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# Associations between initial American Board of Internal Medicine certification and maintenance of certification status of attending physicians and in-hospital mortality of patients with acute myocardial infarction or congestive heart failure: a retrospective cohort study of hospitalisations in Pennsylvania, USA

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## ABSTRACT

**Objective** To determine whether internists' initial specialty certification and the maintenance of that certification (MOC) is associated with lower in-hospital mortality for their patients with acute myocardial infarction (AMI) or congestive heart failure (CHF).

**Design** Retrospective cohort study of hospitalisations in Pennsylvania, USA, from 2012 to 2017.

**Setting** All hospitals in Pennsylvania.

**Participants** All 184 115 hospitalisations for primary diagnoses of AMI or CHF where the attending physician was a self-designated internist.

**Primary outcome measure** In-hospital mortality.

**Results** Of the 2575 physicians, 2238 had initial certification and 820 were eligible for MOC. After controlling for patient demographics and clinical characteristics, hospital-level factors and physicians' demographic and medical school characteristics, both initial certification and MOC were associated with lower mortality. The adjusted OR for initial certification was 0.835 (95% CI 0.756 to 0.922; p<0.001). Patients cared for by physicians with initial certification had a 15.87% decrease in mortality compared with those cared for by non-certified physicians (mortality rate difference of 5.09 per 1000 patients; 95% CI 2.12 to 8.05; p<0.001). The adjusted OR for MOC was 0.804 (95% CI 0.697 to 0.926; p=0.003). Patients cared for by physicians who completed MOC had an 18.91% decrease in mortality compared with those cared for by MOC lapsed physicians (mortality rate difference of 6.22 per 1000 patients; 95% CI 2.0 to 10.4; p=0.004).

**Conclusions** Initial certification was associated with lower mortality for AMI or CHF. Moreover, for patients whose physicians had initial certification, an additional advantage was associated with its maintenance.

## Strengths and limitations of this study

- ► The study is based on a sizeable number of patients and physicians and extensive sensitivity analyses were conducted.
- ► This is a retrospective observational study and cannot establish causality.
- ► Unmeasured institutional effects may have influenced the results, but a hospital fixed effect analysis significantly reduced this possibility.
- ► Despite our inclusion of a standard set of covariates for both patients and physicians, there might be other unobserved factors that were potentially confounding.
- ► Our work is based on only two primary diagnoses in one state in the USA so broader sampling is needed to increase the generalisability of the results.

## INTRODUCTION

Initial certification in internal medicine has been offered by the American Board of Internal Medicine (ABIM) since its establishment in 1936. These certificates were of unlimited duration until 1990, when ABIM restricted their validity to 10 years and introduced a recertification or maintenance of certification (MOC) programme.[1] Board certification in internal medicine seeks to recognise physicians who have demonstrated that they have the knowledge, skills and attitudes to provide excellent patient care.[2] Given this mission, it is reasonable to expect an association between initial board certification, MOC and patient outcomes. There is some evidence of this kind for initial certification but less for MOC. This retrospective observational study seeks to test whether such relationships exist.

The requirements for initial certification in internal medicine have changed over time, but they have been broadly similar since the oral examination was discontinued in 1970. Candidates must have graduated from a US medical school or been certified by the Educational Commission for Foreign Medical Graduates (ECFMG), satisfactorily completed accredited training, have an unrestricted licence to practise medicine and perform successfully on the certifying examination. There has been more variability in the MOC programme over time, but the programme has basically required initial certification, an unrestricted licence to practise medicine, some form of educational experience and successful performance on an assessment.

There is considerable evidence that initial board certification and educational markers of performance are associated.[3–5] While this form of evidence is important for building an argument for the validity of the certificate, it would fall short of the appropriate expectations of patients and physicians if certification were not also associated with the quality of care provided in practice. In this regard, there is reasonable evidence of a relationship with clinical care. For instance, there are several studies showing that certification is positively associated with the process of care provided to patients and their outcomes, while being negatively associated with disciplinary actions by state licensing boards.[6–10] One aim of this study is to gather additional validity evidence based on the association between initial certification and patient outcomes.

Although it is a newer process, there is evidence of the relationship between MOC and educational markers of performance as well.[11] Nevertheless MOC is a controversial programme, and evidence of a relationship with clinical care is essential.[12–14] On this front, studies have demonstrated a positive association of MOC with process of care measures[15 16] and negative associations with diagnostic errors,[17] healthcare cost[18] and state licensing board disciplinary actions.[19–23] However, there is little evidence speaking to the relationship between MOC and patient outcomes. Consequently, the second aim of this study is to determine whether such an association exists for those physicians who already have initial certification and are choosing to maintain it by taking ongoing assessments over the course of their careers.

To achieve our two aims, we analysed all the hospitalisations for acute myocardial infarction (AMI) or congestive heart failure (CHF) in the state of Pennsylvania for a 6-year period starting in 2012. We limited our focus to the patients of self-identified internists. Included in our study was the initial certification status of the attending physicians, whether they were eligible for MOC, and whether they maintained this status. The outcome measure was in-hospital mortality and we controlled for characteristics of patients and hospitals as well as other physician characteristics.

## METHODS

The Strengthening the Reporting of Observational Studies in Epidemiology reporting guidelines were followed for the study.[24]

### Sources of the data

Data for this study were drawn from the records of the Pennsylvania Health Care Cost Containment Council (PHC4), the American Medical Association (AMA) Physician Masterfile, the ABIM and the ECFMG.

In Pennsylvania, all hospitals (both public and private) are required to send data to PHC4 each time a patient is discharged. Included are patient demographics, primary and secondary diagnoses, discharge status, hospital and the attending physician. The attending physician is identified by the hospital as the individual who has overall responsibility for the medical care and treatment of the patient. Validation and editing processes are applied to the data by PHC4 and hospitals can correct the information. In this study, hospitalisations with a principal diagnosis of AMI or CHF from 1 January 2012 to 31 December 2017 were available for analysis. AMI and CHF were chosen because they occur in sufficient volume and are often used to judge quality of care.[25–27]

The AMA Physician Masterfile contains information on practising physicians in the USA. For this study, we limited the analysis to self-identified general internists who were the attending physicians for patients with AMI and/or CHF in the PHC4 database (we explored the inclusion of self-designated hospitalists as well but not all are internists, and the group was too small (n=60) for analysis). The initial certification status of the self-designated internists, their eligibility for MOC, their initial subspecialty certifications, as well as whether they retained their certification, if eligible, were available from the files of the ABIM. In addition, an indication of whether the physician was an international medical school graduate (IMG) was available from the ECFMG.

### Data elements

From our data sources, we extracted patient age, sex, race, ethnicity, principal and secondary diagnoses, year of admission, discharge status and hospital. For the attending physicians, we knew whether they were US medical graduates (USMGs) or international medical school graduates (IMGs), whether they had initial certification in internal medicine, their sex, age, and year of initial certification, the year they were due for MOC and whether they maintained their certification.

From the data for patients, we calculated a modified version of the Charlson Comorbidity Index.[28] This offered a measure of the severity of illness of the patients in the study. We also combined data for race and ethnicity to a single variable, where white, non-Hispanic patients were

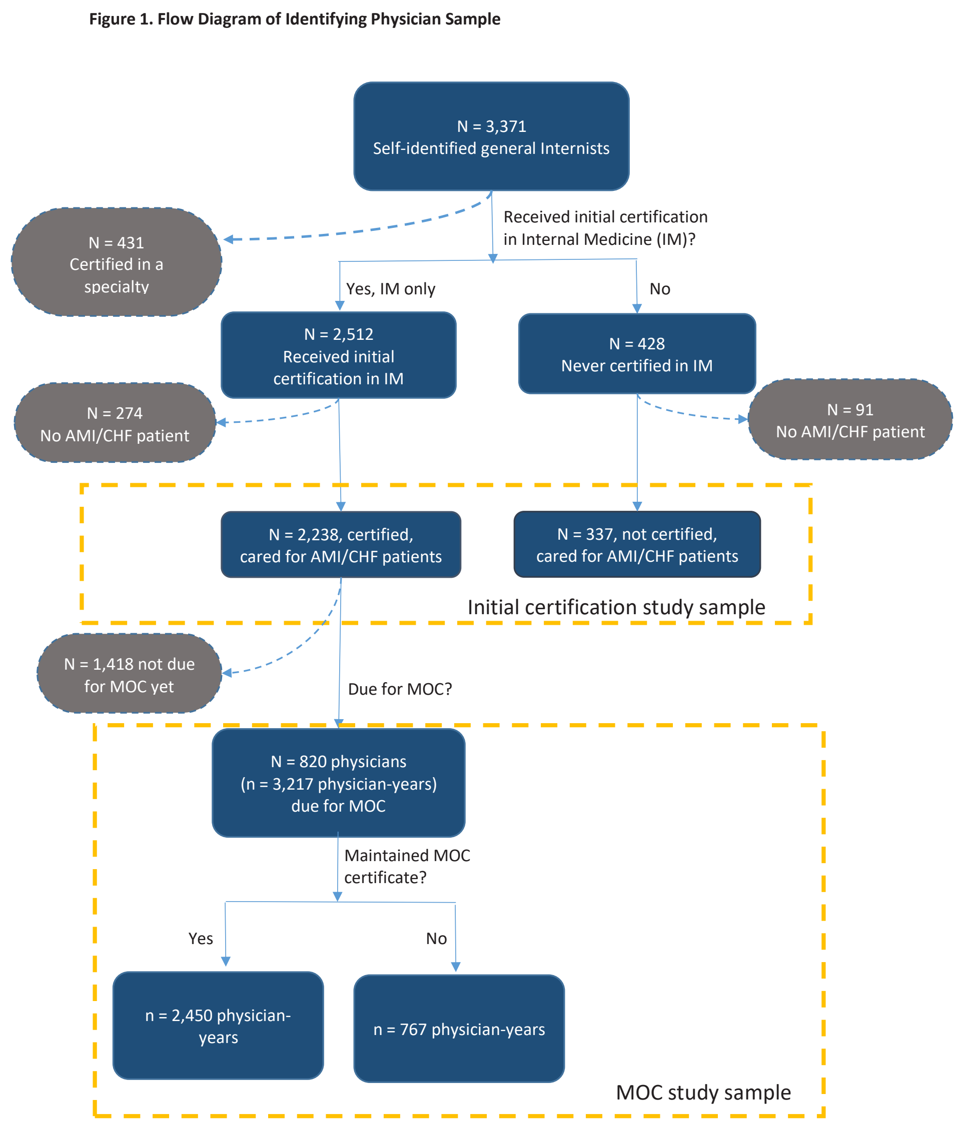


**Figure 1** Flow diagram of the physicians in the study. AMI, acute myocardial infarction; CHF, congestive heart failure; MOC, maintenance of certification.

in one group and all others were in another. We did this because some of the subgroups were too small for reasonable analysis. Finally, we ascertained whether the patient died while in the hospital based on their discharge status.

For the hospitals in the study, we developed two measures. The first was an indicator of whether the hospital was in a rural county by reference to a list maintained by the Pennsylvania Office of Rural Health.[29] The second, an indicator of institutional experience, was a count of the number of patients with AMI or CHF treated by study physicians in the hospital.

## Physicians

Figure 1 presents a flow diagram that identifies the physicians included in the study. From the group of all self-identified internists who were attending physicians to patients in the PHC4 data, we eliminated those who were certified in internal medicine but had a subspecialty certificate as well (n=431) and those who did not care for patients with AMI or CHF (n=274). To determine if initial certification was associated with better patient outcomes, we compared the in-hospital mortality of the patients whose attending physician had initial certification (n=2238) with those who did not (n=428).

To address the question of whether MOC was associated with better patient outcomes, we eliminated from the 2238 physicians with initial certification those who were certified prior to 1990 or were within 10 years of initial certification at the end of the study (ie, by 31 December 2017). The remaining 820 physicians were MOC eligible for some or all the time between 1 January 2012 and 31 December 2017.

During the period of study, a physician's status may have changed from year to year for a variety of reasons. For example, some physicians may have allowed their certification to lapse but restored it at a later point in time, while others may have been within 10 years of

Table 1 Characteristics of the patients and hospitals by attending physician certification status

| | Physicians | | | |
|---|---|---|---|---|
| | Never certified | Initial certification | All hospitalisations | |
| Patient age: n (%) | | | | |
| ≤49 | 1200 (5) | 8391 (5.2) | 9591 (5.2) | |
| 50–64 | 4368 (18.3) | 30 299 (18.9) | 34 667 (18.8) | |
| 65–74 | 4912 (20.6) | 33 209 (20.7) | 38 121 (20.7) | |
| 75–84 | 6499 (27.2) | 43 184 (27) | 49 683 (27.0) | |
| ≥85 | 6900 (28.9) | 45 153 (28.2) | 52 053 (28.3) | |
| Total | 23 879 (13) | 160 236 (87) | 184 115 (100) | P<0.05 |
| Patient sex: n (%) | | | | |
| Female | 11 998 (50.2) | 78 861 (49.2) | 90 859 (49.4) | Missing=3 |
| Male | 11 881 (49.8) | 81 372 (50.8) | 93 253 (50.6) | P<0.005 |
| Patient race/ethnicity: n (%) | | | | |
| White, non-Hispanic | 4083 (17.1) | 27 913 (17.4) | 31 996 (17.4) | Missing=3 |
| Other | 19 796 (82.9) | 132 323 (82.6) | 152 119 (82.6) | P=0.22 |
| Patient condition: n (%) | | | | |
| Acute myocardial infarction | 6575 (27.5) | 41 669 (26) | 48 224 (26.2) | |
| Congestive heart failure | 17 304 (72.5) | 118 567 (74) | 135 871 (73.8) | P<0.0001 |
| Patient comorbid conditions: mean (SD) | 1.012 (1.112) | 0.953 (1.117) | 0.960 (1.117) | P<0.0001 |
| Patient deaths: n (% hospitalisations for that condition) | | | | |
| Acute myocardial infarction | 315 (4.8) | 1553 (3.7) | 1868 (3.9) | P<0.0001 |
| Congestive heart failure | 494 (2.9) | 2664 (2.3) | 3158 (2.3) | P<0.0001 |
| Total | 809 (3.4) | 4217 (2.6) | 5026 (2.7) | P<0.0001 |
| Facility location: n (%) | | | | |
| Non-rural | 17 170 (71.9) | 122 850 (76.7) | 140 020 (76) | |
| Rural | 6709 (28.1) | 37 386 (23.3) | 37 386 (24) | P<0.0001 |
| Facility volume/1000: mean (SD) | 4.41 (3.08) | 5.89 (3.55) | 5.70 (3.52) | P<0.0001 |

initial certification for part of the study (eg, they acquired initial certification in 2005 and were not eligible for MOC until 2015). Consequently, we determined the status of the physician in the year they treated the patient, and in figure 1 we present physician-years (ie, the number of years physicians were eligible for MOC) as well as the number of physicians.

## Analysis

Descriptive statistics were calculated for the hospitalisations and institutions, both for the total patient population and for the subpopulation treated by the MOC group. To determine the adjusted relationship between initial certification and patient mortality, we applied a multivariable logistic regression model which was adjusted for (1) the comorbidity index, (2) the condition (with CHF as the reference), (3) patient age, (4) patient sex (with female as the reference), (5) patient race/ethnicity (with white/non-Hispanic as the reference), (6) whether the physician was an IMG (with USMG as the reference), (7) physician sex (with male as the reference), (8) physician age, (9) hospital location (with non-rural as the reference), and (10) the number of hospitalisations in the institution for AMI or CHF. We applied a similar model to determine the adjusted relationship between MOC and patient mortality. Generalised estimating equations (Stata V.14, StataCorp) were applied to adjust for the clustering of patients within physicians and physicians within hospitals. We used the margins function to simulate the percentage point change in mortality if patients who were cared for by never-certified internists had instead been cared for by ever-certified internists. We did the same for patients who were cared for by internists who did not maintain their certification versus those who had been cared for by internists who maintained their certification.

## Sensitivity analyses

Although we included hospital volume and location in our analyses, it is possible that additional unmeasured institutional characteristics, such as on-site percutaneous coronary intervention or coronary artery bypass graft surgery, might influence the findings. To rule out these and other unknown potential institutional confounds,

**Table 2** Estimated adjusted ORs with 95% CI for in-hospital mortality for patients of all physicians

| Parameter | OR (95% CI) | P value |
|---|---|---|
| **Patient characteristics** | | |
| Acute myocardial infarction | 2.071 (1.937 to 2.214) | <0.001 |
| Comorbidity index | 1.119 (1.091 to 1.149) | <0.001 |
| Sex (female) | 1.113 (1.051 to 1.179) | <0.001 |
| Age | 1.046 (1.039 to 1.054) | <0.001 |
| White, non-Hispanic | 1.028 (0.573 to 1.844) | 0.93 |
| Race/ethnicity × age | 1.004 (0.996 to 1.011) | 0.34 |
| **Physician characteristics** | | |
| Ever certified | 0.835 (0.756 to 0.922) | <0.001 |
| Sex | | |
| Female | 0.923 (0.847 to 1.006) | 0.07 |
| Missing | 0.644 (0.411 to 1.009) | 0.06 |
| Age | 1.005 (1.002 to 1.009) | <0.01 |
| USMG | 0.974 (0.906 to 1.048) | 0.48 |
| **Facility** | | |
| Volume/1000 | 0.997 (0.987 to 1.008) | 0.64 |
| Rural location | 1.228 (1.128 to 1.337) | <0.001 |

USMG, US medical graduate.

we also ran a hospital fixed effect regression model to control the effect of all hospital-level factors.

Likewise, in our models we controlled for condition (AMI vs CHF) but it is possible that the findings could be driven primarily by one or the other. Consequently, we conducted separate analyses for AMI and CHF.

In preliminary analyses we found that there was a significant difference in age between the white non-Hispanic patients (mean=76.3, SD=13.0) and other patients (mean=65.8, SD=14.6). Consequently, we included the interaction of age and race/ethnicity in our multivariate models. Other interactions were tested but not included since they did not alter the interpretation of the results. Likewise, we tested whether a non-linear version of age might be more appropriate, but again it did not make an appreciable difference.

## Patient and public involvement

No patients were involved.

# RESULTS

## Initial certification

There were 184155 hospitalisations for AMI or CHF in the study with an average of 71.5 per physician. The attending physicians for 160236 hospitalisations had initial certification. The mean age of the physicians for these hospitalisations was 44.5 (SD=10.0) and 27.0% of them were managed by women (sex was missing for 771 (0.5%) hospitalisations). The attending physicians for the remaining 23879 hospitalisations did not have initial certification, the mean age of the physicians for these hospitalisations was 52.8 (SD=12.3) and 21.1% of them were managed by women (sex was missing for 235 (1%) hospitalisations).

Table 1 presents the characteristics of the hospitalisations and facilities broken down by whether the attending physician achieved initial certification or was never certified. The patients of the doctors who achieved initial certification were slightly younger and slightly less likely to be female (49.2% vs 50.2%) than the patients of the doctors who were never certified. The difference between groups in terms of race/ethnicity was not statistically significant. As a group, a slightly lower proportion of the patients of the certified doctors had a primary diagnosis of AMI (26% vs 27.5%) and they had slightly fewer comorbid conditions (1.012 vs 0.953). The raw mortalities of the patients of certified doctors were lower (2.6% vs 3.4%).

Most hospitalisations were in facilities located in non-rural settings (76%). However, a smaller proportion of the hospitalisations of the initially certified group were in rural counties (23.3% vs 28.1%). In addition, the hospitalisations of the initially certified group were in hospitals with higher volume (5.89 vs 4.41).

Table 2 shows the results of the multivariable generalized estimating equations (GEE) analysis which incorporates characteristics of the patients, physicians and facilities. After adjustment, initial certification was associated with lower mortality. The adjusted OR was 0.835 (95% CI 0.756 to 0.922; p<0.001). Patients cared for by physicians with initial certification had a 15.87% decrease in mortality compared with those cared for by non-certified physicians (mortality rate difference of 5.09 per 1000 patients; 95% CI 2.12 to 8.05; p<0.001).

In the hospital fixed effect sensitivity analysis which incorporates the same patient and physician characteristics and controls for all hospital-level factors, the adjusted OR for initial certification was 0.826 (95% CI 0.754 to 0.905; p<0.001) (online supplemental table 1). In the sensitivity analysis which models patients with AMI and CHF separately, the adjusted OR for initial certification was 0.827 (95% CI 0.715 to 0.957; p=0.01) for the AMI model and 0.842 (95% CI 0.747 to 0.95; p<0.01) for CHF model (online supplemental table 2). Whether using GEE or hospital fixed effect or fitting patients with AMI and CHF in one combined model or two separate models, all analyses indicate that after adjustment, initial certification was associated with lower mortality and the adjusted ORs were similar across different models.

## Maintenance of certification

The attending physicians for 40468 hospitalisations maintained their certification. The mean age of the physicians for these hospitalisations was 49.8 (SD=6.2), and 22.5% of them were managed by women (sex was missing for 284 hospitalisations). The attending physicians for the

Table 3 Characteristics of the patients by attending physician certification status for those MOC eligible

| | Physicians | | | |
|---|---|---|---|---|
| | Lapsed certification | Certified | All hospitalisations | |
| Patient age: n (%) | | | | |
| ≤49 | 506 (3.6) | 1810 (4.5) | 2316 (4.3) | |
| 50–64 | 2116 (15.1) | 7081 (17.5) | 9197 (16.9) | |
| 65–74 | 2800 (20.0) | 8214 (20.3) | 11 014 (20.2) | |
| 75–84 | 4040 (28.8) | 11 105 (27.6) | 15 145 (27.8) | |
| ≥85 | 4534 (32.4) | 12 258 (30.3) | 16 792 (30.8) | |
| Total | 13 996 (25.7) | 40 468 (74.3) | 54 464 (100%) | P<0.0001 |
| Patient sex: n (%) | | | | |
| Female | 7159 (51.2) | 20 113 (49.7) | 27 272 (50.1) | Missing=1 |
| Male | 6837 (48.9) | 20 354 (50.3) | 27 191 (49.9) | P=0.003 |
| Patient race/ethnicity: n (%) | | | | |
| White, non-Hispanic | 12 125 (86.6) | 33 964 (83.9) | 46 089 (84.6) | Missing=1 |
| Other | 1871 (13.4) | 6404 (16.1) | 8375 (15.4) | P<0.0001 |
| Patient condition: n (%) | | | | |
| Acute myocardial infarction | 3455 (24.7) | 10 112 (25.0) | 13 567 (24.9) | |
| Congestive heart failure | 10 541 (75.3) | 30 356 (75.0) | 40 897 (75.1) | P=0.48 |
| Comorbid conditions: mean (SD) | 0.9303 (1.0986) | 0.9658 (1.1177) | 0.9566 (1.1122) | P<0.0001 |
| In-hospital deaths: n (% hospitalisations for that condition) | | | | |
| Acute myocardial infarction | 171 (5.0) | 380 (3.8) | 551 (4.1) | P<0.003 |
| Congestive heart failure | 299 (2.8) | 666 (2.2) | 965 (2.4) | P<0.0003 |
| Total | 470 (3.4) | 1046 (2.6) | 1516 (2.8) | P<0.0001 |
| Facility location: n (%) | | | | |
| Non-rural | 10 710 (76.5) | 31 244 (77.2) | 41 954 (77.0) | |
| Rural | 3286 (23.5) | 9224 (22.8) | 12 510 (23.0) | P=0.10 |
| Facility volume/1000: mean (SD) | 5.11 (3.34) | 5.82 (3.58) | 5.64 (3.54) | P<0.0001 |

MOC, maintenance of certification.

remaining 13 996 hospitalisations were eligible for MOC but did not maintain it, the mean age of the physicians for these hospitalisations was 52.6 (SD=6.3) and 23.0% of them were managed by women (no missing data).

Table 3 presents the characteristics of the hospitalisations and facilities for attending physicians who had achieved initial certification and were eligible for MOC, broken into two groups depending on whether the physician had maintained his/her certification in the year the patient was treated.

The patients of the doctors who maintained their certification were slightly younger and more often male (50.3% vs 48.9%) than the patients of the doctors who did not. Moreover, a greater proportion of non-white/Hispanic patients were cared for by physicians who maintained their certification (16.1% vs 13.4%). There was not a statistically significant difference between groups of patients in terms of their primary diagnosis and the patients of doctors who maintained their certification had slightly more comorbid conditions. The raw mortalities of the patients of doctors who maintained their certification were lower (2.6% vs 3.4%).

Again, most hospitalisations were in facilities located in non-rural settings (77%). There was not a statistically significant difference in hospital location between the patients of the doctors who maintained their certification and those who did not. The hospitalisations of doctors who maintained certification were in facilities with higher volume (5.82 vs 5.11).

Table 4 shows the results of the multivariable GEE analysis which incorporates characteristics of the patients, physicians and facilities. After adjustment, MOC was associated with lower mortality. The adjusted OR was 0.804 (95% CI 0.697 to 0.926; p=0.003). Patients cared for by physicians who completed MOC had an 18.91% decrease in mortality compared with those cared for by MOC lapsed physicians (mortality rate difference of 6.22 per 1000 patients; 95% CI 2.0 to 10.4; p=0.004).

In the hospital fixed effect sensitivity analysis which incorporates the same patient and physician characteristics

Table 4 Estimated adjusted ORs with 95% CI for in-hospital mortality for patients of physicians eligible for MOC

| Parameter | OR (95% CI) | P value |
|---|---|---|
| **Patient characteristics** | | |
| Acute myocardial infarction | 2.077 (1.839 to 2.347) | <0.001 |
| Comorbidity index | 1.159 (1.107 to 1.215) | <0.001 |
| Sex (female) | 1.07 (0.959 to 1.194) | 0.23 |
| Age | 1.054 (1.04 to 1.068) | <0.001 |
| White, non-Hispanic | 2.61 (0.901 to 7.561) | 0.08 |
| Race/ethnicity × age | 0.991 (0.977 to 1.004) | 0.18 |
| **Physician characteristics** | | |
| MOC | 0.804 (0.697 to 0.926) | <0.01 |
| Sex | | |
| Female | 0.919 (0.775 to 1.089) | 0.33 |
| Missing | 0.718 (0.26 to 1.983) | 0.52 |
| Age | 0.998 (0.987 to 1.009) | 0.72 |
| USMG | 0.978 (0.853 to 1.123) | 0.76 |
| **Facility** | | |
| Volume/1000 | 0.997 (0.978 to 1.016) | 0.77 |
| Rural location | 1.228 (1.044 to 1.444) | 0.01 |

MOC, maintenance of certification; USMG, US medical graduate.

and controls for all hospital-level factors, the adjusted OR for MOC was 0.794 (95% CI 0.695 to 0.908; p<0.01) (online supplemental table 3). In the sensitivity analysis which models patients with AMI and CHF separately, the adjusted OR for MOC was 0.853 (95% CI 0.678 to 1.074; p=0.18) for the AMI model and 0.777 (95% CI 0.66 to 0.915; p<0.01) for the CHF model (online supplemental table 4). Both the main GEE analysis and sensitivity analyses indicate that after adjustment, MOC was associated with lower mortality and the adjusted ORs were similar across different models, except for AMI model. Due to the small sample size, the adjusted OR, even though it was of similar magnitude, was not statistically significant.

## DISCUSSION

The first aim of this study was to ascertain whether there was an association between the initial certification status of attending physicians and the in-hospital mortality of their patients with AMI or CHF. After adjustment for physician, patient and hospital characteristics, initial certification was associated with a 15.87% decrease in in-hospital mortality. These findings are consistent with others reported in the literature.[30 31]

For our analysis of MOC, we focused only on physicians who had initial certification and eliminated those who were certified prior to 1990 or within 10 years of completing training at the end of the study. After adjustment, the MOC status of these physicians was associated with an 18.91% decrease in in-hospital mortality. This adds patient outcomes to the literature on the association of MOC with disciplinary actions and process of care measures.[15–23]

Initial certification assesses the medical knowledge and judgement needed for independent practice and MOC assesses whether physicians remain current throughout their careers. Thus, we propose that the mechanism for the associations we found is that physicians with greater medical knowledge and better medical judgement are, as a group, providing better care which results in improved outcomes, including decreased mortality. Our findings are concordant with other studies associating increased medical knowledge with better care as demonstrated by process measures, costs, state medical board disciplinary actions and specifically diagnostic knowledge as measured by MOC with emergency department visits, hospitalisations and death.[8–10 15–18 21 32]

The magnitude of the associations we found is clinically significant. In fact, the relative decrease in mortality associated with certification and MOC is similar in magnitude to those observed for the use of aspirin in AMI (23%) and for the decrease in all-cause mortality when aspirin is used for the secondary prevention of cardiovascular and cerebrovascular events (18%).[33 34] Ours is an observational study and we are not claiming causality based on our results alone; however, given our hypothesised mechanism, it is plausible that physicians who are staying current in medical knowledge and practice may be more likely to practise in accordance with the best available evidence thus mediating better outcomes.

We found that increased physician age was associated with increased patient mortality. Lending credence to our model is that our finding is concordant with many studies that have demonstrated negative associations of age with educational and patient-relevant outcomes.[3 35 36] Based on our proposed mechanism, it is plausible that increased age, and in particular time from completion of medical training, may make staying current in knowledge and practice more challenging.[37 38] Regrettably, age is not modifiable, but medical knowledge is. Our study showed that, controlling for age, those physicians who stayed current as evidenced by MOC had better patient outcomes.[39]

Of course, our work has the limitations associated with retrospective observational studies. By definition, such studies alone are unable to establish causality. However, for prediction or prognosis investigations, cohort studies are appropriate, and the hospital fixed effect analysis significantly reduced the possibility of unmeasured institutional differences. Despite our inclusion of a standard set of covariates for both patients (age, race, sex and primary and comorbid conditions) and physicians (age, sex, IMG status), there might be other unobserved factors that were potentially confounding. For instance, we did not have access to clinical data for the studied conditions (eg, left ventricular ejection fraction or B-type natriuretic peptide concentrations). However, we have no reason to believe these would vary consistently by physicians' certification status and the measure we used incorporates a broad range of potential morbidities specific to AMI and CHF.

Finally, our work is based on two primary diagnoses in one state in the USA and we could not include cardiologists because there were too few for appropriate analysis. However, Pennsylvania is the fifth most populous state in the USA with a population exceeding 13 million spread across a large, geographically diverse area with both urban and rural communities. Notably, our findings are concordant with studies associating lower mortality in hospitals with more board-certified cardiologists in Japan where board certification also requires a periodic test of medical knowledge consistent with the mechanism we have proposed.[40] Nonetheless, broader sampling across US states and other countries with other disciplines and other diagnoses would increase confidence in the generalisability of our results.

Our study raises questions which could serve as the focus of future work as additional data become available. For instance, we had to exclude cardiologists and physicians certified prior to 1990 from our MOC analyses; yet it is important to know if initial certification without continued maintenance has similar associations with care outcomes among these physicians. Our study is based on hospital care and there are many conditions that are primarily managed in the outpatient setting now that may lend themselves to similar analyses if data sets are available to assess them. Finally, there are several studies demonstrating an association with patient outcomes not just based on whether a physician passed the initial certification or MOC examination, but on how well they performed on the examination (ie, score).[17 21 32 41 42] If a similar association (ie, a 'dose effect') existed with decreased mortality in a population like ours, it would lend further evidence to the underlying medical knowledge of the physician as a factor contributing to these improved outcomes.

Despite the limitations of our study and the opportunities for future investigations, we demonstrated a clear relationship between initial certification and mortality. Moreover, for patients whose physicians had initial certification, there was an additional associated advantage if they maintained it. At this point, it is unknown whether this advantage is related to the educational aspects of the programme, the assessment component or both. Future work is needed to address this issue. Regardless of mechanism, the successful engagement of general internists with MOC is associated with lower in-hospital mortality in their patients with AMI or CHF.

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**Contributors** JJN, WW, JB, FM, and RSL take full responsibility for the work, had access to the data, and controlled the decision to publish. JJN, WW, JB, FM and RSL made substantial contributions to the conception and design of the work. JJN, WW, JB, FM and RSL made substantial contributions to the acquisition, analysis or interpretation of data for the work. JJN drafted the paper. JJN, WW, JB, FM and RSL revised the paper critically for important intellectual content. JJN, WW, JB, FM and RSL gave final approval of the version to be published. JJN, WW, JB, FM and RSL agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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**Supplemental Table 1**. **Estimated Adjusted Odds Ratios with 95% Confidence Interval (CI) for In-Hospital Mortality for Patients of All Physicians: Conditional Hospital Fixed-Effects Logistic Regression**

| **Parameter** | ***Odds Ratio (95% CI)*** | ***p-value*** |
|---|---|---|
| **Patient characteristics** | | |
| Acute Myocardial Infarction | 2.081 (1.957 - 2.214) | <0.001 |
| Comorbidity Index | 1.12 (1.092 - 1.149) | <0.001 |
| Sex (Female) | 1.113 (1.05 - 1.179) | <0.001 |
| Age | 1.047 (1.04 - 1.055) | <0.001 |
| White, non-Hispanic | 0.906 (0.495 - 1.658) | 0.75 |
| Race/Ethnicity x Age | 1.004 (0.996 - 1.012) | 0.32 |
| **Physician characteristics** | | |
| Ever certified | 0.826 (0.754 - 0.905) | <0.001 |
| Sex | | |
| Female | 0.969 (0.9 - 1.043) | 0.40 |
| Missing | 0.619 (0.391 - 0.981) | 0.04 |
| Age | 1.003 (1 - 1.006) | <0.05 |
| USMG | 1.004 (0.94 - 1.072) | 0.91 |

**Supplemental Table 2. Estimated Adjusted Odds Ratios with 95% Confidence Interval (CI) for In-Hospital Mortality for Patients of All Physicians**

**A. Acute Myocardial Infarction Patients**

| Parameter | *Odds Ratio (95% CI)* | *p-value* |
|---|---|---|
| **Patient characteristics** | | |
| Comorbidities | 1.189 (1.136 - 1.245) | <0.001 |
| Sex (Female) | 1.041 (0.944 - 1.148) | 0.42 |
| Age | 1.046 (1.034 - 1.058) | <0.001 |
| White, non-Hispanic | 0.463 (0.194 - 1.109) | 0.08 |
| Race/Ethnicity x Age | 1.01 (0.998 - 1.022) | 0.10 |
| **Physician characteristics** | | |
| Ever certified | 0.827 (0.715 - 0.957) | 0.01 |
| Sex | | |
| Female | 0.889 (0.776 - 1.017) | 0.09 |
| Missing | 0.711 (0.36 - 1.402) | 0.33 |
| Age | 1.005 (1 - 1.01) | 0.07 |
| USMG | 0.914 (0.816 - 1.023) | 0.12 |
| **Facility** | | |
| Volume/1000 | 0.993 (0.977 - 1.009) | 0.39 |
| Rural location | 1.177 (1.039 - 1.334) | 0.01 |

**B. Congestive Heart Failure Patients**

| Parameter | *Odds Ratio (95% CI)* | *p-value* |
|---|---|---|
| **Patient characteristics** | | |
| Comorbidities | 1.082 (1.049 - 1.116) | <0.001 |
| Sex (Female) | 1.157 (1.078 - 1.242) | <0.001 |
| Age | 1.049 (1.039 - 1.059) | <0.001 |
| White, non-Hispanic | 2.553 (1.132 - 5.759) | 0.02 |
| Race/Ethnicity x Age | 0.995 (0.985 - 1.005) | 0.34 |
| **Physician characteristics** | | |
| Ever certified | 0.842 (0.747 - 0.95) | <0.01 |
| Sex | | |
| Female | 0.937 (0.846 - 1.039) | 0.22 |
| Missing | 0.56 (0.385 - 0.815) | <0.01 |
| Age | 1.005 (1.001 - 1.009) | 0.01 |
| USMG | 1.016 (0.934 - 1.106) | 0.71 |
| **Facility** | | |
| Volume/1000 | 1.002 (0.989 - 1.015) | 0.78 |
| Rural location | 1.263 (1.141 - 1.397) | <0.001 |

**Supplemental Table 3. Estimated Adjusted Odds Ratios with 95% Confidence Interval (CI) for In-Hospital Mortality for Patients of Physicians Eligible for MOC: Conditional Hospital Fixed-Effects Logistic Regression**

| **Parameter** | ***Odds Ratio (95% CI)*** | ***p-value*** |
|---|---|---|
| Acute Myocardial Infarction | 2.124 (1.897 - 2.377) | <0.001 |
| Comorbidity Index | 1.161 (1.108 - 1.216) | <0.001 |
| Sex (Female) | 1.073 (0.966 - 1.193) | 0.19 |
| Age | 1.056 (1.041 - 1.071) | <0.001 |
| White, non-Hispanic | 2.299 (0.686 - 7.702) | 0.18 |
| Race/Ethnicity x Age | 0.991 (0.976 - 1.006) | 0.24 |
| **Physician characteristics** | | |
| MOC | 0.794 (0.695 - 0.908) | <0.01 |
| Sex | | |
| Female | 1.006 (0.867 - 1.167) | 0.94 |
| Missing | 0.833 (0.324 - 2.142) | 0.71 |
| Age | 0.996 (0.986 - 1.006) | 0.41 |
| USMG | 1.076 (0.941 - 1.23) | 0.29 |

**Supplemental Table 4**. **Estimated Adjusted Odds Ratios with 95% Confidence Interval (CI) for In-Hospital Mortality for Patients of Physicians Eligible for MOC**

**A. Acute Myocardial Infarction Patients**

| **Parameter** | ***Odds Ratio (95% CI)*** | ***p-value*** |
|---|---|---|
| **Patient characteristics** | | |
| Comorbidities | 1.168 (1.077 - 1.266) | <0.001 |
| Sex (Female) | 1.011 (0.842 - 1.214) | 0.91 |
| Age | 1.062 (1.037 - 1.088) | <0.001 |
| White, non-Hispanic | 2.677 (0.385 - 18.634) | 0.32 |
| Race/Ethnicity x Age | 0.987 (0.963 - 1.013) | 0.33 |
| **Physician characteristics** | | |
| MOC | 0.853 (0.678 - 1.074) | 0.18 |
| Sex | | |
| Female | 0.86 (0.662 - 1.117) | 0.26 |
| Missing | 0.406 (0.139 - 1.186) | 0.10 |
| Age | 1.004 (0.986 - 1.022) | 0.68 |
| USMG | 0.896 (0.718 - 1.117) | 0.33 |
| **Facility** | | |
| Volume/1000 | 0.989 (0.959 - 1.019) | 0.47 |
| Rural location | 1.193 (0.931 - 1.529) | 0.16 |

**B. Congestive Heart Failure Patients**

| **Parameter** | ***Odds Ratio (95% CI)*** | ***p-value*** |
|---|---|---|
| **Patient characteristics** | | |
| Comorbidities | 1.149 (1.088 - 1.213) | <0.001 |
| Sex (Female) | 1.103 (0.964 - 1.263) | 0.15 |
| Age | 1.051 (1.035 - 1.067) | <0.001 |
| White, non-Hispanic | 3.217 (0.872 - 11.861) | 0.08 |
| Race/Ethnicity x Age | 0.99 (0.973 - 1.006) | 0.23 |
| **Physician characteristics** | | |
| MOC | 0.777 (0.66 - 0.915) | <0.01 |
| Sex | | |
| Female | 0.94 (0.768 - 1.15) | 0.55 |
| Missing | 0.906 (0.29 - 2.826) | 0.87 |
| Age | 0.995 (0.982 - 1.009) | 0.50 |
| USMG | 1.029 (0.879 - 1.205) | 0.72 |
| **Facility** | | |
| Volume/1000 | 1.005 (0.983 - 1.028) | 0.63 |
| Rural location | 1.27 (1.059 - 1.523) | 0.01 |