in which ADR improvements are most likely to translate into cancer prevention.[7,12,26,67,70,77,79,82,83]

Endoscopists-in-training and non-experts derived consistent ADR benefits, and AI-assisted novices achieved adenoma miss rates non-inferior to those of experts in a tandem trial. These data support the use of CADe as a safety net during training and in low-volume or community settings, while acknowledging that the gains observed in trainees were not uniformly significant in pragmatic designs and that experience effects interact with baseline ADR.[20,57,66,73,75,88]

Clinical relevance: advanced neoplasia, serrated lesions and surveillance burden

The absence of an effect on advanced adenomas and advanced colorectal neoplasia is a central finding. Most PCCRC is thought to arise from missed or incompletely resected advanced or serrated lesions, whereas the additional lesions detected by CADe are predominantly diminutive adenomas with low short-term malignant potential. Low-risk adenomas confer little excess long-term cancer risk, yet their detection can shift patients into more intensive surveillance categories: in a Taiwanese trial CADe nearly doubled intensive surveillance assignments in FIT-positive patients, and in a prospective series additional detections changed surveillance intervals in 2.3% of patients. Physician SSLDR is independently associated with PCCRC, so the imprecise and inconsistent effect of CADe on serrated lesions represents an important gap.[10,11,13,67,80,108]

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These considerations underpin current guidance. The American Gastroenterological Association panel, drawing on microsimulation, estimated only 11 fewer colorectal cancers and 2 fewer colorectal cancer deaths per 10,000 individuals at the cost of 635 additional surveillance colonoscopies, and made no recommendation for or against CADe; the BMJ living guideline issued a weak recommendation against routine use, and recent commentaries have called for value-based, context-sensitive implementation. Our finding that benefits concentrate in lower-performing settings supports a targeted rather than universal deployment strategy.[23–26]

Human–AI interaction and deskilling

Continuous exposure to CADe may alter endoscopist behaviour. In a multicentre observational study, the ADR of unassisted colonoscopies fell from 28.4% to 22.4% within three months of CADe introduction, and a Japanese single-centre study reported a marked decline in ADR for non-CADe procedures after partial room equipment. Other studies, however, found no deskilling: a three-year propensity-matched study observed maintained or accelerated learning curves in unassisted procedures, particularly among high detectors, and a pragmatic three-phase trial showed transient improvement in polyp detection among inexperienced endoscopists during CADe use without deskilling after removal. These conflicting data likely reflect different phases of human–AI adaptation, cognitive offloading and automation bias, and highlight the need to monitor unassisted performance as part of quality assurance.[22,23,51,52,100]

Harms, workload and resource implications

CADe modestly prolonged withdrawal time and increased the detection and resection of non-neoplastic, predominantly hyperplastic, polyps in several trials, with attendant pathology costs and a small incremental procedural risk; previous meta-analyses quantified this as approximately 0.18 extra non-neoplastic polypectomies per colonoscopy and a 39% relative increase in non-neoplastic resections. False-positive alerts, distraction and perceived prolongation of procedures were the main concerns voiced by endoscopy staff. Integration of detection with computer-aided characterisation (CADx), allowing diminutive rectosigmoid hyperplastic polyps to be left in situ, may mitigate these harms, and recent trials have reported acceptable optical diagnostic accuracy and improved specificity with CADx. Economic models generally favour CADe but are highly sensitive

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to the assumed ADR gain, which our data suggest may be smaller in routine practice than in early trials.[20,23,36,82,95,101,115]

Implications for practice and for resource-limited settings

For clinical services, the evidence supports CADe as a quality-improvement adjunct rather than a substitute for meticulous technique. Priority deployment may be justified for endoscopists or units with ADR below recommended benchmarks, for training programmes and for diagnostic or mixed-indication lists, whereas incremental benefit in high-performing FIT-positive programmes appears limited. Implementation should be accompanied by audit of ADR, APC, SSLDR, non-neoplastic resection rate and unassisted ADR, by protocols encouraging consistent activation, and by attention to alert fatigue and monitor ergonomics. In transitioning health systems, including those in Southeast Asia where colorectal cancer incidence is rising and endoscopist training capacity is uneven, CADe could help standardise detection quality, but procurement decisions should weigh cost against local baseline ADR, bowel preparation quality and the capacity to absorb increased surveillance demand.[1,3,24,27,66,93]

Implications for research

Future research should prioritise (i) concealed, cluster-randomised or stepped-wedge pragmatic trials that minimise observer effects; (ii) patient-important outcomes, including PCCRC incidence, colorectal cancer mortality and surveillance burden, through long-term follow-up and registry linkage; (iii) head-to-head comparisons of CADe platforms and of CADe combined with quality-assurance modules, mucosal exposure devices and CADx; (iv) dedicated evaluation of advanced and serrated lesions and of specific populations such as inflammatory bowel disease and hereditary syndromes; (v) human-factors research on alert design, fatigue and skill retention; and (vi) standardised reporting of CADe use rates, false-alert rates and arm-level data to facilitate evidence synthesis.[15,50,51,94,119,120]

Strengths

Strengths of this review include its comprehensive scope, integrating randomised, real-world and validation evidence within a single framework; restriction to the last 15 years with inclusion of trials published up to October 2026; use of REML estimation with HKSJ intervals and prediction

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intervals; extensive pre-specified subgroup, meta-regression, sensitivity, influence and small-study analyses; formal risk-of-bias assessment with design-specific tools; and GRADE-based translation into absolute effects. All references are linked to persistent records for verification.[29,30,40,43,44]

CONCLUSIONS

Real-time AI-based computer-aided detection increases adenoma detection during colonoscopy (RR 1.16) and roughly halves the adenoma miss rate, predominantly through the detection of diminutive, non-advanced adenomas, without improving the detection of advanced neoplasia. The magnitude of benefit is strongly dependent on baseline endoscopist performance and is attenuated in high-performing, FIT-positive and real-world settings, with low to very low certainty for most detection outcomes and no direct evidence on cancer incidence or mortality. CADe should be implemented as a targeted, audited adjunct to high-quality colonoscopy, particularly for lower-performing endoscopists and training environments, while rigorously designed pragmatic trials with patient-important outcomes and monitoring of human–AI interaction effects are awaited.[4,22,24,25]

DECLARATIONS

Ethics approval and consent to participate	Not applicable. This study is a synthesis of previously published aggregate data and involved no new collection of identifiable human data.
Consent for publication	Not applicable.
Availability of data and materials	All data supporting the findings are contained within the article and its tables. The extraction dataset and the analysis scripts, including the independently implemented random-effects, trim-and-fill, meta-regression and bivariate accuracy routines, are available from the corresponding author on reasonable request.
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Author contributions	The sole author was responsible for conceptualisation, protocol development, search strategy design, study selection, data extraction, risk-of-bias appraisal, statistical analysis, figure generation, drafting and critical revision of the manuscript, and approved the final version for submission.
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