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# Assessing the Impact of Colonoscopy Complications on use of Colonoscopy among Primary Care Physicians and Other Connected Physicians: An Observational Study

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## ABSTRACT

**Objectives**: Psychological biases can distort treatment decision-making. The availability heuristic is one such bias, wherein events that are recent, vivid, or easily imagined are readily "available" to memory and are therefore judged more likely to occur than expected based on epidemiologic data. We assessed if the occurrence of a serious colonoscopy complication for a primary care physician's patient influenced colonoscopy rates for the physician's other patients.

**Design**: Observational study with a difference-in-differences design.

**Setting/Participants**: Individuals living in 51 hospital referral regions across the U.S. identified based on enrollment in fee-for-service Medicare during 2005-2010. We assigned patients to a primary care physician based on office visits during the prior 2 years.

**Exposures**: For each physician in each month, we calculated the proportion of patients assigned to them who had a colonoscopy. We identified 2 serious complications of which the primary care provider would very likely be aware: gastrointestinal bleed or perforation leading to hospitalization or death within 14 days of colonoscopy.

**Main Outcome Measures**: We employed a difference-in-differences design using Poisson regression models including physician fixed effects to assess the change in number of colonoscopies in the 4 quarters following an adverse colonoscopy event.

**Results**: We identified 5,360,191 patients assigned to 30,704 physicians. 4,864 physicians (16%) had at least 1 patient with an adverse event. The estimated change in the quarterly number of colonoscopies among physicians' patients was significantly lower in quarter 2 following an adverse colonoscopy event (change=-2.1% (95%CI=-3.4 to -0.8%)), before returning to the rate expected in the absence of an adverse event.

**Conclusions**: Having a patient experience a serious adverse colonoscopy event was associated with a small and temporary decline in colonoscopy rates among a physician's other patients. These findings provide empirical evidence for the influence of notable adverse events on care, possibly due to the availability heuristic.

Key words: colorectal cancer screening, medical decision making

Abstract word count=300

## Article Summary

Strengths and limitations of this study

- We studied a large representative cohort of patients and their physicians allowing us to assess consequences of infrequent but very serious adverse events of colonoscopy, a frequently recommended screening procedure.
- We used a difference-in-differences design to adjust for patient and physician factors in our longitudinal data.
- Limitations included our focus on Americans aged 65 and older, the possibility of misattribution of patients to physicians, and the lack of direct information about physicians' and patients' decision making processes.

## INTRODUCTION

A physician's recommendation is an important determinant of whether a patient undergoes recommended screening and preventive testing such as colorectal cancer screening.[1-3] Traditionally, cancer screening is a core component of primary care, and adherence to screening recommendations is a key quality indicator for primary care physicians and practices. Colorectal cancer screening is particularly effective, and expanded screening is credited as contributing to at least some of the declining incidence and mortality from this condition.[4 5] The United States Preventative Services Task Force recommends screening for colorectal cancer for adults beginning at age 50 for average-risk individuals.[6] Although there are several accepted methods for colorectal cancer screening, including annual fecal occult blood screening and flexible sigmoidoscopy every five years, most primary care physicians and gastroenterologists favor colonoscopy as the preferred method of screening.[7] Colonoscopy, however, has potential risks, which have been increasingly highlighted by guideline panels. These risks include complications from the procedure,[8] as well as the possibility of false positive tests and overdiagnosis and overtreatment.

Evidence suggests that psychological biases can distort treatment decision-making relative to a traditional utility maximization reference.[9] The availability heuristic is one such bias wherein events that are recent, vivid, or easy to imagine are readily "available" to memory and are therefore judged to be more likely to occur than would be expected based on epidemiologic data.[10] Yet, few data are available that quantify the impact of such biases on physician decision-making and the care that is delivered to patients. Two prior studies have provided some evidence for the effect of availability bias on diagnostic judgments, but these studies were small and limited to resident physicians.[11 12] Expanding the evidence base regarding the rational and non-rational forces driving physician behavior will help to identify

specific types of clinical decisions that might be influenced by such biases, which could allow physicians and organizations to design interventions to overcome biases when they are likely to occur. In addition, such data could help to identify opportunities for improving physicians' understanding of clinical evidence and how that evidence is shared with patients making decisions about care.

We used administrative data from the U.S. Medicare program for beneficiaries and their physicians from 2005 through 2010 to assess for empirical evidence of cognitive bias in colorectal cancer screening. Specifically, we examined if the occurrence of a serious complication of screening colonoscopy among a primary care physician's patients influenced colonoscopy rates among the physician's other patients in subsequent months. We hypothesized that screening rates for physicians' patients would decrease in the period following experience with a patient having a serious adverse event. We next assessed if any effects of serious adverse events of screening on future screening differed for patients in a physician's panel who were older (vs. younger), for whom the relative ratio of benefit to harm of colonoscopy screening is lower, and current guidelines recommend against routine screening for patients older than 75 years.[6] We hypothesized effects would be greater for a physicians' older patients. Finally, we assessed if the serious adverse event changed screening behaviors for other primary care physicians within that primary care physician's practice as might be expected if physicians shared experiences of adverse events with their colleagues. We hypothesized that if overall effects were large, there may be similar but smaller effects among peers.

## METHODS

### Data and subjects

We used 100% Medicare data from the inpatient, outpatient, and carrier files for this analysis. Medicare is the national health insurance program for Americans aged 65 and older. We studied care for patients living in 50 hospital referral regions in the U.S. during 2005-2010; the regions were randomly sampled with probability proportional to their size; we also included the Boston hospital referral region. We identified all patients aged ≥65 who were continuously enrolled in parts A and B of fee-for-service Medicare for at least 1 year (or until death if <1 year) during the study period.

Because our focus was on screening behaviors of physicians for patients they treated, we assigned all patients to a physician for each month during 2006 through the end of 2010 based on the plurality of office visits for primary care services in the two years preceding that month.[13] This study is similar to attribution algorithms used to assign patients to physicians in U.S. Accountable Care Organizations. We assigned patients to physicians based on 2 years of data to provide more stable panels and to account for patients aging into or leaving fee-for-service Medicare or dying. We weighted physician visits from the more recent year 0.67 and from the earlier year 0.33. For example, for January 2007, the algorithm assigned patients to a physician using claims from February 2005 through January 2007, with visits during February 2005-January 2006 weighted 0.33 and visits from February 2006-January 2007 weighted 0.67. The algorithm uses evaluation and management codes for face-to-face office visits and first assigns patients to generalist physicians (internal medicine, family practice, general practice, geriatrics); then for patients with no visits to generalists physicians, it assigns to other medical specialists who might plausibly serve as the patient's primary care physician. We assessed specialty based on the specialty code on the submitted claims, which may best reflect the type of care that they are delivering to patients at that visit.[14] We then focused analyses on primary care physicians (the generalist specialties described above) and medical specialists who may be

providing primary care (cardiology, pulmonary, nephrology, infectious disease, endocrinology, and rheumatology; we did not include gastroenterology to avoid including physicians who may also be performing a patient's colonoscopy). In preliminary analyses, findings were similar when including only primary care physicians.

Among 45,652 physicians to whom patients were assigned from 2005-2010, we excluded 14,323 physicians with fewer than 25 Medicare patients assigned to them in any month (based on the assignment algorithm over the current and prior year described above) and an additional 625 physicians were excluded by focusing on care during 2006-2010. The final cohort included 5,360,191 patients assigned to 30,704 physicians.

We obtained information about physician age, and sex from the American Medical Association Physician Masterfile. For each physician, we also identified peer physicians who were working in the same practice based on the tax identification number used for billing and considered all other physicians billing under the same tax identification number as peers whose practice decisions might be influenced by their colleagues' experiences and behavior. For the 1.0% of physicians who submitted claims under more than one tax identification number, we assigned them to the tax identification number for the first claim they submitted during the calendar year.

**Identifying colonoscopy and serious complication associated with colonoscopy**

We identified all patients who underwent screening or diagnostic colonoscopies in the outpatient setting (Medicare place of service codes 22, 24, 49) using procedure codes included in the Appendix Table.[8] If patients had more than 1 colonoscopy in a 1-year period, we only included the first occurrence. Prior work has examined complications of colonoscopy leading to emergency department visit or hospitalization within 30 days of the procedure.[8] But primary

care providers may be unaware of relatively minor complications that may not come to their attention. Therefore, in this analysis, we focused on two serious complications that were highly likely to be associated with the colonoscopy and for which the primary care provider would very likely be aware: gastrointestinal bleed or perforation within 14 days of the colonoscopy that led to hospitalization or death (Appendix Table).

For each physician in each month from January 2006 through December 2010, we calculated the number of colonoscopies and the colonoscopy rate, defined as the number of colonoscopies that his/her assigned patients had in that month divided by all patients assigned to that physician in that month. We also identified each month during which a physician had a patient that experienced a serious complication.

**Patient involvement**

The research protocol was approved by the Harvard Medical School Committee on Human Subjects. Patient consent was not obtained because our data, which were previously collected for billing purposes, did not include patient identifiers. Patients were not involved in the study design, although we studied a common procedure that most older Americans have been asked to consider for colorectal cancer screening.[7]

**Analyses**

We used a difference-in-difference design to understand the impact of colonoscopy complications on future screening behaviors. Because we examined care with 5 years of longitudinal data, physicians served as their own control during months prior to any adverse event; physicians who had no adverse event in any month (84% of physicians) also served as controls. We used fixed effect Poisson regression with a logarithmic link function to

model the expected number of colonoscopies in each month during the study period. The models included fixed effects for each physician as well as indicator variables for study month (which address monthly and/or seasonal differences in colonoscopy use) and 4 indicator variables reflecting the presence or absence of a colonoscopy adverse event in each of the 4 quarters before the month of interest. We also included the number of patients assigned to each physician in that month as the Poisson offset variable; this effectively serves as a denominator for the dependent variable (number of colonoscopies in a month), allowing us to interpret model coefficients as estimates of the change in the rate of colonoscopies among a physician's assigned patients. Because a patient will have at most one colonoscopy per quarter, the rate is essentially the proportion of all assigned patients who receive a colonoscopy per quarter.

In a second set of models, we conducted stratified analyses for patients aged 65-74 and aged 75 and older to assess if effects of an adverse colonoscopy event on future colonoscopies varied for younger vs. older patients, since for older patients the benefits of colonoscopies may be less and the risk of adverse events greater. We also ran a single model to test the statistical significance of the age group interaction.

In a third model, we restricted to the 5513 practices with more than one physician in our cohort and included quarterly indicators reflecting a prior adverse event in one of those 4 quarters for each physician as well as a second set of quarterly indicator variables reflecting presence or absence of a colonoscopy adverse event among another physician practicing in the same practice for each of the 4 prior quarters. This allowed us to assess whether an adverse colonoscopy event among a peer physician in the practice influenced a physician's colonoscopy ordering.

Finally, as a robustness check, we reran our models using the number of mammograms as the dependent variable as a falsification test, since colonoscopy adverse events should not have any influence on breast cancer screening. To do this, we assessed if physicians whose patients had an adverse event related to colonoscopy had any temporal changes in their rate of screening mammography among women patients aged 65 and older (we expected no changes). We identified screening mammography based on procedure codes (Appendix Table).

In all models, the repeated (monthly) observations on physicians were accounted for by using generalized estimating equations using the identity as the working correlation matrix. The resulting standard errors are robust to the true correlation structure among a physician's observations. Data on physician age and sex were missing for 334 physicians; however, because we included physician fixed effects in models to adjust for physician differences, we did not include these variables, and therefore all physicians and patients are included in final analyses.

The sponsor had no role in the research.

## RESULTS

We identified 5,360,191 patients assigned to 30,704 physicians practicing in 21,770 practices for which 5,513 practices had more than one physician in our cohort. Characteristics of the patients and physicians are included in Table 1. The mean age of the physicians was 50.5 (SD=11.0); 73.3% were male, and they had an average of 122.5 Medicare patients assigned (SD=121.9). Physicians were observed for a mean (SD) of 42.2

(12.4) months (range=1-49). Among assigned patients, approximately 10 patients had a colonoscopy in any year, consistent with the number expected for a test that is recommended once every 10 years. Overall, 6,095 patients (0.1%) experienced a serious adverse colonoscopy event between January 2006 and December 2010; 4,864 physicians (16%) had at least 1 patient with a serious adverse event; 951 (3%) of physicians had 2 or more patients experience an adverse event.

In models with physician fixed effects, the estimated number of colonoscopies among physicians' patients following an adverse colonoscopy event was significantly lower by 2.1% (95% confidence interval, -3.4 to -0.8) in quarter 2 following the adverse event (Table 2 and Figure), before returning to the number that would be expected in the absence of an adverse event. In stratified analyses comparing physicians' patients aged 65-74 years vs. aged 75 and older, the association of an adverse colonoscopy event was generally similar to our primary model (Table 2), and the interaction of quarter following adverse colonoscopy event by patient age group was not statistically significant (P for interaction=0.15). When assessing for peer effects, there was no detectable decrease in the colonoscopy rates among other primary care physicians in the physicians' practice (all P>.15) (Table 2).

In our falsification test assessing if the expected number of mammograms for a physician's patients changed in the quarters following an adverse colonoscopy event, we found no differences (Table 3).

## DISCUSSION

Having a patient experience a serious adverse event from colonoscopy was associated with a small and temporary decline in rates of colonoscopy among a physician's other Medicare

patients. These findings provide empirical evidence for the influence of notable adverse events on care, possibly due to the availability heuristic. The negative impact is relatively modest for this clinical condition, wherein screening generally is supported by strong evidence; effects could be larger for other clinical conditions. The decline we observed was seen in the 2nd quarter following the adverse event, which is consistent with the lag in obtaining colonoscopy from the time a physician recommends/orders it and it is compled, such that the lower likelihood of referring for screening might not be evident until several months after the adverse event. As more time from the adverse event passed, this effect disappeared, suggesting that more recent experience with no adverse events led physicians to return to their baseline rate of ordering.

The small decline in colonoscopy rates was evident for physicians' patients who were relatively younger (65-74) and older (75 and older), suggesting that the decline was not related to specific consideration of an individual patient's risk of an adverse event (older patients experience less benefit from screening colonoscopy and have greater risks). Rather, physicians seem to have reflexively ordered fewer colonoscopies for all patients. Prior work suggests substantial overuse of colonoscopies in patients over the ages of 75 and 85 years.[15 16]. Nevertheless, fewer colonoscopies were performed overall among the older versus younger patients, which may reflect physicians' appreciation of the lower benefit in this group.

We found no evidence of an effect on a physician's peers in a practice (those billing under the same tax identification number), suggesting that the impact of the negative adverse event was not sufficiently great as to influence practice-level discussions about screening. It may be that physicians do not discuss such events or their thoughts about screening

routinely with their practice partners. Alternatively, they may have such discussions with a limited group of colleagues, for which our method of identifying practice peers was not adequately sensitive.

Our findings suggest that efforts may be needed to help physicians avoid influences of psychological biases on the care they deliver. Prior work suggests challenges in improving care delivery even after helping clinicians correct inaccurate estimation of the probability an event will occur. For example, one study succeeded in substantially improving clinicians' prior overestimations of the probability of streptococcal pharyngitis, but the proportion of patients prescribed antibiotics showed a trend toward increasing.[17] Nevertheless, expanded use of shared decision-making tools holds great promise in helping physicians avoid cognitive biases in their estimates of probabilities of adverse events. If physicians and patients routinely discuss or review the benefits and harms of tests, procedures, and treatments, then the associated probabilities and their expected implications will remain familiar to them. Decision aids can help with making such information easily accessible to patients and their physicians.[18]

Our study has several limitations. First, we focused on older Americans enrolled in fee-for-service Medicare; however, we do not expect the results to differ in other populations. Second, our evidence is indirect; we had no information about the physician's decision-making process, if the assigned physician was the one who actually ordered the screening test, or the timing of colonoscopy orders for colonoscopies that were received. In addition, we inferred that these primary care physicians learned about the serious adverse events, but we have no direct knowledge of this; nevertheless, such lack of awareness would tend to bias towards the null. We also did not observe colonoscopies that were ordered but not

obtained by patients; nor did we observe changes to other screening strategies, such as fecal occult blood testing, which are not accurately identified in administrative data.[19] In addition, we were not able to identify precisely patients who required more frequent colonoscopies per current screening guidelines. We therefore relied on the assumption that rates among a physician's panel would be relatively stable over time, consistent with prior studies.[20] Finally, there may have been some misattribution of patients to physicians, although we do not expect that would create any bias.

In conclusion, a physician's experience of a patient having a serious adverse event from colonoscopy was associated with a small and temporary decline in rates of colonoscopy among that physician's other patients that did not vary by the baseline risk of the physician's patients based on age. This finding suggests that cognitive bias can lead physicians to inaccurately interpret the relative harm to benefit ratio. Increased use of tools to enhance shared decision-making with patients may be one strategy to assure that clinical decisions are based on the best available evidence about benefits and harms.

**Contributorship Statement:** Dr. Keating had full access to all of the data in the study and affirms that the manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained.

Study concept and design: All authors

Analysis and interpretation of data: All authors

Drafting of the manuscript: Keating

Critical revision of the manuscript for important intellectual content: All authors

Final approval of the manuscript: All authors

**Competing Interest Statement**: All authors have completed the ICMJE uniform disclosure form at http://www.icmje.org/coi_disclosure.pdf and declare: no support from any organisation for the submitted work; no financial relationships with any organisations that might have an interest in the submitted work in the previous three years, no other relationships or activities that could appear to have influenced the submitted work except as described. Dr. Keating serves as a medical editor for the Informed Medical Decisions Foundation, now part of Healthwise, a non-profit organization that seeks to improve health care decisions. None of the other authors have relationships with any entities with potential financial interest in this topic.

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**Data Sharing**. Data were obtained from the U.S. Centers for Medicare and Medicaid Services (CMS). Due to data use agreement restrictions, we cannot share our project data with other investigators, but the Medicare data can be obtained from CMS. Statistical code is available from the authors upon request.

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Table 1. Characteristics of physicians in the cohort, N=30,704*

| Characteristic | |
|---|---|
| Physician age in years, mean (SD) | 50.5 (11.0) |
| Sex, % | |
| Male | 73.3 |
| Female | 26.7 |
| Specialty, % | |
| Primary care physician | 85.0 |
| Medical specialist | 15.0 |
| N assigned patients, mean (SD) | 122.5 (121.9) |
| Age of assigned patients in years, mean (SD) | 77.1 (2.0) |
| Proportion of physicians' assigned patients who are male, mean (SD) | 39.9 (13.7) |
| Race/ethnicity of physicians' assigned patients | |
| Proportion who are white, mean (SD) | 83.9 (23.6) |
| Proportion who are black, mean (SD) | 8.9 (18.0) |
| Proportion who are Hispanic, mean (SD) | 3.1 (9.5) |
| Hierarchical condition category score of physicians' assigned patients, mean (SD) | 1.45 (.42) |
| Yearly number of colonoscopies among physicians' assigned patients, mean (SD) | 10.2 (16.6) |
| Quarterly number of colonoscopies among physicians' assigned patients, mean (SD) | |
| Among all patients | 2.5 (3.4) |
| Among patients aged 65-74 | 1.6 (2.2) |
| Among patients aged 75 and older | 1.0 (1.6) |
| Monthly number of colonoscopies among physicians' assigned patients, mean (SD) | 0.8 (1.4) |

*Patient and physician characteristics and characteristics of physicians' patients were calculated for each month that they were in the data set (physicians) or were attributed to a physician (patients) and averaged over all months that they were observed. Data on physician age and sex were missing for 334 physicians.

Table 2. Change in quarterly number of colonoscopies among physicians' patients following an adverse colonoscopy event among a physician's patient

| | % Change (95% CI)* | P value* |
|---|---|---|
| **Primary model** | | |
| Quarter 1 | -0.7 (-2.0 to 0.7) | .34 |
| Quarter 2 | **-2.1 (-3.4 to -0.8)** | **.002** |
| Quarter 3 | -0.9 (-2.3 to 0.4) | .18 |
| Quarter 4 | 0.0 (-1.4 to 1.4) | 1.00 |
| **Models stratified by patient age**** | | |
| Patients 65-75 years | | |
| Quarter 1 | -0.1 (-2.5 to 2.3) | .91 |
| **Quarter 2** | **-4.3 (-6.6 to -2.0)** | **<.001** |
| Quarter 3 | -1.1 (-3.6 to 1.4) | .39 |
| Quarter 4 | -1.6 (-4.0 to 0.9) | .21 |
| Patients >75 years | | |
| **Quarter 1** | **-3.4 (-6.0 to -0.7)** | **.01** |
| **Quarter 2** | **-2.7 (-5.3 to -0.1)** | **.04** |
| **Quarter 3** | **-3.5 (-6.1 to -0.7)** | **.01** |
| Quarter 4 | -1.1 (-3.8 to 1.7) | .43 |
| **Model including physicians' patients and patients of other physicians in their practice (among 5513 practices with 2 or more physicians)** | | |
| Physician | | |
| Quarter 1 | -0.8 (-2.5 to 0.8) | 0.31 |
| Quarter 2 | -2.6 (-4.1 to -1.1) | 0.001 |
| Quarter 3 | -1.0 (-2.6 to 0.7) | 0.25 |
| Quarter 4 | 0.8 (-0.9 to 2.4) | 0.37 |
| Physicians' practice peers | | |
| Quarter 1 | 0.3 (-0.4 to 1.0) | .39 |
| Quarter 2 | 0.5 (-0.2 to 1.2) | .16 |
| Quarter 3 | 0.0 (-0.7 to 0.7) | .95 |
| Quarter 4 | 0.6 (0.0 to 1.3) | .07 |

*Using fixed effects Poisson regression to model the number of colonoscopies. Models included fixed effects for each physician and indicators for study month as well as 4 indicator variables reflecting presence or absence of a colonoscopy adverse event in each of the 4 quarters before the month of interest. Models also include the number of patients assigned to the physician in that month, which serves as an offset variable allowing an interpretation of the dependent variable (number of colonoscopies) as a rate (number of colonoscopies per number of assigned patients).

**P for interaction=0.15

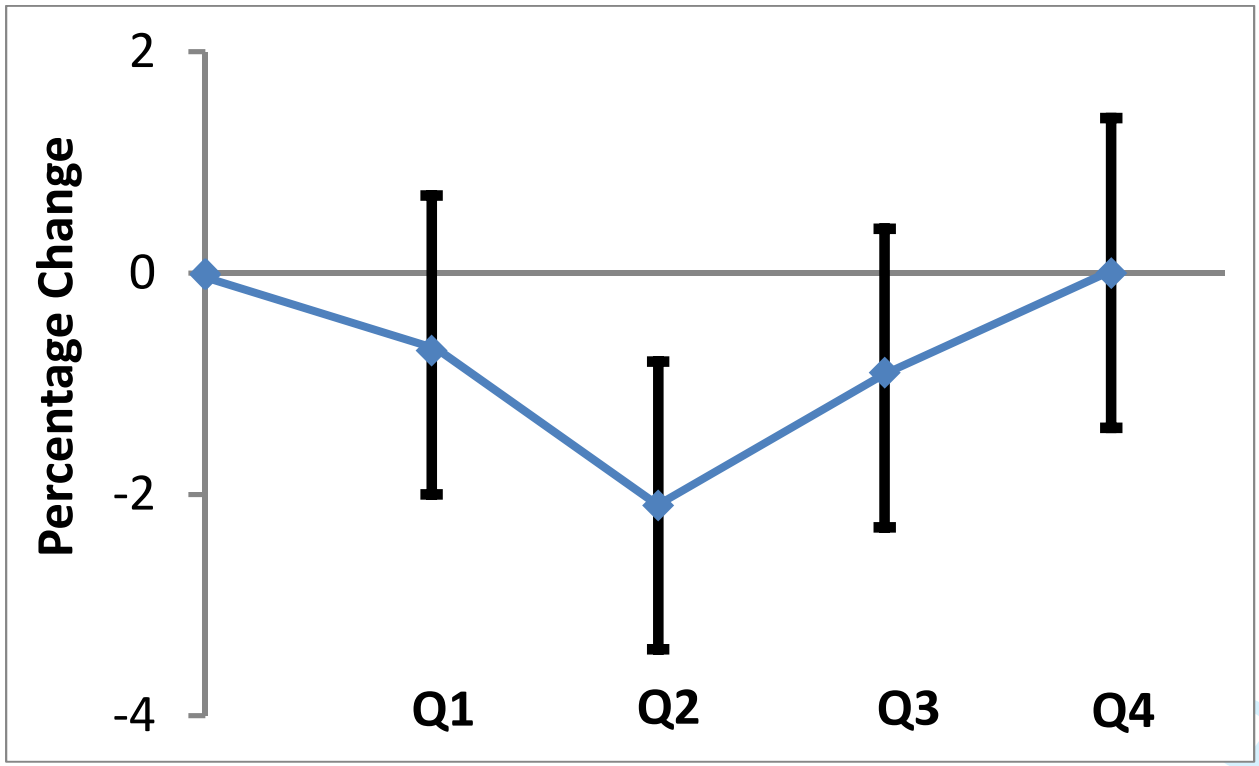
Bolded values reflect statistical significance at two-sided P<.05.

Table 3. Falsification test: change in quarterly number of mammograms among physicians' patients following an adverse colonoscopy event among a physician's patient

| | % Change (95% CI) | P value |
|---|---|---|
| Quarter 1 | -0.4 (-1.2 to 0.3) | .26 |
| Quarter 2 | -0.2 (-0.9 to 0.6) | .66 |
| Quarter 3 | 0.1 (-0.6 to 0.9) | .74 |
| Quarter 4 | 0.0 (-0.7 to 0.8) | .95 |

*Using fixed effects Poisson regression to model the number of mammograms. Models included fixed effects for each physician and indicators for study month as well as 4 indicator variables reflecting presence or absence of a colonoscopy adverse event in each of the 4 quarters before the month of interest. Models also include the number of patients assigned to the physician in that month, which serves as an offset variable allowing an interpretation of the dependent variable (number of mammograms) as a rate (number of mammograms per number of assigned patients).

Figure. Percentage Change in Quarterly Number of Colonoscopies among Physician's Patients Following Adverse Event




Percentage change and 95% confidence interval for each quarter following a physician's patient experiencing an adverse colonoscopy event.

Appendix Table. CPT, ICD-9, and HCPCS codes for colonoscopy and sentinel events and for mammography

| Procedure | CPT | ICD-9 Procedure | ICD-9 Diagnosis | HCPCS | Revenue center |
|---|---|---|---|---|---|
| **Complications of Colonoscopy and Colonoscopy Screening*** | | | | | |
| **Identify outpatient colonoscopy based on Medicare place of service code = 22, 24, 49** | | | | | |
| Screening | | | | G0105, G0121 | |
| Diagnostic | 45378 | 45.23 | | | |
| With Polypectomy | 45380, 45383, 45384, 45385, 45392 | 45.42 | | | |
| **Complications from colonoscopy** | | | | | |
| **Note: all based on ER visit† or hospitalization within 30 days of the date of the procedure** | | | | | |
| Serious gastrointestinal events | | | | | |
| Perforation | | | 569.83, 998.2 | | |
| Gastrointestinal bleeding | | | 285.1, 578.x, 998.1 | | |
| | | | | | |
| **Mammography‡** | 77055, 77056, 77057 76090, 76091, 76092 77061, 77062, 77063 | 87.36, 87.37 | | G0202, G0204, G0206 | 0401, 0403 |

*As per Warren JL, Klabunde CN, Mariotto AB, et al. Adverse events after outpatient colonoscopy in the Medicare population. Ann Intern Med. Jun 16 2009;150(12):849-857. Note that did not include colonoscopy with other procedures, including foreign-body removal, submucosal injection, hemostasis, endoscopic ultrasound, and transmural or intramural aspiration and/or biopsy. To identify ER visits, we used revenue center codes of 0450-0459 or 0981 in the outpatient file or ER_AMT>0 in the MEDPAR file.

‡ Mammography based on HEDIS 2015 technical specifications[17], but also including prior similar codes phased out in 2007 (76090-76092) and tomosynthesis codes (77061-77063) (note G0203, G0205 deleted 1/2005). To avoid double counting mammograms due to false positives or facility + physician bills, patients can only have one mammogram in a 3-month period—use the date of the first of these codes. We examined codes in the carrier and outpatient files.

STROBE Statement—checklist of items that should be included in reports of observational studies [Yellow highlighting reflects check. Our study has some elements of a cohort study and some elements of a cross section al study. Blue highlighting reflects not applicable.]

| | Item No | Recommendation |
|---|---|---|
| **Title and abstract** | 1 | (*a*) Indicate the study's design with a commonly used term in the title or the abstract (page 1) |
| | | (*b*) Provide in the abstract an informative and balanced summary of what was done and what was found (page 2) |
| **Introduction** | | |
| Background/rationale | 2 | Explain the scientific background and rationale for the investigation being reported (page 5-6) |
| Objectives | 3 | State specific objectives, including any prespecified hypotheses (page 6) |
| **Methods** | | |
| Study design | 4 | Present key elements of study design early in the paper (page 7) |
| Setting | 5 | Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection (Page 7) |
| Participants | 6 | (*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up (page 7-8)<br>*Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls [N/A]<br>*Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participant (page 7-8) |
| | | (*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed [N/A-not matched]<br>*Case-control study*—For matched studies, give matching criteria and the number of controls per case [N/A] |
| Variables | 7 | Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable (page 7-9) |
| Data sources/ measurement | 8* | For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group (page 7-9) |
| Bias | 9 | Describe any efforts to address potential sources of bias (page 7-11) |
| Study size | 10 | Explain how the study size was arrived at (page 7-all patients were included) |
| Quantitative variables | 11 | Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why (page 10-11) |
| Statistical methods | 12 | (*a*) Describe all statistical methods, including those used to control for confounding (page 10-11) |
| | | (*b*) Describe any methods used to examine subgroups and interactions (page 10-11) |
| | | (*c*) Explain how missing data were addressed (page 11) |
| | | (*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed [N/A]<br>*Case-control study*—If applicable, explain how matching of cases and controls was addressed [N/A]<br>*Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy [N/A-included all physicians and their patients] |
| | | (*e*) Describe any sensitivity analyses (page 11) |

Continued on next page

| | | |
|---|---|---|
| **Results** | | |
| Participants | 13* | (a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed (page 8) |
| | | (b) Give reasons for non-participation at each stage (page 8) |
| | | (c) Consider use of a flow diagram [Note: we considered but because we included all patients of all physicians with at least 25 patients aged 65+, we didn't think this was necessary] |
| Descriptive data | 14* | (a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders (page 11-12, Table 1) |
| | | (b) Indicate number of participants with missing data for each variable of interest (page 11) |
| | | (c) *Cohort study*—Summarise follow-up time (eg, average and total amount ) (page 11-12) |
| Outcome data | 15* | *Cohort study*—Report numbers of outcome events or summary measures over time (page 12) |
| | | *Case-control study*—Report numbers in each exposure category, or summary measures of exposure [N/A] |
| | | *Cross-sectional study*—Report numbers of outcome events or summary measures (page 12) |
| Main results | 16 | (*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included (page 12, Table 2, Figure) |
| | | (*b*) Report category boundaries when continuous variables were categorized [N/A] |
| | | (*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period [N/A-do not provide relative risk ratios] |
| Other analyses | 17 | Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses (page 12, Table 2, Figure) |
| **Discussion** | | |
| Key results | 18 | Summarise key results with reference to study objectives (page 12-13) |
| Limitations | 19 | Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias (page 14-15) |
| Interpretation | 20 | Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence (page 14, 15) |
| Generalisability | 21 | Discuss the generalisability (external validity) of the study results (page 14) |
| **Other information** | | |
| Funding | 22 | Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based (page 16, 11) |

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

**Note:** An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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# Assessing the Impact of Colonoscopy Complications on use of Colonoscopy among Primary Care Physicians and Other Connected Physicians: An Observational Study of Older Americans



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# Assessing the Impact of Colonoscopy Complications on Use of Colonoscopy among Primary Care Physicians and Other Connected Physicians: An Observational Study of Older Americans

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**Running head**: Physician psychological biases and colonoscopy use

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## ABSTRACT

**Objectives**: Psychological biases can distort treatment decision-making. The availability heuristic is one such bias, wherein events that are recent, vivid, or easily imagined are readily "available" to memory and are therefore judged more likely to occur than expected based on epidemiologic data. We assessed if the occurrence of a serious colonoscopy complication for a primary care physician's patient influenced colonoscopy rates for the physician's other patients.

**Design**: Longitudinal study with time-varying exposure variables.

**Setting/Participants**: Individuals living in 51 hospital referral regions across the U.S. identified based on enrollment in fee-for-service Medicare during 2005-2010. We assigned patients to a primary care physician based on office visits during the prior 2 years.

**Exposures**: For each physician in each month, we calculated the proportion of patients assigned to them who had a colonoscopy. We identified 2 serious complications of which the primary care provider would very likely be aware: gastrointestinal bleed or perforation leading to hospitalization or death within 14 days of colonoscopy.

**Main Outcome Measures**: We employed Poisson regression models including physician fixed effects to assess the change in number of colonoscopies in the 4 quarters following an adverse colonoscopy event.

**Results**: We identified 5,360,191 patients assigned to 30,704 physicians. 4,864 physicians (16%) had at least 1 patient with an adverse event. The estimated change in the quarterly number of colonoscopies among physicians' patients was significantly lower in quarter 2 following an adverse colonoscopy event (change=-2.1% (95%CI=-3.4 to -0.8%)), before returning to the rate expected in the absence of an adverse event.

**Conclusions**: Having a patient experience a serious adverse colonoscopy event was associated with a small and temporary decline in colonoscopy rates among a physician's other patients. These findings provide empirical evidence for the influence of notable adverse events on care, possibly due to the availability heuristic.

Key words: colorectal cancer screening, medical decision making

Abstract word count=296

## Article Summary

Strengths and limitations of this study

- We studied a large representative cohort of patients and their physicians allowing us to assess consequences of infrequent but very serious adverse events of colonoscopy, a frequently recommended screening procedure.
- We used a longitudinal study design with time varying exposure variables to adjust for patient and physician factors in our longitudinal data.
- Limitations included our focus on Americans aged 65 and older, the possibility of misattribution of patients to physicians, and the lack of direct information about physicians' and patients' decision making processes.

## INTRODUCTION

A physician's recommendation is an important determinant of whether a patient undergoes recommended screening and preventive testing such as colorectal cancer screening.[1-3] Traditionally, cancer screening is a core component of primary care, and adherence to screening recommendations is a key quality indicator for primary care physicians and practices. Colorectal cancer screening is particularly effective, and expanded screening is credited as contributing to at least some of the declining incidence and mortality from this condition.[4 5] The United States Preventative Services Task Force recommends screening for colorectal cancer for adults beginning at age 50 for average-risk individuals.[6] Although there are several accepted methods for colorectal cancer screening, including annual fecal occult blood screening and flexible sigmoidoscopy every five years, most primary care physicians and gastroenterologists favor colonoscopy as the preferred method of screening.[7] Colonoscopy, however, has potential risks, which have been increasingly highlighted by guideline panels. These risks include complications from the procedure,[8] as well as the possibility of false positive tests and overdiagnosis and overtreatment.

Evidence suggests that psychological biases can distort treatment decision-making relative to a traditional utility maximization reference.[9] The availability heuristic is one such bias wherein events that are recent, vivid, or easy to imagine are readily "available" to memory and are therefore judged to be more likely to occur than would be expected based on epidemiologic data.[10] Yet, few data are available that quantify the impact of such biases on physician decision-making and the care that is delivered to patients. Two prior studies have provided some evidence for the effect of availability bias on diagnostic judgments, but these studies were small and limited to resident physicians.[11 12] Expanding the evidence base regarding the rational and non-rational forces driving physician behavior will help to identify

specific types of clinical decisions that might be influenced by such biases, which could allow physicians and organizations to design interventions to overcome biases when they are likely to occur. In addition, such data could help to identify opportunities for improving physicians' understanding of clinical evidence and how that evidence is shared with patients making decisions about care.

We used administrative data from the U.S. Medicare program for beneficiaries and their physicians from 2005 through 2010 to assess for empirical evidence of cognitive bias in colorectal cancer screening. Specifically, we examined if the occurrence of a serious complication of screening colonoscopy among a primary care physician's patients influenced colonoscopy rates among the physician's other patients in subsequent months. We hypothesized that screening rates for physicians' patients would decrease in the period following experience with a patient having a serious adverse event. We next assessed if any effects of serious adverse events of screening on future screening differed for patients in a physician's panel who were older (vs. younger), since the relative ratio of benefit to harm of colonoscopy screening is lower for patients older than 75 years and current guidelines recommend against routine screening for this group.[6] We hypothesized that effects would be greater for a physician's older patients. We also assessed if the effects differed by physicians' experience in practice, hypothesizing that younger (less experienced physicians) may be more impacted than others by a serious adverse event. Finally, we assessed if the serious adverse event changed screening behaviors for other primary care physicians within that primary care physician's practice as might be expected if physicians shared experiences of adverse events with their colleagues. We hypothesized that if overall effects were large, there may be similar but smaller effects among peers.

## METHODS

### Data and subjects

We used 100% Medicare data from the inpatient, outpatient, and carrier files for this analysis. Medicare is the national health insurance program for Americans aged 65 and older. We studied care for patients living in 50 hospital referral regions in the U.S. during 2005-2010; the regions were randomly sampled with probability proportional to their size; we also included the Boston hospital referral region. We identified all patients aged ≥65 who were continuously enrolled in parts A and B of fee-for-service Medicare for at least 1 year (or until death if <1 year) during the study period.

Because our focus was on screening behaviors of physicians for patients they treated, we assigned all patients to a physician for each month during 2006 through the end of 2010 based on the plurality of office visits for primary care services in the two years preceding that month.[13] This study is similar to attribution algorithms used to assign patients to physicians in U.S. Accountable Care Organizations. We assigned patients to physicians based on 2 years of data to provide more stable patient panels and to account for patients aging into or leaving fee-for-service Medicare or dying. We weighted physician visits from the more recent year 0.67 and from the earlier year 0.33. For example, for January 2007, the algorithm assigned patients to a physician using claims from February 2005 through January 2007, with visits during February 2005-January 2006 weighted 0.33 and visits from February 2006-January 2007 weighted 0.67. The algorithm uses evaluation and management codes for face-to-face office visits and first assigns patients to generalist physicians (internal medicine, family practice, general practice, geriatrics); patients with no visits to generalists physicians, were assigned to other medical specialists who might plausibly serve as their primary care physician. We assessed physician specialty based on the specialty code on the submitted claims, which may best reflect the type

of care that they delivered to patients at that visit.[14] We then focused analyses on primary care physicians (the generalist specialties described above) and medical specialists who may be providing primary care (cardiology, pulmonary, nephrology, infectious disease, endocrinology, and rheumatology; we did not include gastroenterology to avoid including physicians who may also be performing a patient's colonoscopy). In preliminary analyses, findings were similar when including only primary care physicians.

Among 45,652 physicians to whom patients were assigned from 2005-2010, we excluded 14,323 physicians with fewer than 25 Medicare patients assigned to them in any month (based on the assignment algorithm over the 2-year window described above) and an additional 625 physicians were excluded by focusing on care during 2006-2010. The final cohort included 5,360,191 patients assigned to 30,704 physicians.

We obtained information about physician age, and sex from the American Medical Association Physician Masterfile. For each physician, we also identified peer physicians who were working in the same practice based on the tax identification number used for billing; we considered all other physicians billing under the same tax identification number as peers whose practice decisions might be influenced by their colleagues' experiences and behaviors. We assigned the 1.0% of physicians who submitted claims under more than one tax identification number to the tax identification number for the first claim they submitted during the calendar year.

**Identifying colonoscopy and serious complication associated with colonoscopy**

We identified all patients who underwent screening or diagnostic colonoscopies in the outpatient setting (Medicare place of service codes 22, 24, 49) using procedure codes included in the Appendix Table.[8] If patients had more than 1 colonoscopy in a 1-year period, we only

included the first occurrence. Prior work has examined complications of colonoscopy leading to emergency department visit or hospitalization within 30 days of the procedure.[8] But primary care providers may be unaware of relatively minor complications that may not come to their attention. Therefore, in this analysis, we focused on two serious complications that were highly likely to be associated with the colonoscopy and of which the primary care provider would very likely be aware: gastrointestinal bleed or perforation within 14 days of the colonoscopy that led to hospitalization or death (Appendix Table).

For each physician in each month from January 2006 through December 2010, we calculated the number of colonoscopies and the colonoscopy rate, defined as the number of colonoscopies that his/her assigned patients had in that month divided by all patients assigned to that physician in that month. We also identified each month during which a physician had a patient that experienced a serious complication.

**Patient involvement**

The research protocol was approved by the Harvard Medical School Committee on Human Subjects (#23686). Patient consent was not obtained because our data, which were previously collected for billing purposes, did not include patient identifiers. Patients were not involved in the study design, although we studied a common procedure that most older Americans have been asked to consider for colorectal cancer screening.[7]

**Analyses**

We used a longitudinal study design with time-varying exposure variables to understand the impact of colonoscopy complications on future screening behaviors. This is akin to a difference-in-differences design in that we examined care with 5 years of longitudinal data,

physicians served as their own control during months prior to any adverse event; physicians who had no adverse event in any month (84% of physicians) also served as controls. We used fixed effect Poisson regression with a logarithmic link function to model the expected number of colonoscopies in each month during the study period. The models included fixed effects for each physician as well as indicator variables for each of the 60 study months (which adjusts for differences over time and/or seasonal differences in colonoscopy use) and 4 time-varying indicator variables reflecting the presence or absence of a colonoscopy adverse event in each of the 4 quarters before the month of interest. We also included the number of patients assigned to each physician in that month as the Poisson offset variable; this effectively serves as a denominator for the dependent variable (number of colonoscopies in a month), allowing us to interpret model coefficients as estimates of the change in the rate of colonoscopies among a physician's assigned patients. Because a patient will have at most one colonoscopy per quarter, the rate is essentially the proportion of all assigned patients who receive a colonoscopy per quarter.

In a second set of models, we conducted stratified analyses for patients aged 65-74 and aged 75 and older to assess if effects of an adverse colonoscopy event on future colonoscopies varied for younger vs. older patients, since for older patients the benefits of colonoscopies may be less and the risk of adverse events greater. We also ran a single model to test the statistical significance of the age group interaction.

In a third set of models, we stratified analyses by physician age (as a proxy for experience/years in practice) above or below the median to assess if effects of a serious adverse colonoscopy event were more pronounced for younger (less experienced physicians). We also tested the statistical significance of the physician age interaction.

In a fourth model, we restricted to the 5513 practices with more than one physician in our cohort and included quarterly indicators reflecting an adverse event in one of the preceding 4 quarters for each physician as well as a second set of quarterly indicator variables reflecting presence or absence of a colonoscopy adverse event among other physicians practicing in the same practice for each of the 4 prior quarters. This allowed us to assess whether an adverse colonoscopy event among a peer physician in the practice influenced a physician's colonoscopy ordering.

Finally, as a robustness check, we reran our models using the number of mammograms as the dependent variable as a falsification test, since colonoscopy adverse events should not have any influence on breast cancer screening. To do this, we assessed if physicians whose patients had an adverse event related to colonoscopy had any temporal changes in their rate of screening mammography among women patients aged 65 and older (we expected no changes). We identified screening mammography based on procedure codes (Appendix Table).

In all models, the repeated (monthly) observations on physicians were accounted for by using generalized estimating equations using the identity as the working correlation matrix. The resulting standard errors are robust to the true relationship between the variance and the mean of the outcome variable, which are restrictively assumed to be equal when the outcomes have a Poisson distribution, and to the correlation structure among a physician's observations. Data on physician age and sex were missing for 334 physicians; however, because we included physician fixed effects in models to adjust for physician differences,

we did not include these time-invariant variables, and therefore all physicians and patients are included in final analyses.

The sponsor had no role in the research.

## RESULTS

We identified 5,360,191 patients assigned to 30,704 physicians practicing in 21,770 practices for which 5,513 practices had more than one physician in our cohort. Characteristics of the patients and physicians are included in Table 1. The mean age of the physicians was 50.5 (SD=11.0); 73.3% were male, and they had an average of 122.5 Medicare patients assigned (SD=121.9). Physicians were observed for a mean (SD) of 42.2 (12.4) months (range=1-49). Among assigned patients, approximately 10 patients had a colonoscopy in any year, consistent with the number expected for a test that is recommended once every 10 years. Overall, 6,095 patients (0.1%) experienced a serious adverse colonoscopy event between January 2006 and December 2010; 4,864 physicians (16%) had at least 1 patient with a serious adverse event; 951 (3%) of physicians had 2 or more patients experience an adverse event.

In models with physician fixed effects, the estimated number of colonoscopies among physicians' patients following an adverse colonoscopy event was significantly lower by 2.1% (95% confidence interval, -3.4 to -0.8) in quarter 2 following the adverse event (Table 2 and Figure 1), before returning to the number that would be expected in the absence of an adverse event. In stratified analyses comparing physicians' patients aged 65-74 years vs. aged 75 and older, the association of an adverse colonoscopy event was generally similar to our primary model (Table 2), and the interaction of quarter following an adverse

colonoscopy event by patient age group was not statistically significant (P for interaction=0.15). In stratified analyses comparing younger versus older physicians, the association of an adverse colonoscopy event with fewer subsequent colonoscopies was observed only for younger physicians (p for interaction=0.007, Table 2). When assessing for peer effects, there was no detectable decrease in the colonoscopy rates among other primary care physicians in the physicians' practices (all P>.15) (Table 2).

In our falsification test assessing if the expected number of mammograms for a physician's patients changed in the quarters following an adverse colonoscopy event, we found no differences (Table 3).

## DISCUSSION

Having a patient experience a serious adverse event from colonoscopy was associated with a small and temporary decline in rates of colonoscopy among a physician's other Medicare patients. These findings provide empirical evidence for the influence of notable adverse events on care, possibly due to the availability heuristic. The negative impact is relatively modest for this clinical condition, wherein screening generally is supported by strong evidence; effects could be larger for other clinical conditions. The decline we observed was seen in the 2nd quarter following the adverse event, which is consistent with the lag in obtaining colonoscopy from the time a physician recommends/orders it and it is completed, such that the lower likelihood of referring for screening might not be evident until several months after the adverse event. As more time from the adverse event passed, this effect disappeared, suggesting that more recent experience with no adverse events led physicians to return to their baseline rate of ordering.

The small decline in colonoscopy rates was evident for physicians' patients who were relatively younger (65-74) and older (75 and older), suggesting that the decline was not related to specific consideration of an individual patient's risk of an adverse event (older patients experience less benefit from screening colonoscopy and have greater risks). Rather, physicians seem to have ordered fewer colonoscopies for all patients. Prior work suggests substantial overuse of colonoscopies in patients over the ages of 75 and 85 years.[15 16] Nevertheless, fewer colonoscopies were performed overall among the older versus younger patients, which may reflect physicians' appreciation of the lower benefit of screening in this group. The decline in colonoscopy rates was observed for younger but not older physicians. Younger physicians, with less experience, may be particularly at risk of psychological biases associated with rare events.

We found no evidence of an effect on a physician's peers in a practice (those billing under the same tax identification number), suggesting that the impact of the negative adverse event was not sufficiently great as to influence practice-level discussions about screening. It may be that physicians do not discuss such events or their thoughts about screening routinely with their practice partners. Alternatively, they may have such discussions with a limited group of colleagues, for which our method of identifying practice peers was not adequately sensitive.

Our findings suggest that efforts may be needed to help physicians avoid influences of psychological biases on the care they deliver. Decision making is complex, and prior work suggests challenges in improving care delivery even after helping clinicians correct inaccurate estimation of the probability an event will occur. For example, one study succeeded in substantially improving clinicians' prior overestimations of the probability of

streptococcal pharyngitis, but the proportion of patients prescribed antibiotics showed a trend toward increasing.[17] Nevertheless, expanded use of shared decision-making tools holds great promise in helping physicians avoid cognitive biases in their estimates of probabilities of adverse events. If physicians and patients routinely discuss or review the benefits and harms of tests, procedures, and treatments, then the associated probabilities and their expected implications will remain familiar to them. Decision aids can help with making such information easily accessible to patients and their physicians.[18]

Our study has several limitations. First, we focused on older Americans enrolled in fee-for-service Medicare; however, we do not expect the results to differ in other populations. We also studied only physicians caring for at least 25 Medicare beneficiaries, thus our findings may not generalize to very-low-volume physicians. Second, our evidence is indirect; we had no information about the physician's decision-making process (including the possible use of decision aids), if the assigned physician was the one who actually ordered the screening test, or the timing of colonoscopy orders for colonoscopies that were received. In addition, we inferred that these primary care physicians learned about the serious adverse events, but we have no direct knowledge of this; nevertheless, such lack of awareness would tend to bias the results towards the null. We also did not observe colonoscopies that were ordered but not obtained by patients; nor did we observe changes to other screening strategies, such as fecal occult blood testing, which are not accurately identified in administrative data.[19] In addition, we were not able to identify precisely patients who required more frequent colonoscopies per current screening guidelines. We therefore relied on the assumption that rates among a physician's panel would be relatively stable over time, consistent with prior studies.[20] Next, there may have been some misattribution of patients to physicians, although we do not expect that would create any bias. Also, the

relatively few serious adverse events observed, despite being consistent with prior studies,[8] limited our power to assess for differences among physicians experiencing multiple adverse events. Finally, we did not attempt to distinguish between screening and diagnostic colonoscopies. While we might expect to see a greater decrease in screening colonoscopies following an adverse colonoscopy event because these may be less necessary, we also might also see a decline in diagnostic colonoscopies, which have higher baseline rates of adverse events. A new algorithm for identifying screening colonoscopies using claims data[21] may allow for such distinctions once externally validated.

In conclusion, a physician's experience of a patient having a serious adverse event from colonoscopy was associated with a small and temporary decline in rates of colonoscopy among that physician's other patients that did not vary by the baseline risk of the physician's patients based on age, but was observed primarily for younger physicians, who have less clinical experience. These findings suggest that cognitive bias can lead some physicians to inaccurately interpret the relative harm to benefit ratio. Increased use of tools to enhance shared decision-making with patients may be one strategy to ensure that clinical decisions are based on the best available evidence about benefits and harms.

**Contributorship Statement:** Dr. Keating had full access to all of the data in the study and affirms that the manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained.

Study concept and design: All authors

Analysis and interpretation of data: All authors

Drafting of the manuscript: Keating

Critical revision of the manuscript for important intellectual content: All authors

Final approval of the manuscript: All authors

**Competing Interest Statement**: All authors have completed the ICMJE uniform disclosure form at http://www.icmje.org/coi_disclosure.pdf and declare: no support from any organisation for the submitted work; no financial relationships with any organisations that might have an interest in the submitted work in the previous three years, no other relationships or activities that could appear to have influenced the submitted work except as described. Dr. Keating serves as a medical editor for the Informed Medical Decisions Foundation, now part of Healthwise, a non-profit organization that seeks to improve health care decisions. None of the other authors have relationships with any entities with potential financial interest in this topic.

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**Data Sharing**. Data were obtained from the U.S. Centers for Medicare and Medicaid Services (CMS). Due to data use agreement restrictions, we cannot share our project data with other investigators, but the Medicare data can be obtained from CMS. Statistical code is available from the authors upon request.

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Table 1. Characteristics of physicians in the cohort, N=30,704*

| Characteristic | |
|---|---|
| Physician age in years, mean (SD) | 50.5 (11.0) |
| Sex, % | |
| Male | 73.3 |
| Female | 26.7 |
| Specialty, % | |
| Primary care physician | 85.0 |
| Medical specialist | 15.0 |
| N assigned patients, mean (SD) | 122.5 (121.9) |
| Age of assigned patients in years, mean (SD) | 77.1 (2.0) |
| Proportion of physicians' assigned patients who are male, mean (SD) | 39.9 (13.7) |
| Race/ethnicity of physicians' assigned patients | |
| Proportion who are white, mean (SD) | 83.9 (23.6) |
| Proportion who are black, mean (SD) | 8.9 (18.0) |
| Proportion who are Hispanic, mean (SD) | 3.1 (9.5) |
| Hierarchical condition category score of physicians' assigned patients, mean (SD) | 1.45 (.42) |
| Yearly number of colonoscopies among physicians' assigned patients, mean (SD) | 10.2 (16.6) |
| Quarterly number of colonoscopies among physicians' assigned patients, mean (SD) | |
| Among all patients | 2.5 (3.4) |
| Among patients aged 65-74 | 1.6 (2.2) |
| Among patients aged 75 and older | 1.0 (1.6) |
| Monthly number of colonoscopies among physicians' assigned patients, mean (SD) | 0.8 (1.4) |

*Patient and physician characteristics and characteristics of physicians' patients were calculated for each month that they were in the data set (physicians) or were attributed to a physician (patients) and averaged over all months that they were observed. Data on physician age and sex were missing for 334 physicians.

Table 2. Change in quarterly number of colonoscopies among physicians' patients following an adverse colonoscopy event among a physician's patient

| | % Change (95% CI)* | P value* |
|---|---|---|
| **Primary model** | | |
| Quarter 1 | -0.7 (-2.0 to 0.7) | .34 |
| Quarter 2 | **-2.1 (-3.4 to -0.8)** | **.002** |
| Quarter 3 | -0.9 (-2.3 to 0.4) | .18 |
| Quarter 4 | 0.0 (-1.4 to 1.4) | 1.00 |
| **Model stratified by patient age (above/below 75 years)**** | | |
| Patients 65-75 years | | |
| Quarter 1 | -0.1 (-2.5 to 2.3) | .91 |
| **Quarter 2** | **-4.3 (-6.6 to -2.0)** | **<.001** |
| Quarter 3 | -1.1 (-3.6 to 1.4) | .39 |
| Quarter 4 | -1.6 (-4.0 to 0.9) | .21 |
| Patients >75 years | | |
| **Quarter 1** | **-3.4 (-6.0 to -0.7)** | **.01** |
| **Quarter 2** | **-2.7 (-5.3 to -0.1)** | **.04** |
| **Quarter 3** | **-3.5 (-6.1 to -0.7)** | **.01** |
| Quarter 4 | -1.1 (-3.8 to 1.7) | .43 |
| **Model stratified by physician experience (age above/below median)***** | | |
| Physicians <50.2 years | | |
| Quarter 1 | -1.2 (-3.3 to 0.9) | .25 |
| **Quarter 2** | **-5.1 (-7.3 to -3.0)** | **<.001** |
| **Quarter 3** | **-2.4 (-4.4 to -0.4)** | **.02** |
| Quarter 4 | -0.2 (-2.4 to 2.0) | .85 |
| Physicians ≥50.2 years | | |
| Quarter 1 | -0.6 (-2.4 to 1.1) | .48 |
| Quarter 2 | -0.1 (-1.9 to 1.7) | .93 |
| Quarter 3 | 0.1 (-1.8 to 2.0) | .93 |
| Quarter 4 | -0.1 (-2.0 to 1.8) | .91 |
| **Model including physicians' patients and patients of other physicians in their practice (among 5513 practices with 2 or more physicians)** | | |
| Physician | | |
| Quarter 1 | -0.8 (-2.5 to 0.8) | 0.31 |
| Quarter 2 | -2.6 (-4.1 to -1.1) | 0.001 |
| Quarter 3 | -1.0 (-2.6 to 0.7) | 0.25 |
| Quarter 4 | 0.8 (-0.9 to 2.4) | 0.37 |
| Physicians' practice peers | | |
| Quarter 1 | 0.3 (-0.4 to 1.0) | .39 |
| Quarter 2 | 0.5 (-0.2 to 1.2) | .16 |
| Quarter 3 | 0.0 (-0.7 to 0.7) | .95 |
| Quarter 4 | 0.6 (0.0 to 1.3) | .07 |

*Using fixed effects Poisson regression to model the number of colonoscopies. Models included fixed effects for each physician and indicators for study month as well as 4 indicator variables reflecting presence or absence of a colonoscopy adverse event in each of the 4 quarters before the month of interest. Models also include the number of patients assigned to the physician in that month, which serves as an offset variable allowing an interpretation of the dependent variable (number of colonoscopies) as a rate (number of colonoscopies per number of assigned patients).
**P for interaction=0.15
***P for interaction=0.007
Bolded values reflect statistical significance at two-sided P<.05.

Table 3. Falsification test: change in quarterly number of mammograms among physicians' patients following an adverse colonoscopy event among a physician's patient

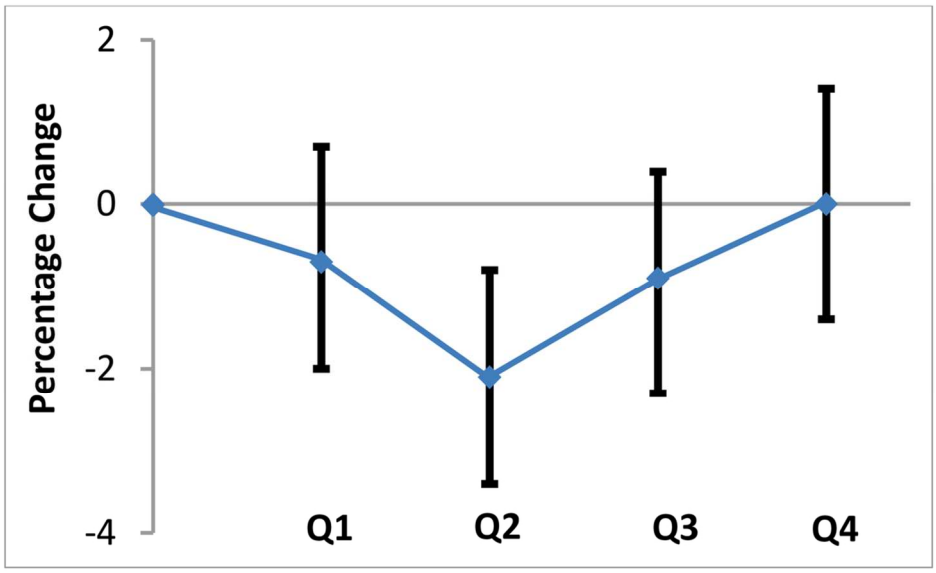
| | % Change (95% CI) | P value |
|---|---|---|
| Quarter 1 | -0.4 (-1.2 to 0.3) | .26 |
| Quarter 2 | -0.2 (-0.9 to 0.6) | .66 |
| Quarter 3 | 0.1 (-0.6 to 0.9) | .74 |
| Quarter 4 | 0.0 (-0.7 to 0.8) | .95 |

*Using fixed effects Poisson regression to model the number of mammograms. Models included fixed effects for each physician and indicators for study month as well as 4 indicator variables reflecting presence or absence of a colonoscopy adverse event in each of the 4 quarters before the month of interest. Models also include the number of patients assigned to the physician in that month, which serves as an offset variable allowing an interpretation of the dependent variable (number of mammograms) as a rate (number of mammograms per number of assigned patients).

Figure Legend

Figure 1. Percentage Change in Quarterly Number of Colonoscopies among Physician's Patients Following Adverse Event

Percentage change and 95% confidence interval for each quarter following a physician's patient experiencing an adverse colonoscopy event.




108x68mm (300 x 300 DPI)

Appendix Table. CPT, ICD-9, and HCPCS codes for colonoscopy and sentinel events and for mammography

| Procedure | CPT | ICD-9 Procedure | ICD-9 Diagnosis | HCPCS | Revenue center |
|---|---|---|---|---|---|
| **Complications of Colonoscopy and Colonoscopy Screening*** | | | | | |
| **Identify outpatient colonoscopy based on Medicare place of service code = 22, 24, 49** | | | | | |
| Screening | | | | G0105, G0121 | |
| Diagnostic | 45378 | 45.23 | | | |
| With Polypectomy | 45380, 45383, 45384, 45385, 45392 | 45.42 | | | |
| **Complications from colonoscopy** | | | | | |
| **Note: all based on ER visit† or hospitalization within 30 days of the date of the procedure** | | | | | |
| Serious gastrointestinal events | | | | | |
| Perforation | | | 569.83, 998.2 | | |
| Gastrointestinal bleeding | | | 285.1, 578.x, 998.1 | | |
| | | | | | |
| **Mammography‡** | 77055, 77056, 77057 76090, 76091, 76092 77061, 77062, 77063 | 87.36, 87.37 | | G0202, G0204, G0206 | 0401, 0403 |

*As per Warren JL, Klabunde CN, Mariotto AB, et al. Adverse events after outpatient colonoscopy in the Medicare population. Ann Intern Med. Jun 16 2009;150(12):849-857. Note that did not include colonoscopy with other procedures, including foreign-body removal, submucosal injection, hemostasis, endoscopic ultrasound, and transmural or intramural aspiration and/or biopsy. To identify ER visits, we used revenue center codes of 0450-0459 or 0981 in the outpatient file or ER_AMT>0 in the MEDPAR file.

‡ Mammography based on HEDIS 2015 technical specifications[17], but also including prior similar codes phased out in 2007 (76090-76092) and tomosynthesis codes (77061-77063) (note G0203, G0205 deleted 1/2005). To avoid double counting mammograms due to false positives or facility + physician bills, patients can only have one mammogram in a 3-month period—use the date of the first of these codes. We examined codes in the carrier and outpatient files.

**Instructions for Reviewers Checklist**

**Research articles**

Research submissions should have a clear, justified research question.
All articles should include the following.

- The article title should include the research question and the study design. Titles should not declare the results of the study. **DONE**
- A structured abstract (max. 300 words) including all the following where appropriate (please note that for RCTs there is a specific CONSORT extension for abstracts): **DONE-PAGE 3**
    - objectives: clear statement of main study aim and major hypothesis/research question
    - design: e.g. prospective, randomised, blinded, case control
    - setting: level of care e.g. primary, secondary; number of participating centres. Generalise; don't use the name of a specific centre, but give geographical location if important
    - participants: numbers entering and completing the study; sex and ethnic group if appropriate. Clear definitions of selection, entry and exclusion criteria
    - interventions: what, how, when and how long (this can be deleted if there were no interventions)
    - primary and secondary outcome measures: planned (i.e. in the protocol) and those finally measured (if different, explain why) - for quantitative studies only
    - results: main results with (for quantitative studies) 95% confidence intervals and, where appropriate, the exact level of statistical significance and the number need to treat/harm. Whenever possible, state absolute rather than relative risks
    - conclusions: primary conclusions and their implications, suggest areas for further research if appropriate. Do not go beyond the data in the article
    - where applicable, trial registration: registry and number (for clinical trials and, if available, for observational studies and systematic reviews)
- An 'Article summary' section consisting of the heading: 'Strengths and limitations of this study', and containing up to five short bullet points, no longer than one sentence each, that relate specifically to the methods of the study reported. They should not include the results of the study and should be placed after the abstract. **DONE-PAGE 5**
- The original protocol for the study, where one exists, as a supplementary file. **N/A**

- A funding statement, preferably worded as follows. Either: 'This work was supported by [name of funder] grant number [xxx]' or 'This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors'. You must ensure that the full, correct details of your funder(s) and any relevant grant numbers are included. **DONE-PAGE 13, 18**

- A competing interests statement. See this advice from the BMJ on what to include. **DONE-PAGE 18**

- Articles should list each author's contribution individually at the end; this section may also include contributors who do not qualify as authors. Please visit the ICMJE website for more information on authorship. **DONE-PAGE 18**

- Any checklist and flow diagram for the appropriate reporting statement, e.g. STROBE (see below). **DONE-STROBE CHECKLIST INCLUDED**

- Any article that contains personal medical information about an identifiable living individual requires the patient's explicit consent before we can publish it. We will need the patient to sign our consent form, which requires the patient to have read the article. This form is available in multiple languages. **N/A**

- Please provide a data sharing statement such as: "Technical appendix, statistical code, and dataset available from the Dryad repository, DOI: [include DOI for dataset here]. **DONE-PAGE 18**

We recommend your article does not exceed 4000 words, with up to five figures and tables. This is flexible, but exceeding this will impact upon the paper's 'readability'. Supplementary and raw data can be placed online alongside the article although we prefer raw data to be made publicly available and linked to in a suitable repository (e.g. Dryad, FigShare). We may request that you separate out some material into supplementary data files to make the main manuscript clearer for readers. **DONE-3341 WORDS**

We also recommend, but do not insist, that the discussion section is no longer than five paragraphs and follows this overall structure (you do not need to use these as subheadings): a statement of the principal findings; strengths and weaknesses of the study; strengths and weaknesses in relation to other studies, discussing important differences in results; the meaning of the study: possible explanations and implications for clinicians and policymakers; and unanswered questions and future research. **DONE**

Authors are encouraged to submit figures and images in colour - there are no colour charges. **COLOR FIGURE INCLUDED**

At upload you will be asked to choose one general subject area that applies to your article - it will be published under this banner on the main table of contents. You will also be asked to select further subject headings to be used for the 'Browse by topic' section, and specific keywords for help with identifying reviewers. **DONE**

STROBE Statement—checklist of items that should be included in reports of observational studies [Yellow highlighting reflects check. Our study has some elements of a cohort study and some elements of a cross section al study. Blue highlighting reflects not applicable.]

| | Item No | Recommendation |
|---|---|---|
| **Title and abstract** | 1 | (*a*) Indicate the study's design with a commonly used term in the title or the abstract (page 1) |
| | | (*b*) Provide in the abstract an informative and balanced summary of what was done and what was found (page 2) |
| **Introduction** | | |
| Background/rationale | 2 | Explain the scientific background and rationale for the investigation being reported (page 6-7) |
| Objectives | 3 | State specific objectives, including any prespecified hypotheses (page 7) |
| **Methods** | | |
| Study design | 4 | Present key elements of study design early in the paper (page 7) |
| Setting | 5 | Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection (Page 8) |
| Participants | 6 | (*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up (page 8-9)<br>*Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls [N/A]<br>*Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participant (page 8-9) |
| | | (*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed [N/A-not matched]<br>*Case-control study*—For matched studies, give matching criteria and the number of controls per case [N/A] |
| Variables | 7 | Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable (page 8-10) |
| Data sources/ measurement | 8* | For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group (page 8-10) |
| Bias | 9 | Describe any efforts to address potential sources of bias (page 8-12) |
| Study size | 10 | Explain how the study size was arrived at (page 8-all patients were included) |
| Quantitative variables | 11 | Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why (page 10-12) |
| Statistical methods | 12 | (*a*) Describe all statistical methods, including those used to control for confounding (page 10-12) |
| | | (*b*) Describe any methods used to examine subgroups and interactions (page 10-12) |
| | | (*c*) Explain how missing data were addressed (page 12-13) |
| | | (*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed [N/A]<br>*Case-control study*—If applicable, explain how matching of cases and controls was addressed [N/A]<br>*Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy [N/A-included all physicians and their patients] |
| | | (*e*) Describe any sensitivity analyses (page 12) |

Continued on next page

| | | |
|---|---|---|
| **Results** | | |
| Participants | 13* | (a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed (page 9) |
| | | (b) Give reasons for non-participation at each stage (page 9) |
| | | (c) Consider use of a flow diagram [Note: we considered but because we included all patients of all physicians with at least 25 patients aged 65+, we didn't think this was necessary] |
| Descriptive data | 14* | (a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders (page 13, Table 1) |
| | | (b) Indicate number of participants with missing data for each variable of interest (page 12-13) |
| | | (c) *Cohort study*—Summarise follow-up time (eg, average and total amount ) (page 13) |
| Outcome data | 15* | *Cohort study*—Report numbers of outcome events or summary measures over time (page 13) |
| | | *Case-control study*—Report numbers in each exposure category, or summary measures of exposure [N/A] |
| | | *Cross-sectional study*—Report numbers of outcome events or summary measures (page 13) |
| Main results | 16 | (*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included (page 13-14, Table 2, Figure) |
| | | (*b*) Report category boundaries when continuous variables were categorized [N/A] |
| | | (*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period [N/A-do not provide relative risk ratios] |
| Other analyses | 17 | Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses (page 13-14, Table 2, Figure) |
| **Discussion** | | |
| Key results | 18 | Summarise key results with reference to study objectives (page 14) |
| Limitations | 19 | Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias (page 16-17) |
| Interpretation | 20 | Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence (page 14-17) |
| Generalisability | 21 | Discuss the generalisability (external validity) of the study results (page 16) |
| **Other information** | | |
| Funding | 22 | Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based (page 13, 18) |

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

**Note:** An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.