CT Colonography (virtual colonoscopy): A systematic review of commercially available systems for computer-assisted-detection (CAD) for colorectal polyps and cancer.

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Executive Summary.

This review has been performed using the principles of evidence-based medicine and systematic review in order to search the available medical literature in an all-inclusive and unbiased fashion. The aim was to determine the volume and quality of medical research available for commercially available systems of Computer-Assisted-Detection (CAD) for CT Colonography. Commercially available algorithms were identified from 4 independent vendors and 3 CT scanner manufacturers.

The most exacting standard for medical research is peer-reviewed full papers published in indexed medical journals. Thirty-one papers were identified over the search period (to September 2008) that could be linked to commercially available products, and a breakdown is provided in this document. The largest contribution was from Medicsight PLC who supported 14 papers – 45% of the total overall and 88% of those submissions from independent companies.

Although they are not as rigorous as full peer-reviewed papers, this review also included peer-reviewed abstracts of research findings presented at key medical meetings dealing with CT Colonography. Fifty-nine abstracts were identified over the search period and Medicsight PLC was again the largest single contributor with 24 abstracts identified (41% of overall total and 67% of the abstracts were supported by independent companies).

Only two companies sponsored papers that used a genuine external validation to test the performance characteristics of their CAD software. Using this methodology, Medicsight CAD had the highest sensitivity for polyps >/= 6mm; 96%.

Ten of the papers identified directly examined the impact of CAD on the decision-making of those observers interpreting the data. Six of these (60%) were supported by Medicsight PLC, who also provided the largest study (10 readers; 107 datasets; 2140 patient interpretations), which found that CAD significantly improved reader sensitivity without a corresponding detrimental effect on specificity.

Contents.

1.0 Introduction.

CT Colonography is a relatively novel health technology that is used to examine the large bowel. Specifically, it combines helical CT scanning of the cleansed and distended colorectum with complex image rendering techniques that simulate the view obtained at conventional endoscopy, hence the alternative term 'virtual colonoscopy'.[2] Some comparisons with colonoscopy have suggested equivalent sensitivity and specificity when CT Colonography is used to detect adenomatous polyps and invasive cancer in both symptomatic patients,[2-4] and asymptomatic screenees.[5-7] However, other studies have found it less effective.[8,9] Competent interpretation of CT Colonography requires considerable skill and training, and observer inexperience has been cited as a major factor when results have been poor. Additionally, reader fatigue has as also been implicated. For example, it has been estimated that over 13,000 individual images must be interpreted to identify a single 1cm polyp.[10]

Computer-aided detection (CAD) has proved effective in situations where radiologists must detect small lesions that occur infrequently, for example during screening mammography[11] and when looking for pulmonary nodules.[12] Researchers working in academic institutions have also shown that CAD may also be effective for CT Colonography[13-15] and a recent large study of 1186 screening patients found that CAD detected colonic adenomas at 8mm and 10mm diameter thresholds with an efficacy not significantly different from colonoscopy.[16] It is therefore hoped that CAD can both increase sensitivity for colorectal polyps and cancers while simultaneously reducing observer fatigue.

Until relatively recently, assessment of CAD systems for CT Colonography has been restricted to those academic centres who have developed their own software. However, the recent advent of commercially available systems means that this technology is now available to purchasers and consequently potential users are faced with a choice of systems.
The purpose of this document is to compare the systems that are commercially available at the time of writing (October 2008).

2.0 Critical appraisal of CAD systems for CT Colonography.

Potential purchasers of CAD systems will be most interested in the sensitivity and specificity of the software. These are, respectively, the degree to which the software correctly identifies patients with disease (i.e. colorectal polyps) and the degree to which it correctly rejects patients who do not have disease. It should be noted that CAD systems must first be trained or developed to recognise the abnormality being sought for, in this case colorectal polyps. This is often achieved by exposing the software to clinical cases with proven polyps (during the 'development' or 'training' phase of the software). The performance of the software is then tested subsequently in order to determine its sensitivity and specificity for polyp detection.

However, clinical data is an expensive and scarce commodity, not least because most patients undergoing CT Colonography will be normal (i.e. they will not have any polyps and so cannot contribute to development data). Because of this, it is common for systems to be trained and then tested on the same data, an experimental paradigm known as internal cross-validation.[17,18] However, testing CAD software using data with which it has been trained does not pose a stringent challenge – the software is already familiar with the data. Instead, a more realistic estimate of software capability is obtained when it is tested using data that it has not encountered before. One way of achieving this is to randomize cases to either development or testing sets. However, while usually desirable, randomization in this particular context is unhelpful because randomization aims to minimize differences between groups.[17,18] It therefore follows that the development and test sets will be very similar bar chance variation – the result is that the software avoids a rigorous challenge. The most stringent test of a CAD system is to test it using clinical data obtained from a source completely separated from those used to provide data for software development, an experimental paradigm known as 'external' validation. This paradigm best simulates the ultimate market for CAD since the software will be purchased and used by hospitals and scanning centres who have not contributed clinical data for software development. Unfortunately, the precise experimental methodology used to obtain the estimates of CAD performance quoted in peer-reviewed articles is often obscure, with the result that sensible and informed assessment of algorithm performance cannot be made.[1]

Systematic review is the most exacting and unbiased method with which to assess published research in a field of medicine.[19] At the time of writing there has been only one systematic review of CAD for CT Colonography, performed by the author.[1] The systematic review described data published from to 2001 to 2005 inclusive, and the results are interesting because they reveal the relatively poor standard of data presentation for CAD studies of CT Colonography, even amongst the recent peer-reviewed medical literature: Twenty-three studies were identified that described CAD for the detection of polyps in human subjects, which met the entry criteria for the systematic review.[1] While 21 (91%) studies provided a technical description of how the software worked (which is largely irrelevant from a users perspective), only 11 (48%) made a clear distinction between CAD training and testing data. Of these, 9 studies used internal cross-validation (which is likely to result in an over-optimistic assessment of CAD performance for the reasons described above). Only two studies stated explicitly that the data used for training and testing was different, but in both cases splitting had been obtained by randomization. Furthermore, the precise experimental method used to establish a gold-standard against which the CAD output could be judged was described by only 12 (52%) studies.[1] It is also worth noting that only 2 studies incorporated human observers; One made an indirect assessment of the effect of CAD prompting by comparison with responses from unaided observers, while the other assessed the effect of CAD on decision making directly, albeit using a 'first-reader' reporting paradigm which is very unlikely to gain approval from the FDA. The authors concluded that the standard of data reporting was poor for studies of CAD applied to CT Colonography, and they proposed a minimum dataset for future studies.[1] The lack of external validation was singled out for particular criticism.

This is a fast moving area of research and it should be noted that the current review includes data presented up to September 2008: Consequently it includes studies that examine the effect of CAD on observer decision-making for commercially available systems, and studies that have used genuine external validation for assessment of the performance of commercially available systems. It is particularly important that the effect of CAD on human decision-making is estimated directly because ultimately a human observer issues the clinical report, not the CAD system. Many researchers have attempted to estimate the potential incremental benefit of CAD assistance by comparing the performance of an isolated stand-alone CAD system with those from unassisted observers. However, these 'indirect' assessments will inevitably overestimate the magnitude of benefit ascribable to CAD because there is no guarantee that human observers will correctly interpret the CAD output. In particular, it is possible that observers may fail to classify CAD true-positive prompts as such, instead choosing to misclassify them as false-positives. For example, a recent study of 10 observers asked to interpret a dataset of 107 cases without and with CAD found that although CAD correctly identified 17 of 19 polyps measuring 10mm or larger, overall only 10 of these were correctly recognised as true-positive prompts by readers.[20]

The need for direct assessment of the effects of CAD on observer decision making has been stressed[21] and others have noted the need for more detailed data presentation by researchers, particularly the origin of data used to train and test the software.[1,22] Supporting this observation, the systematic review described in sections above found that the composition of the CAD validation dataset was described sufficiently well so that it could be reasonably replicated by other researchers in only 6 (26%) of the eligible studies.[1] For example, researchers frequently fail to state the data origin, age and sex demographics, whether patients are symptomatic or not, and whether the data contains normal patients or not.

3.0 Commercially available CAD systems.

At the time of writing (September 2008) the following CAD algorithms for CT Colonography are known to be commercially available from independent, stand-alone companies (i.e. as opposed to those companies that supply a vendor specific CT workstation).

Medicsight PLC.

Product: ColonCAD™ API
Medicsight PLC. Kensington Centre, 66 Hammersmith Road, London, W14 8U.

iCAD.

Product: CT Colon
iCAD, Inc. 98 Spit Brook Road, Suite 100, Nashua, NH 03062, USA.

Median Technologies.

Product: LMS-colon.
Median Technologies, Les 2 Arcs B, 1800 Route des Crêtes, 06560 Valbonne Sophia Antipolis, France.

iM3D.

Product: Colon CAD.
iM3D SpA - Medical Imaging Lab. Via Lessolo 3, 10153, Torino, Italy.

CAD for CT Colonography is also now available from some of the major international vendors of multi-detector row CT scanning machines. Although the use of such software is usually limited to the vendor-specific workstations, these algorithms were included in the present review in the spirit of full data presentation. Products identified were:

1. GE – Colon VCAR.

2. Siemens – Syngo Colonography PEV.

3. Philips – Colon CAR.

4.0 Methodology and data sources for this review.

All manufacturers will likely make ambitious claims for their products, perhaps with over-optimistic assessments of their capabilities and stating them to be the best in the marketplace. As a result, comparisons based on manufacturers' claims are unlikely to be helpful for potential purchasers.

In contrast, the peer-reviewed, indexed medical literature demands a minimum level of scientific rigour and commercial pressures do not influence publication. The medical literature can also be searched objectively and thoroughly via easily-accessible electronic databases. Similarly (but to a less rigorous extent), contents of the proceedings of well-respected medical scientific meetings will also demonstrate the level of research activity in a given field of medicine.

4.1 Aim of the review.

This document aims to describe available data from the peer-reviewed medical literature and conference proceedings for commercially available CAD systems for CT Colonography as of September 2008.

4.2 Data sources and search terms.

4.2.1: Peer-reviewed full papers.

The following electronic databases were searched the period 2002 to September 2008:

- MEDLINE database via the National Institutes of Health PUBMED portal.
- ISI Web-of-Science via the MIMAS portal.

The search terms used were:

- "CT Colonography" AND:
  - "CAD"
  - "computer"
  - "computer AND assist"
  - "computer AND aided"
  - "computer AND diagnosis"

The search was performed September 2008 by Prof. Steve Halligan.

Any article detailing the use of a commercially available CAD algorithm in the Methodology section of the article was included in the review (see section below).

4.2.2: Abstracts of conference proceedings.

Abstracts of the following conferences were searched in hard copy and online where available (see Section 5.2):

- Radiological Society of North America (RSNA) 2005, 2006, 2007.
- European Congress of Radiology (ECR) 2006, 2007, 2008.
- European Society of Gastrointestinal Radiology (ESGAR) 2006, 2007, 2008.

4.3 Data extraction and synthesis.

4.3.1 Peer-reviewed papers.

Abstracts of those papers arising from the above search were retrieved on-line by Prof. Steve Halligan and read in order to identify those whose subject appeared to be computer-assisted detection for CT Colonography. When this was the case, the PDF file of the full paper was retrieved electronically and read in order to identify if a commercial origin for the CAD software was described. Additionally, author affiliations were also interrogated in order to identify commercial support; e.g. where an author affiliation to a commercial company was declared (e.g. an employee), a link with that company could be inferred and the article was thus included in the review. If no direct evidence of a commercial sponsor or link could be made from the original article, whether explicitly stated or inferred, then the article was excluded. If eligible, the full paper was then read and a synopsis of its content prepared for this review.

4.3.2 Abstracts of conference proceedings.

Conference proceedings were scrutinised using the book of abstracts from the relevant conference. Where no such book had been provided by the congress (e.g. ESGAR 2008), the on-line supplement of the relevant journal that contained the abstracts was examined. Where detailed in print and/or on-line, author affiliations were again examined for evidence of commercial support using the process described in section 4.3.1.

For both searches, eligible topics were restricted to those that described computer-assisted-detection of polyps and/or cancers by CAD software, or those that described automatic determination of polyp diameter and/or volume by CAD. Narrative reviews were excluded as were articles not written in the English language.

5.0 Research identified by the review:

5.1 Full publications in peer-reviewed indexed medical journals:

Full publications in peer-reviewed indexed medical journals identified by this review are presented below, split by Company. Below each paper is a synopsis of key findings made by Prof. Steve Halligan. The full abstract for each individual citation is detailed in Appendix 1.

5.1.1: Independent CAD companies:

A: Medicsight PLC

1. Burling D, Halligan S, Roddie ME, McQuillan J, Honeyfield L, Amin H, Dehmeshki J, Taylor SA, McFarland EG. Computed Tomography Colonography: automated diameter and volume measurement of colonic polyps compared with a manual technique—in vitro study. Journal of Computed Assisted Tomography 2005;29:387-93.

   • *The Medicsight CAD can determine the diameter and volume of polyps detected by it. The authors found that using this feature resulted in superior inter- and intraobserver agreement when compared to conventional manual measurements made by a human observer.*

2. Halligan S, Taylor SA, Dehmeshki J, Amin H, Ye X, Tsang J, Roddie ME. Computer-assisted detection for CT Colonography: external validation. Clinical Radiology 2006;61:758-63; with *Directed Editorial* 764-5.

   • *This appears to be the first study in the CT Colonography literature that recognises the problems of validation paradigms and attempts to address them via external validation. Detection characteristics for CAD were excellent when tested thus, achieving a per-patient sensitivity of 96% for polyps measuring 6mm or greater.*

3. Taylor SA, Halligan S, Burling D, Roddie ME, Honeyfield L, McQuillan J, Amin H, Dehmeshki J. Computer-assisted reader software versus expert reviewers for polyp detection on CT Colonography. American Journal of Roentgenology 2006;186:696-702.

   • *The detection characteristics of the CAD system tested were superior to that of three experienced readers with which it was compared. CAD detected 81% of all polyps and 92% of polyps measuring 10mm or larger, whereas experienced reviewers averaged 70%.*

4. Taylor SA, Halligan S, Slater A, Goh V, Burling DN, Roddie ME, Honeyfield L, McQuillan J, Amin H, Dehmeshki J. Polyp detection with CT Colonography: primary 3D endoluminal analysis versus primary 2D transverse analysis with computer-assisted reader software. Radiology 2006;239:759-67.

   • *The authors found that the CAD system tested was significantly more time-efficient than a conventional 3D read (widely regarded to be the optimal viewing paradigm since Pickhardt's study [5]), while remaining equally sensitive for polyps.*

5. Halligan S, Altman DG, Mallett S, Taylor SA, Burling D, Roddie M, Honeyfield L, McQuillan J, Amin H, Dehmeshki J. Computed Tomographic Colonography: assessment of radiologist performance with and without computer-aided detection. Gastroenterology 2006;131:1690-9.

   • *10 readers interpreted 107 CT Colonography studies with and without CAD (in a concurrent paradigm). CAD significantly increased reader sensitivity while not impacting significantly on specificity. On average 12 more polyps were detected by each reader when using CAD. Furthermore, reading time was significantly shorter when using CAD (by 1.9 minutes for patients with polyps and by 2.9 minutes for patients without).*

6. Dehmeshki J, Halligan S, Taylor SA, Roddie ME, McQuillan J, Honeyfield L, Amin H. Computer assisted detection software for CT Colonography: effect of sphericity filter on performance characteristics for patients with and without fecal tagging. European Radiology 2007;17:662-8.

* *Colonography data from 138 patients was examined using CAD and the effect of bowel preparation on algorithm performance investigated. CAD had a sensitivity of 95.2% for polyps > 1cm and 87.8% for those >6mm.*

7. Zheng Y, Yang X, Beddoe G. Reduction of false positives in polyp detection using weighted support vector machines. Conf Proc IEEE Eng Med Biol Soc. 2007;2007:4433-6.

* *A technical paper that describes the use of a weighted support vector machine in 209 cases to train the classifier to favour true polyps, thus reducing the false-positive rate.*

8. Burling D, Halligan S, Taylor SA, Honeyfield L, Roddie ME. CT Colonography: automatic measurement of polyp diameter compared with manual assessment - an in-vivo study. Clin Radiol 2007;62:145-51.

* *Two observers measured 50 polyps using conventional techniques and then CAD, and their estimates were compared to those obtained from endoscopy. Automated and conventional methods were found to have comparable inter-observer agreement.*

9. Taylor SA, Slater A, Halligan S, Honeyfield L, Roddie ME, Dehmeshki J, Amin H, Burling D. CT Colonography: automated measurement of colonic polyps compared with manual techniques-human in vitro study. Radiology 2007;242:120-8.

* *A colectomy specimen containing 27 polyps was used to investigate agreement between conventional methods of polyp measurement and those from CAD. Given the histological nature of the specimen, the true size of polyps could be determined (vs those methods that employ endoscopic estimates). The authors found that automated CAD measurements were superior to conventional 2D estimates.*

10. Taylor SA, Iinuma G, Saito Y, Zhang J, Halligan S. CT Colonography: computer-aided detection of morphologically flat T1 colonic carcinoma. Eur Radiol 2008;18:1666-73.

* *24 patients with early (T1) cancers were subjected to CAD, which detected 20 of the cancers (83.3%), showing promise for the detection of what are known to be difficult tumours to diagnose.*

11. Burling D, Moore A, Marshall M, Weldon J, Gillen C, Baldwin R, Smith K, Pickhardt PJ, Honeyfield L, Taylor SA. Virtual colonoscopy: effect of computer-assisted detection (CAD) on radiographer performance. Clin Radiol 2008;63:549-56.

* *Four radiographic technician read 62 CT Colonography studies with and without CAD (second-reader and concurrent paradigms). Second reader CAD significantly improved sensitivity for polyps by an average of 12% overall while concurrent CAD showed no significant difference from an unassisted read.*

12. Taylor SA, Greenhalgh R, Ilangovan R, Tam E, Sahni VA, Burling D, Zhang J, Bassett P, Pickhardt PJ, Halligan S. CT Colonography and computer-aided detection: effect of false-positive results on reader specificity and reading efficiency in a low-prevalence screening population. Radiology 2008;247:133-40.

* *In order to investigate the effect of false-positive prompts on sensitivity the authors asked 4 readers to interpret 48 colonography studies, 50% of which had a high false-positive CAD rate and 50% of which were low. The authors found that increasing false-positive prompts by CAD did not adversely affect reader sensitivity or specificity, but interpretation time was prolonged.*

13. Taylor SA, Burling D, Roddie M, Honeyfield L, McQuillan J, Bassett P, Halligan S. Computer-aided detection for CT Colonography: incremental benefit of observer training. Br J Radiol 2008;81:180-6.

* *The authors investigated the effect of a singe day of intensive one-to-one training on the performance of readers who had previously participated in a CAD study of CT Colonography. When using CAD after the session of training, sensitivity rose by 18% overall. The authors concluded that CAD does not abrogate the need for reader training but, rather, should be used in conjunction with established training programmes.*

14. Taylor SA, Charman SC, Lefere P, McFarland EG, Paulson EK, Yee J, Aslam R, Barlow JM, Gupta A, Kim DH, Miller CM, Halligan S. CT Colonography: investigation of the optimum reader paradigm by using computer-aided detection software. Radiology 2008;246:463-71.

   • *In order to compare the performance of second- and concurrent-read CAD 10 observers read 25 colonography studies using both paradigms, with a temporal separation to diminish recall bias. The concurrent read was significantly shorter overall (by 2.9 minutes) but found that reader sensitivity was optimal with the second-read paradigm.*

Synopisis:

These 14 peer-reviewed papers detail the performance of a CAD scheme for CT Colonography. The authors have externally validated this algorithm (paper 2), have shown that the product is more sensitive than experienced readers (paper 3), and have shown that it significantly improves the performance of both radiologists (paper 5) and radiographic technicians (paper 11). The company has also supported work that shows the superiority of a second-read paradigm over concurrent (paper 14) and have shown that false-positive CAD prompts do not necessarily translate into reduced reader specificity (paper 12). There has also been work in flat cancers (paper 10) and on the automatic measurement of polyp diameter and volume (papers 1,8,9).

B: iCAD.

1. Huang A, Roy DA, Summers RM, Franaszek M, Petrick N, Choi JR, Pickhardt PJ. Teniae coli-based circumferential localization system for CT Colonography: feasibility study. Radiology 2007;243:551-60.

   • *A technical paper that describes the extraction of anatomical features from the dataset (the teniae coli) that are then used to improve the facility with which location of polyps in the colon is estimated.*

2. Summers RM, Handwerker LR, Pickhardt PJ, Van Uitert RL, Deshpande KK, Yeshwant S, Yao J, Franaszek M. Performance of a previously validated CT Colonography computer-aided detection system in a new patient population. Am J Roentgenol 2008;191:168-74.

   • *Taking the lead from Medicsight paper 2, the authors applied a similar external validation methodology to their own algorithm. A per patient sensitivity of 82.4% was achieved for polyps 6mm or larger.*

Synopsis:

This review identified two papers supported by iCAD: one a technical report and the second an external validation of the stand-alone algorithm performance. There were no assessments of observer performance using the algorithm.

C: Median technologies.

No peer-reviewed full publications were identified.

D: iM3D.

No peer-reviewed full publications were identified.

A further paper was identified from Viatronix, who market a commercially available workstation. This described a CAD algorithm but no commercially available CAD product was identified at the time of this review:

- *Hong W, Qiu F, Kaufman A. A pipeline for computer aided polyp detection. IEEE Trans Vis Comput Graph 2006;12:861-8.*

5.1.2: CT vendors:

A: Siemens.

1. Bogoni L, Cathier P, Dundar M, Jerebko A, Lakare S, Liang J, Periaswamy S, Baker ME, Macari M. Computer-aided detection (CAD) for CT Colonography: a tool to address a growing need. British Journal of Radiology 2005;78 Spec No 1:S57-62.
   - *The authors present the detection characteristics of a system described as a "prototype" in a paper published as part of a supplement, which dealt with the topic of CAD in general. The authors found that CAD detected 81.8% of "medium" sized polyps and 100% of "large" polyps. It should be noted that the data used to test the CAD system was a subset randomized from data used to train the CAD system – i.e. validation was internal rather than external.*
2. Barbu A, Bogoni L, Comaniciu D. Hierarchical part-based detection of 3D flexible tubes: application to CT colonoscopy. Med Image Comput Comput Assist Interv Int Conf Med Image Comput Comput Assist Interv. 2006;9:462-70
   - *A technical paper that described methodology used to reduce false-positive detections.*
3. Jerebko A, Lakare S, Cathier P, Periaswamy S, Bogoni L. Symmetric curvature patterns for colonic polyp detection. Med Image Comput Comput Assist Interv Int Conf Med Image Comput Comput Assist Interv 2006;9:169-76.
   - *A technical paper that described methodology to improve algorithm sensitivity.*
4. Baker ME, Bogoni L, Obuchowski NA, Dass C, Kendzierski RM, Remer EM, Einstein, DM, Cathier P, Jerebko A, Lakare S, Blum A, Caroline DF, Macari M. Computer-aided detection of colorectal polyps: can it improve sensitivity of less-experienced readers? Preliminary findings. Radiology 2007;245:140-9.
   - *Seven inexperienced readers interpreted colonography data from 30 patients, with a very high prevalence of abnormality (80%). Sensitivity increased significantly (from 0.81 to 0.91) but specificity decreased (from 0.70 to 0.96). Confidence intervals of the difference with and without CAD respectively were 0.027 to 0.171 and -0.39 to 0.91.*
5. Fletcher JG, Booya F, Summers RM, Roy D, Guendel L, Schmidt B, McCollough CH, Fidler JL. Comparative performance of two polyp detection systems on CT Colonography. AJR Am J Roentgenol. 2007;189:277-82
   - *The authors compared a commercially available CAD algorithm (Siemens PEV) with an academic algorithm in a stand-alone paradigm. The academic algorithm had higher sensitivity for polyps = or >1cm (96% vs 61%) but its specificity was reduced (5.2 false-positive detections per patient vs 1.18).*
6. Graser A, Kolligs FT, Mang T, Schaefer C, Geisbüsch S, Reiser MF, Becker CR. Computer-aided detection in CT Colonography: initial clinical experience using a prototype system. Eur Radiol 2007;17:2608-15.
   - *Using a "prototype" system and an indirect study design the authors compared the stand-alone performance of CAD to an experienced reader, finding that the radiologist outperformed CAD, with a per-patient sensitivity of 89% for all polyps versus 73% for CAD.*

7. Mang T, Peloschek P, Plank C, Maier A, Graser A, Weber M, Herold C, Bogoni L, Schima W. Effect of computer-aided detection as a second reader in multidetector-row CT Colonography. Eur Radiol 2007;17:2598-607

   • *Using a second-read paradigm with 4 readers and 52 colonography datasets with a prevalence of abnormality of 71.2%, the authors found that CAD improved sensitivity for all readers*.

8. Kim SH, Lee JM, Shin CI, Kim HC, Lee JG, Kim JH, Choi JY, Eun HW, Han JK, Lee JY, Choi BI. Effects of spatial resolution and tube current on computer-aided detection of polyps on CT colonographic images: phantom study. Radiology 2008;248:492-503.

   • *A phantom study that investigated the effect of z-axis resolution and tube current on CAD algorithm performance. The authors found that CAD performance was highly dependent on the former but not the latter.*

Synopsis:

These papers elegantly confirm the benefit of external validation of algorithm performance when an unbiased assessment is needed (see Section 2.0 above): When internally validated the Siemens CAD achieved a sensitivity of 100% for polyps 1cm or larger (paper 1), yet this dropped to 61% when externally validated (paper 5). Using an indirect design, an experienced reader outperformed the CAD (study 6). Two studies of reader performance using the Siemens CAD and a direct design were identified (papers 4 and 6): Both found that sensitivity increased while specificity decreased. Although the first (paper 4) had intended an analysis that combined both sensitivity and specificity, the authors found that this was ultimately not possible because the confidence-score data were non-normally distributed.

B: GE.

1. Bhotika R, Mendonça PR, Sirohey SA, Turner WD, Lee YL, McCoy JM, Brown RE, Miller JV. Part-based local shape models for colon polyp detection. Med Image Comput Comput Assist Interv Int Conf Med Image Comput Comput Assist Interv. 2006;9:479-86.

   • A technical paper that describes an approach to polyp detection by CAD.

2. Melonakos J, Mendonça P, Bhotka R, Sirohey S. A probabilistic model for haustral curvatures with applications to colon CAD. Med Image Comput Comput Assist Interv Int Conf Med Image Comput Comput Assist Interv. 2007;10(Pt 2):420-7.

   • A technical paper that describes an approach to polyp detection by CAD using haustral folds and their characteristics.

3. Johnson KT, Fletcher JG, Johnson CD. Computer-aided detection (CAD) using 360 degree virtual dissection: can CAD in a first reviewer paradigm be a reliable substitute for primary 2D or 3D search? AJR Am J Roentgenol 2007;189:W172-6(web-only)

   • *Again using the virtual dissection display employed in the study above, the authors used CAD as a first-reader, finding that this resulted in acceptable sensitivity. There were no patients without lesions (i.e. prevalence of abnormality was 100%) and no comparison to a CAD unassisted reader (this article is available on the Web only: there is no printed version).*

4. Hock D, Ouhadi R, Materne R, Aouchria AS, Mancini I, Broussaud T, Magotteaux P, Nchimi A. Virtual dissection CT Colonography: evaluation of learning curves and reading times with and without computer-aided detection. Radiology 2008;248:860-8.

- *CAD was employed in this study using the unconventional "virtual dissection" display, whereby the colonic lumen is opened and displayed flattened. Four inexperienced radiologists interpreted 100 datasets, two using CAD concurrently. All readers improved as the study progressed. CAD had no effect on reader performance by the end of the study. Interpretation time was not increased significantly by CAD.*

Synopsis:

The two clinical studies described above both used an unconventional display and CAD was employed as a first-reader in one and concurrently in another; the conventional second-reader paradigm has not been tested using the virtual dissection display. Because of this, it is difficult to generalise the results of these studies. However, CAD apparently had no beneficial effect by the time all readers had completed the concurrent study (paper 4 above).

C: Philips.

1. Zhao L, Botha CP, Bescos JO, Truyen R, Vos FM, Post FH. Lines of curvature for polyp detection in virtual colonoscopy. IEEE Trans Vis Comput Graph. 2006;12:885-92.
   - *A technical paper that describes approaches to improving CAD detection characteristics.*
2. van Wijk C, van Ravesteijn VF, Vos FM, Truyen R, de Vries AH, Stoker J, van Vliet LJ. Detection of protrusions in curved folded surfaces applied to automated polyp detection in CT Colonography. Med Image Comput Comput Assist Interv Int Conf Med Image Comput Comput Assist Interv. 2006;9:471-8.
   - *A technical paper that describes an approach to improved polyp detection by CAD using assumptions that polyps are not spherical.*
3. van Wijk C, Florie J, Nio CY, Dekker E, de Vries AH, Venema HW, van Vliet LJ, Stoker J, Vos FM. Protrusion method for automated estimation of polyp size on CT Colonography. AJR Am J Roentgenol 2008;190:1279-85
   - *A mixed phantom and patient study that investigated automated polyp measurement by CAD with those obtained from human observers. Using the phantom data, the authors found least variability in the CAD-derived estimates.*

Synopsis:

There are no studies from Philips that describe the performance of their CAD algorithm for polyp detection in patients, either using a stand-alone indirect design or a direct approach.

5.2 Abstracts of work-in-progress presented at key radiological meetings.

5.2.2: Abstracts from conference proceedings.

Because CAD for CT Colonography is a rapidly evolving field the abstract book for the following key scientific meetings was also hand-searched in order to identify potential studies in-progress. Hand-searching was performed by Prof. Steve Halligan.

It should be noted that abstracts of work presented at scientific meetings are *not generally indexed* and attract a *substantially lower index-of-esteem* than do full papers published in peer-reviewed, indexed journals.

Abtracts of the following conferences were searched in hard copy and online where available.

- Radiological Society of North America (RSNA) 2005, 2006, 2007.
- European Congress of Radiology (ECR) 2006, 2007, 2008.
- European Society of Gastrointestinal Radiology (ESGAR) 2006, 2007, 2008.

Inclusion criteria:

- Abstracts were included in this review if their text stated explicitly that a commercially available CAD system had been used.
- For those conferences that stipulate presenters declare a commercial interest (i.e. RSNA), the "Disclosure" information was also scrutinized so as to attempt to identify the origin of the products tested or a commercial linkage. Where a disclosure suggested a commercial link but the abstract stated explicitly that a "research" or "academic" CAD was tested, the algorithm was assumed to not be commercially available and so was excluded from the review.
- Where more than one system was used (in a face-to-face comparison for example), the abstract was ascribed to each of the companies tested.
- Only oral presentations of novel research findings were eligible since these are generally accepted to be the highest quality level presented at scientific meetings; "poster" exhibits were discounted, as were "review" type presentations.

Abstracts of work presented at the three key meetings selected for this review are presented below, split by Company. The meetings chosen were the Radiological Society of North America (RSNA) annual meeting and the European Congress of Radiology (ECR) annual meeting, which represent the largest North American and European radiological meetings respectively. The European Society of Gastrointestinal and Abdominal Radiology (ESGAR) annual meeting was also chosen, as this is the largest meeting worldwide dedicated to the subspecialty of gastrointestinal radiology.

A total of 59 individual abstracts were identified, 36 (61%) from independent CAD companies and 23 (39%) from CT scanner vendors. The largest contributor was Medicsight PLC who supported 24 abstracts (41% of total). The next largest contributor was Siemens, who contributed 15 abstracts (25% of total). The second largest independent CAD company contributed 7 abstracts (12% of total).

A synopsis is displayed in the table below: The full citation for each abstract is detailed in Appendix 1.

	Company						
	Medicsight	iCAD	Median	im3D	Siemens	Philips	GE
Meeting							
RSNA 2005	4				5	1	
ECR 2006	3		1		2		
ESGAR 2006	2				1		
RSNA 2006	3	1			3	1	
ECR 2007	3				1		1
ESGAR 2007	2				1		
RSNA 2007	2	2	6	1	2	2	2
ECR 2008	2						1
ESGAR 2008	3			1			
TOTAL	24	3	7	2	15	4	4

6.0 Summary of findings

This review has been performed using the principles of systematic review to search the available medical literature in an unbiased fashion.

- There were 7 CAD companies identified who were commercially active at the time of this review; 4 independent vendors and 3 CT scanner manufacturers.
- The review identified 31 peer-reviewed indexed papers in medical journals, 16 from independent companies and 15 from CT scanner vendors. Of the 16 papers from independent companies, 14 (88%) were supported by Medicsight PLC (45% of overall total). Two independent companies produced no peer-reviewed articles. Siemens was the second largest contributor of peer-reviewed articles, with 8 identified (26% of overall total).
- 59 abstracts of research findings presented at key scientific medical meetings were identified, 36 (61%) from independent companies and 23 (39%) from CT scanner vendors. Of the 36 papers from independent companies, 24 (67%) were supported by Medicsight PLC (41% of overall total). Two independent companies produced no peer-reviewed articles. Siemens was the second largest contributor of abstracted research, with 15 identified (25% of overall total).
- Medicsight PLC has supported the largest contribution to the CT Colonography CAD literature, both indexed and abstracted.
- Of the 31 peer-reviewed indexed papers identified, 10 directly examined the impact of CAD on the decision-making of those interpreting the data. Six of these (60%) were supported by Medicsight PLC, who also provided the largest study (10 readers; 107 datasets; 2140 patient interpretations), which found that CAD significantly improved reader sensitivity without a corresponding detrimental effect on specificity. The other 4 studies were sponsored by CT scanner vendors (2 from Siemens and GE each). The second largest was from Siemens (7 readers; 30 datasets; 420 patient interpretations).
- Only two companies sponsored papers that used a genuine external validation to test the performance characteristics of their CAD software; Medicsight PLC and iCAD. When tested using this methodology the Medicsight CAD had a sensitivity of 96% for polyps >/= 6mm versus 82% for iCAD.

Disclaimer:

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Steve Halligan.

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7.0 References.

1. Robinson C, Halligan S, Taylor SA, Mallett S, Altman DG. CT Colonography: A systematic review of standard of reporting for studies of computer-aided-detection (CAD). Radiology 2008; 246: 426-33.

2. Fenlon HM, Nunes DP, Schroy PC, III, Barish MA, Clarke PD, Ferrucci JT. A comparison of virtual and conventional colonoscopy for the detection of colorectal polyps. N Engl J Med 1999; 341: 1496-1503.

3. Yee J, Akerkar GA, Hung RK, Steinauer-Gebauer AM, Wall SD, McQuaid KR. Colorectal neoplasia: performance characteristics of CT Colonography for detection in 300 patients. Radiology, 2001; 219: 685-92.

4. Pineau BC, Paskett ED, Chen GJ, Espeland MA, Phillips K, Han JP, Mikulaninec C, Vining DJ. Virtual colonoscopy using oral contrast compared with colonoscopy for the detection of patients with colorectal polyps. Gastroenterology 2003; 125: 304-10.

5. Pickhardt PJ, Choi JR, Hwang I, et al. Computed tomographic virtual colonoscopy to screen for colorectal neoplasia in asymptomatic adults. N Engl J Med 2003; 349: 2191-2200.

6. Van Gelder RE, Nio CY, Florie J, et al. Computed tomographic Colonography compared with colonoscopy in patients at increased risk for colorectal cancer. Gastroenterology. 2004; 127: 41-8.

7. Johnson CD,Chen MH, Toledano AY, et al. Accuracy of CT Colonography for detection of large adenomas and cancers. N Engl J Med 2008;359:1207-11.

8. Cotton PB, Durkalski VL, Pineau BC, et al. Computed tomographic Colonography (virtual colonoscopy): a multicenter comparison with standard colonoscopy for detection of colorectal neoplasia. JAMA. 2004; 291: 1713-9.

9. Rockey DC, Paulson E, Niedzwiecki D, et al. Analysis of air contrast barium enema, computed tomographic Colonography, and colonoscopy: prospective comparison.Lancet. 2005; 365: 305-11.

10. Johnson CD, Harmsen WS, Wilson LA, MacCarty RL, Welch TJ, Iilstrup DM, Ahlquist DA. Prospective blinded evaluation of computed tomographic Colonography for screen detection of colorectal polyps. Gastroenterology, 2003; 125: 311-9.

11. Burhenne LJ, Wood SA, D'Orsi CJ, et al. Potential contribution of computer aided detection to the sensitivity of screening mammography. Radiology 2000; 215: 554-562.

12. Awai K, Murao K, Ozawa A, Komi M, Hayakawa H, Hori S, Nishimura Y. Pulmonary nodules at chest CT: effect of computer-aided diagnosis on radiologists' detection performance. Radiology 2004; 230: 347-352.

13. Yoshida H, Masutani Y, MacEneaney P, Rubin DT, Dachman AH. Computerized detection of colonic polyps at CT Colonography on the basis of volumetric features: pilot study. Radiology 2002; 222: 327-36.

14. Summers RM, Johnson CD, Pusanik LM, Malley JD, Youssef AM, Reed JE. Automated polyp detection at CT Colonography: Feasibility assessment in a human population. Radiology 2001; 219: 51-59.

15. Kiss G, Van Cleynenbreugel J, Thomeer M, Suetens P, Marchal G. Computer-aided diagnosis in virtual colonoscopy via combination of surface normal and sphere fitting models. Eur Radiol 2002; 12: 77-81.

16. Summers RM, Yao J, Pickhardt P, Franaszek M, Bitter I, Brickman D, Krishna V, Choi R. Computed tomographic virtual colonoscopy computer-aided polyp detection in a screening population. Gastroenterology 2005; 129: 1832-1844.

17. Altman DG, Royston P. What do we mean by validating a prognostic model? Statist Med 2000; 19: 453-473.

18. Hirsch RP. Validation samples. Biometrics 1991; 47: 1193-1194.

19. Systematic Reviews in Health Care 2nd Edition, Eds Egger M, Davey Smith G, Altman DG. BMJ publishing group, London 2001, ISBN 0-7279-1488-X.

20. Halligan S, Altman DG, Mallett S, et al. Computed tomographic Colonography: assessment of radiologist performance with and without computer-aided detection. Gastroenterology 2006; 131: 1690-9.

21. Bond JH. Progress in refining virtual colonoscopy for colorectal cancer screening. Gastroenterology 2005; 129: 2103-2106.

22. Partain CL, Chan HP, Gelovani JG, et al. Biomedical imaging research opportunities workshop 2: Report and recommendations. Radiology 2005; 236: 389-403.

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Appendix 1: Abstracts presented at scientific meetings over the review period.

Abstracts			
Company	**Medicsight PLC**	**iCAD**	**Median**
RSNA 2005	Halligan S, Dehmeshki, Taylor SA, Amin H, Xujiong Y, Tsang J. External validation of computer-assisted reading for CT Colonography. Radiology 2005;237: supp 336. Taylor SA, Burling DN, Halligan S, Roddie M, Tsang J, Dehmeshki J. Reader performance using CT Colonography computer assisted reader software: Benefit of dedicated CT Colonography training. Radiology 2005;237: supp 337. Taylor SA, Halligan S, Roddie M, McFarland EG, Lim AK, Dehmeshki J. CT Colonography: Automated diameter measurement of colonic polyps compared with a manual technique – in vitro study. Radiology 2005;237: supp 299. Taylor SA, Slater A, Halligan S, Honeyfield L, Roddie M, Dehmeshki J. CT Colonography: Automated measurement of colonic polyps compared with a manual technique. In vitro study using a human colectomy specimen. Radiology 2005;237: supp 299.		
ECR 2006	Halligan S, Altman D, Mallett S, Taylor S, Burling D, Roddie M, Dehmeshki D. CT Colonography: Multi-reader multi-case (MRMC) assessment of performance with and without computer assisted detection. Eur Radiol 2006;16 (supp 1):161 Taylor SA, Slater A, Honeyfield L, Roddie M, Halligan S, Dehmeshki D. CT Colonography: Automated diameter measurement of colonic polyps compared with a manual technique: In vitro study using a human colectomy specimen. Eur Radiol 2006;16 (supp 1):196 Burling D, Halligan S, Taylor S, Honeyfield L, Dehmeshki D, Roddie M. CT Colonography: Automatic measurement of polyp diameter compared with manual assessment in vivo. Eur Radiol 2006;16 (supp 1):197		M. Cadi et al; Impact of computer-aided diagnosis (CAD) on radiologists' performance to detect colonic polyps at CT Colonography.
ESGAR 2006	Halligan S, Altman D, Mallett S, Taylor SA, Burling D, Roddie M, Dehmeshki J. CTC: Assessment of observer performance with and without computer-assisted detection. Eur Radiol 2006;16 (suppl 3):C19 Taylor SA, Slater A, Halligan S, Honeyfield L, Roddie M, Dehmeshki J, Amin H. CTC: Automated measurement of colonic polyps compared with manual techniques – a human in vitro study. Eur Radiol 2006;16 (suppl 3):C45		
RSNA 2006	Taylor SA, Aslam R, Barlow JM, Gupta A, Iannaccone R, Kim DH, et al. CT Colonography: Investigation of the optimum reader paradigm usign computer-aided detection (CAD) software. Radiology 2006;241:supp 201. Halligan S et al. CT Colonography: Assessment of radiologist peformance with and without computer assisted detection (CAD). Radiology 2006;241 (supp1):202 Rengo M, Ferrari R, Paolantonio, et al. Polyp detection in CT virtual colonoscopy: 3D primary approach versus 3D and CAR. Radiology 2006;241 (supp1):313	Fletcher JG, Summers RM, Johnson CD, et al. Feasibility of computer-aided detection in the non-cathartic colon. Reducing barriers to colorectal screening and test performance. Radiology 2006;241:supp 201; 266-7.	
ECR 2007	Rengo M, Ferrari R, Paolantonio, et al. Polyp detection in CT virtual colonoscopy: 3D primary approach versus 3D and CAR. European Radiology 2007;17:275 (supp1). Halligan S, Iinuma G, Taylor SA, et al. CT Colonography: Computer-aided-detection (CAD) of colorectal cancer. European Radiology 2007;17:152 (supp1). Ferrari R, Paolantonio P, Ifrate F, et al. Potential advantages of using virtual dissection and CAD in reporting CT colonoscopy compared with primary 2D approach and CAD. European Radiology 2007;17:153 (supp1).		
ESGAR 2007	Halligan S, Iinuma G, Taylor SA, et al. CT Colonography: Computer-aided-detection (CAD) of colorectal cancer. European Radiology 2007;17:supple3:c32. Burling D, Moore A, Taylor SA, et al. Virtual colonoscopy: Effect of computer-assisted detection on radiographer performance. European Radiology 2007;17:supple3:c33.		
RSNA 2007	Taylor SA, Iinuma G, Halligan S et al. CT Colonography: Computer-assisted detection (CAD) of colorectal cancer. Radiology 2007; suppl 489 Taylor SA, Iinuma G, Halligan S, et al. CT Colonography: Computer-aided detection of morphologically flat early (T1) colonic carcinoma. Radiology 2007; suppl 99	Frentz S, Summers RM, Yao J, et al. Importance of polyp conspicuity for CT Colonography computer assisrted detection. Radiology 2007;suppl 594 Suzuki K, Verceles J, Khankari, et al. Performance of a CAD scheme incorporating a massive training artificial neural network for detection of polyps in false-negative CT Colonography. Radiology 2007;suppl 595	Nagata K, Yoshida H, Zalis M, et al. Performance comparison of computer-aided detection (CAD) in laxative and non-laxative CT Colonography. Radiology 2007; suppl 490 Yoshida H, Nappi JJ, Rockey DC, et al. Comparative performance assessment of CAD and unaided human reading in CT Colonography. Radiology 2007; suppl 99 Nappi JJ, Yoshida H, Lefere P, et al. Fully automated preparation-independent CAD for CT Colonography. Radiology 2007;suppl 594 Tsagaan B, Lefere P, Yoshida H, et al. Estimation of optimal detection threshold for automated volumetric polyp detection in CT Colonography. Radiology 2007;suppl 594 Nappi JJ, Lefere P, Cai w, et al. Optimized polyp detection for high performance CAD in CT Colonography. Radiology 2007;suppl 595 Cai W, Yoshida H, Nappi JJ, et al. Reducing the inhomogeneity artefacts in electronic cleansing of CT Colonography using statistical texture analysis. Radiology 2007; suppl 595
ECR 2008	Taylor SA, Greenhalgh R, Ilangovan R, et al. CT Colonography and computer-aided-detection: Effect of flase positives on reader specificity and reader efficiency in a low prevalence screening population. European radiology 2008; suppl 250 Taylor SA, Iinuma G, Halligan S, et al. CT Colonography: Computer-aided detection of morphologically flat early (T1) colonic carcinoma. European Radiology 2008; suppl 249		
ESGAR 2008	Taylor SA, Iinuma G, Zhang J, Yutaka S, Halligan S. CTC: Computer-aided detection of morphologically flat T1 carcinoma. European Radiology 2008;18:supp2,B29 Burling D, Wylie P, Muckian J, et al. Virtual colonoscopy: Assessment of computer aided detection assisted radiographer performance in routine clinical practice. European Radiology 2008;18:supp2,B29 Rengo M, Vecchietti F, Ferrari R, Iafrate F, Paolantonio P, Laghi A. Influence of CAD software on different experienced readers: Promary 3D flythrough approach versus 3D + CAR. European Radiology 2008;18:supp2,B29		

Im3D	Siemens	Phillips	GE
	Bielen D et al. Accuracy of automated size measurements of CT Colonography in phantom and patient data. Booya F, et al. Automated polyp measurement at CT Colonography: Preliminary observations in a phantom colon model. Fletcher JG et al. Comparative performance of two available CAD systems in CT Colonography (CTC). Baker ME et al. The efficacy of computer aided detection of colorectal polyps when applied to initial, inexperienced radiologist interpretations of CT Colonography – a pilot study. Graser A et al. Computer aided detection (CAD) in MDCT Colonography: Evaluation of the performance of a prototype system in more than 100 cases. T. Mang et al; Effect of computer aided detection as a second reader in multidetector CT Colonography: A multiobserver study. A. Graser et al. Performance of a prototype computer-aided detection (CAD) system in MDCT Colonography.	De Vries et al. Feasibility of automated detection of colon polyps on simulated ultra low dose CTC datasets	
	Mang et al. CTC: effect of computer-aided detection as a second reader on observers with different levels of expertise.		
	Mang et al. Effect of computer-aided detection as a second reader in multislice CT Colonography: A multi-observer study. Radiology 2006;241:supp 202. Lakare S, Barbu A, Dundar M, et al. Learning-based component for suppression of rectal tube false-positives: Evaluation of performance on 780 cases. Radiology 2006;241 (supp1):313 Shin C, Kim SH, Lee JM, et al. Effect of z-axis spatial resolution and radiation dose on CT Colonography CAD performance for polyp detection: An anthropomorphic phantom-based study. Radiology 2006;241 (supp1):358 Bogoni L, Wolf M, Lakare M, et al. Automatic polyp detection in over 1000 CTC cases: Clean and tagged performance. European Radiology 2007;17:153 (supp1).	Sheafor DH, Neuman JD, Virmani S, et al. Computer-assisted reading (CAR) in CT Colonography: Benefit to readers. Radiology 2006;241 (supp1):537	Ferrari R, Paolantonio P, Ifrate F, et al. Potential advantages of using virtual dissection and CAD in reporting CT colonoscopy compared with primary 2D approach and CAD. European Radiology 2007;17:153 (supp1).
Campanella D, Correale L, Cassinis M, et al. CT Colonography using different theoretical CAD software: Influence of false positive prompts on experienced readers' performance. Radiology 2007; suppl 490	Mang TG, Schima W, Plank C, et al. MDCT Colonography: Effect of computer-aided detection on radiologists' performance in a first- and second-reader paradigm. European Radiology 2007;17:supple3:c32. Bogoni L, Wolf M, Barbu et al. Learning-based component for suppression of false-positives located on the ileocaecal valve: Evaluation of performance ion 802 CTC volumes. Radiology 2007; suppl 491 Bogoni L, Wolf M, Lakare S, et al. Automated polyp detection: An evaluation of a CAD system in over 1200 cases. Radiology 2007; suppl 99	De Vries A, Liedenbaum M, Florie J et al. Does second read CAD enhance experienced reader performance in CTC of increased risk individuals? Radiology 2007; suppl 491 Kim SH, Lee JM, Park HS, et al. Comparison of CAD performance between reduced bowel preparation with fecal tagging and full cathartic preparation. Radiology 2007; suppl 399	Johnson K, Johnson CD, Fletcher J. Feasibility study to assess computer-aided detection using virtual dissection in a first reader paradigm. Radiology 2007; (suppl) 775 Ferrari R, Iafrate F, Paolantonio P, et al. Evaluation of potential advantages of CAD in reporting CT Colonography with a primary 2D approach. Radiology 2007; suppl 490
			Ferrari R, Rengo M, Paolantonio P, et al. Evaluation of the potential advantages of computer-aided diagnosis (CAD) in reporting CT Colonography with a primary 2D approach. European Radiology 2008; suppl 248
Turini F, Neri E, Regge D, Cerri, Carmignani G, Bartolozzi C. Impact of CAD on 27 inexpert readers. European Radiology 2008;18:supp2,B28			

CT Colonography (virtual colonoscopy): A systematic review of commercially available systems for computer-assisted-detection (CAD) for colorectal polyps and cancer.