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The association between resident physician work hour regulations and physician safety and health

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CONTRIBUTIONS

MDW, CPL, CAC, and LKB conceived and designed the study. MDW conducted the analysis and wrote the initial draft. All authors contributed to the interpretation of the findings, made critical revisions to the manuscript, and gave final approval for the version to be published.

CONFLICTS OF INTEREST

Dr. Landrigan is supported in part by the Children's Hospital Association for work as an executive council member of the Pediatric Research in Inpatient Settings (PRIS) network. He has served as a paid consultant to Virgin Pulse to help develop a Sleep and Health Program. He has consulted with and holds equity in the I-PASS Patient Safety Institute. In addition, he has received monetary awards, honoraria, and travel reimbursement from multiple academic and professional organizations for teaching and consulting on sleep deprivation, physician performance, handoffs, and safety, and has served as an expert witness in cases regarding patient safety and sleep deprivation.

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Dr. Czeisler's interests were reviewed and managed by Brigham and Women's Hospital and Partners HealthCare in accordance with their conflict of interest policies.

Dr. Barger is on the scientific advisory board for CurAegis Technologies. She has received consulting fees from University of Pittsburgh, Sygma, Insight and Puget Sound Pilots.

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Abstract

Background—In 2011, the Accreditation Council for Graduate Medical Education (ACGME) instituted a 16-h limit on consecutive hours for first-year resident physicians. We sought to examine the effect of these work-hour regulations on physician safety.

Methods—All medical students matched to a United States residency program from 2002–2007 and 2014–2017 were invited to participate in prospective cohort studies. Each month participants reported hours of work, extended duration shifts, and adverse safety outcomes; including motor vehicle crashes , percutaneous injuries, and attentional failures. The incidence of each outcome was compared before and after the 2011 ACGME work-hour limit. Hypotheses were tested using generalized linear models adjusted for potential confounders.

Results—13% of all first-year resident physicians nationwide participated in the study, with 80,266 monthly reports completed by 15,276 first-year resident physicians. Following implementation of the 16-h 2011 ACGME work-hour limit, the mean number of extended duration (≥24-h) shifts per month decreased from 3.9 to 0.2. The risk of motor vehicle crash decreased 24% (RR 0.76; 0.67–0.85), percutaneous injury risk decreased more than 40% (RR 0.54; 0.48–0.61), and the rate of attentional failures was reduced 18% (IRR 0.82; 0.78–0.86). Extended duration shifts and prolonged weekly work hours were associated with an increased risk of adverse safety outcomes independent of cohort.

Conclusions—The 2011 ACGME work-hour limit was associated with meaningful improvements in physician safety and health. Surveillance is needed to monitor the ongoing impact of work hours on physician safety, health, and well-being.

Keywords

physicians; work hours; safety; sleep

BACKGROUND

The search for resident-physician work hours that are safe for both patients and physicians has continued for more than two decades.(1) In 2008, the National Academy of Medicine (NAM) synthesized the available evidence and recommended strategies to enhance sleep, supervision, and safety in this population.(2) The recommendations were intended to, "Promote conditions for safe medical care, improve the education of doctors in training, and increase the safety of residents and the general public." In response, the Accreditation Council for Graduate Medical Education (ACGME) implemented a subset of the NAM recommendations in their 2011 guidelines that limited first-year resident physicians to work shifts of 16 or fewer consecutive hours and emphasized a commitment to patient safety and mitigation of fatigue-related risks (16-h 2011 ACGME work-hour limit).(3)

Evaluations of the 16-h 2011 ACGME work-hour limit focused on its impact on patient safety,(4–8) education,(5, 9–11) and resident well-being.(12–14) However, the critical issue of the safety of resident physicians themselves has been overlooked. Motor vehicle crashes represent the third leading cause of death among resident physicians.(15) Percutaneous injuries are common in some specialties, with recent single-center estimates reporting a career prevalence among surgical residents of 72%,(16) a prior-year prevalence among orthopedic residents of 42%,(17) and an increased risk for first-year residents across specialties.(18) Prior to the 2011 policy change, Barger et al. showed that residents who worked extended duration shifts had twice the risk of a motor vehicle crash on the drive from work.(19) Additional reports revealed that these extended duration shifts were also associated with a 61% increased risk of percutaneous injury,(20) and more than twice the incidence of attentional failures at night.(21) To our knowledge, no evaluations of the 16-h 2011 ACGME work-hour limit have reported on its effectiveness in reducing these adverse safety outcomes.

We sought to evaluate the impact of the 16-h 2011 ACGME work-hour limit on the safety and health of first-year resident physicians. We hypothesized that the restriction of extended duration shifts through the 16-h 2011 ACGME work-hour limit would be associated with reduced risk of motor vehicle crash, percutaneous injury, and attentional failures.

METHODS

We conducted a nationwide prospective cohort study of resident physicians for 5 academic years (2002–2007) prior to introduction of the 16-h 2011 ACGME work-hour limit, and for 3 academic years (2014–2017) post-implementation. All study procedures were approved by the Partners Human Research Committee and a Certificate of Confidentiality was issued by the Centers for Disease Control and Prevention. All variables utilized in this analysis were collected using identical methods in both cohorts. These methods have been described previously.(19, 20, 22)

Recruitment and Data Collection

Each April from 2002–2006, all United States (U.S.) medical school graduates and individuals who matched to a U.S. residency program through the Association of American Medical Colleges match process received an email informing them of the study, without detailing the study hypotheses. Similar recruitment methods were utilized in the subsequent cohort: In May of each year from 2014–2016, all medical school graduates who completed an application through the Electronic Residency Application Service (ERAS) were informed about the study via email. Those interested in participating were asked to complete an electronic informed consent process. In June of each year, individual password-coded links were sent via email to residents who consented to participate. The baseline survey collected individual demographic information, including age, gender, height, weight, medical history, and specialty program. Monthly reports collected work-hour information, including total hours of work, hours engaged in patient care, and additional work related to their residency program. The frequency of extended duration shifts was reported. Hours of sleep at work and away from work were reported. Respondents also reported on the frequency of adverse

safety outcomes; including motor vehicle crashes and near-miss crashes. The instrument used to collect motor vehicle crash information has been previously validated.[19] We asked for documentation for all reported motor vehicle crashes (e.g., police reports, insurance claims). Similarly, we collected information on the frequency of occupational exposures, the source of the exposure, and factors which contributed to the exposure. We requested the occupational health report for each reported occupational exposure. We also queried how many times participants nodded off or fell asleep (attentional failures) during specific patient-care activities (during surgery and while talking to or examining patients), educational activities (during rounds with attending physicians and during lectures, seminars, or grand rounds), and while driving (either stopped at a light, or while the car was in motion).

Statistical Analysis

Data from both cohorts were pooled. We excluded months when: i) participants reported ≥14 work-free days; and ii) work-hour information was missing or exceeded 168 hours of work per week. The primary analysis tested the association between pre- and post-intervention cohorts and the outcomes of interest. Secondary analyses examined the association between weekly work hours, extended duration shifts, and the outcomes of interest across cohorts.

We compared demographics between exposed and unexposed groups using Wilcoxon rank sum and chi square tests. Weekly work hours were calculated as the sum of the number of hours spent physically awake in the hospital, classes, or workplace, plus the number of hours asleep in the hospital. Reports of work and sleep were compared using generalized linear models which accounted for clustering of respondents and the repeated-measures data structure.

We calculated the incidence of each adverse safety outcome before and after the 2011 policy change. Incidence rate ratios were constructed. The significance of the incidence rate ratio was tested using likelihood ratio tests in log-linear models (of note, similar results were obtained using Pearson- and deviance-based scaled Poisson models which accounted for overdispersion, conducted as sensitivity analyses). Rare outcomes were then dichotomized to reflect the presence or absence of at least one outcome during the month. We estimated the risk of each outcome using generalized linear mixed models with a binomial distribution and log-link function. Basic models for occupational exposures and percutaneous injuries were adjusted for hours spent in patient care that month. We identified potentially confounding variables *a priori* based on relevance to the research question and biologic plausibility. For example, body mass index (BMI) was identified as an important predictor for motor vehicle crashes, given its association with sleep apnea;(23) we controlled for BMI in all fully-adjusted models. We imputed data with the median for missing demographic information using the missing indicator method.(24) Fully-adjusted multivariable models controlled for age, gender, BMI, specialty program, and imputation indicator variables. Models examining occupational exposures and percutaneous injuries further controlled for the hours of patient care for that month. We then constructed mixed effects models to utilize data from both cohorts while testing extended duration shifts and weekly work hours as independent variables of interest. These analyses controlled for cohort using a conditional

likelihood approach, in addition to the previously mentioned confounding variables. We conducted further sensitivity analyses that stratified by cohort and limited outcomes to those with supporting documentation.

Motor vehicle crash models were limited to participants who reported a valid driver's license and months where they commuted to or from work. Occupational exposure models were limited to months where participants reported hours in patient care. SAS (version 9.4, Cary, NC) was used for statistical analysis. All tests were two-sided and $p < 0.05$ was considered statistically significant.

RESULTS

21,862 of 167,658 residents who matched to a United States residency program during the study interval consented to participate, representing 9% of all first-year residents nationally from 2002–2007 and 18% of all residents nationally from 2014–2017 (Figure 1). Approximately 75% of those who consented provided data and were included in the study cohort (cooperation rate). 6,211 first-year resident physicians completed 45,261 monthly reports between 2002 and 2007 and 9,778 first-year resident physicians completed 61,205 monthly reports between 2014 and 2017 (106,466 total monthly reports). After applying exclusion criteria, 80,266 monthly reports from 15,276 first-year resident physicians were available for analysis

Characteristics of the Study Sample

Residents who contributed data after 2011 tended to be slightly younger and had a lower body mass index (Table 1). The composition of specialties was largely similar. Mean weekly hours of work decreased following the 16-h 2011 ACGME work-hour limit (71h vs. 62h), while hours engaged in patient care remained the same (Table 2). Participants reported fewer extended duration shifts per month (3.9 vs. 0.2). Nightly hours of sleep increased by 15 minutes of sleep per night (6.47h vs. 6.72h), despite less sleep obtained at work when extended-duration shifts were worked (2.52h vs. 1.86h). Nearly 1 in 3 extended-duration shifts (30%) were completed without sleep after 2011, compared to only 8% of extended duration shifts prior to 2011.

Incidence of Adverse Safety Outcomes Over Time

The incidence for each adverse outcome studied was significantly reduced following the 16-h 2011 ACGME work-hour limit (Table 2). After adjustment for potential confounders, the risk of motor vehicle crash decreased 24% (RR 0.76; 0.67–0.85), near-crashes decreased 44% (IRR 0.56; 0.53–0.60), percutaneous injury risk decreased 46% (RR 0.54; 0.48–0.61), and the rate of attentional failures was reduced 18% (IRR 0.82; 0.78–0.86) (Figure 2). Supporting documentation or additional detailed descriptions were provided for 81% of occupational exposures and 90% of reported motor vehicle crashes. Our results are similar or strengthened when limiting outcomes to those with supporting documentation (Table 3).

Work Hours, Extended Duration Shifts, and Safety Outcomes

Participants in both cohorts reported exceeding 80 hours of work per week (averaged across 4 weeks) and working extended-duration shifts . Independent of cohort, working more than 80 hours per week and working extended duration shifts were each independently associated with an increased risk of adverse resident safety outcomes (Table 4). Compared with working no extended duration shifts, working even one extended duration shift in a month increased the risk of adverse outcomes; and working 5 or more extended duration shifts generally increased the risk of adverse outcomes to a greater degree. Similarly, compared with working up to 60 hours per week, increased risks of adverse outcomes were seen for those residents working >60–70 hours per week, those working >70–80 hours per week, and those working >80 hours per week in a dose-dependent fashion (Table 5). Stratified analyses are presented in the Supplemental Materials (Appendix Tables 1–3).

DISCUSSION

The 2011 ACGME work-hour restrictions were followed by marked improvements in resident safety. Residents reported lower rates of motor vehicle crashes on the commute, occupational exposures (including percutaneous injuries), and attentional failures. Following the policy change to eliminate extended-duration shifts in first-year resident physicians, average weekly work hours were reduced and nightly sleep duration increased. However, despite fears that the policy would limit hands-on training, reported hours spent in patient care remained unchanged.

Nationwide regulations that limited weekly work hours for residents and prohibited extended duration shifts were followed by improved safety. As reported elsewhere, compliance with the policy was not universal, (25, 26) and randomized trials of flexible hours permitted training programs at some institutions to exceed existing work hour limitations.(6, 8) Participants in both cohorts reporting exceeding 80 weekly work hours and working extended duration shifts. Sleep was obtained less frequently during extended duration shifts after the policy change, with a nearly 4-fold increase in the proportion of extended duration shifts without sleep (30% vs. 8%). The work hour limitations were not accompanied by an increased census of residency slots, which may have contributed to workload compression and reduced opportunity for sleep on-shift.(27) Independent of whether extended duration shifts were worked before or after the policy change, they were associated with significantly increased risk of adverse outcomes. Extended-duration shifts and prolonged weekly work hours were independent risk factors that acted synergistically to increase the risk of adverse outcomes. These findings are particularly important now, since the 2017 ACGME guidelines lifted the restrictions on extended duration shifts and again permit shifts of 24–28 consecutive hours of work for first-year resident physicians.(28) Several aspects of this issue, including physician safety, have been under-represented in the work hours debate. The pursuit of resident-physician work hours that are safe for patients and providers deserves further, more comprehensive, investigation.

Motor vehicle crashes are the third leading cause of death for medical residents, trailing only neoplastic disease and suicide.(15) Our findings reveal that elimination of extended duration shifts was associated with a significant reduction in the risk of crashes, particularly on the

commute from work. Driving after extended duration shifts is known to be a high-risk activity.(19, 29) As the National Academy of Medicine recommended in their 2009 report, (2) some training programs have instituted safe transportation programs that enable residents to be reimbursed for ride-share or taxi costs following extended-duration shifts, however, the prevalence of such programs and their utilization by residents remains unclear. Installing alternative transport arrangements as the default following extended-duration shifts may be necessary for adoption of these habits as a cultural norm.

We found that average nightly sleep was increased following the 16-h 2011 ACGME work-hour limit, consistent with evidence that first-year resident physicians working overnight extended duration shifts achieve significantly less sleep than residents who do not work extended overnight shifts.(30) The FIRST trial found that first-year resident physicians assigned to programs which allowed extended-duration shifts were more than 8 times more likely to report that their work hours had a negative effect on their rest, and had a 7-fold increased risk of reporting that their work hours had a negative effect on their health, time for family and friends, and their hobbies.(31) Rosen *et al.* found a 7-fold increased odds of depression among first-year resident physicians who were not sleep deprived prior to their internship, but accumulated a chronic sleep debt over the course of their first postgraduate year.(32) Burnout is twice as common among physicians compared to the general population,(33) and sleep deficiency is a direct contributor to burnout.(34) Burnout, depression, sleepiness, and fatigue have also been associated with reported resident motor vehicle crashes.(35) Our findings suggest that work hour limitations may be an avenue to promote physician wellness.

Our data further reveal that the current ACGME standard of an average of 80 work hours per week is associated with an elevated risk of adverse outcomes. In the United States, resident physicians are allowed to work far longer hours than resident physicians in many other developed nations. The European Working Time Directive limits resident physicians throughout the European Union to 48 hours of work per week.(36) New Zealand has limited physicians-in-training to 16-hour shifts for more than 30 years, and the Province of Quebec in Canada recently cited the Canadian Charter of Rights and Freedoms in limiting resident physicians to 16 consecutive hours of work.(37) Australia does not restrict hours, but cautions that working more than 50 hours per week places the resident at risk, and exceeding 70 hours places the resident at higher risk.(38) Our data suggest that reducing weekly work hours would improve resident safety, and that cautions regarding the increased risk of long work weeks and extended-duration shifts should be made transparent to patients and providers.

Our study was observational, and we are unable to directly attribute the observed associations to the 16-h 2011 ACGME work-hour limit. The estimated associations could be affected by confounding bias. We controlled for multiple potential confounders, but residual confounding may persist through factors we did not collect or imprecise measurement of the confounders that were collected. We examined demographic characteristics for evidence of non-response bias. The demographic characteristics of participants in this sample are similar to the demographic characteristics of resident physicians nationally (Appendix Table 4). In total, 13% of all residents who matched to a United States residency program during the

study interval participated in this study, including nearly 1 in 5 physicians entering residency from 2014–2017 (9% from 2002–2007 and 18% from 2014–2017) (Figure 1). Our findings have important policy implications for the more than 100,000 resident physicians in the US.

Some of the observed reductions in adverse safety outcomes may be attributable to secular trends. The national motor vehicle crash rate was reduced by 3% during our study interval (Appendix Table 5). Although the shift length limitations would have resulted in more commutes, the crash rate in our study sample was reduced by 22%, so it is unlikely that secular trends alone account for the observed improvement in vehicle crash rates in our study. The incidence of needlestick injuries among US health care workers has decreased approximately 1.4% per year since 2002.(39) We observed a 50% reduction in the incidence of needlestick injuries in our study population, exceeding the 20% reduction that would be expected over the time interval. In addition, our secondary analyses indicate that extended duration shifts are associated with an increased risk of adverse outcomes, independent of time period.

We collected outcomes via self-report. While this approach to the collection of adverse outcomes may be subject to social desirability bias, recall bias, and erroneous self-observation, the vast majority of reported occupational exposures and motor vehicle crashes were supported by additional documentation or detailed descriptions. Our results are similar or strengthened when limiting outcomes to those with supporting documentation (Table 3).

CONCLUSIONS

The 2011 ACGME guidelines that reduced work hours of first-year resident physicians was associated with improved resident safety and health. Extended-duration shifts and prolonged weekly work hours continue to adversely impact the safety and well-being of resident physicians. There is a pressing need to monitor changes in the rates of these adverse outcomes now that extended-duration shifts have been re-introduced.

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Appendix

Appendix Table 1.

The adjusted association between extended duration shifts and adverse safety outcomes stratified by cohort.

	Extended Duration Shifts (EDS) 2002–2007				Extended Duration Shifts (EDS) 2014–2017			
	None	1–4	≥5	p-value	None	1–4	≥5	p-value
Crashes	Ref	1.20 (0.94-1.54)	1.46 (1.17-1.81)	0.002	Ref	0.98 (0.65-1.49)	2.02 (1.36-3.01)	0.03
Crashes leaving work	Ref	non-estimable			Ref	1.05 (0.56-1.96)	1.64 (0.83-3.23)	0.51
Near-crashes	Ref	1.48 (1.35-1.62)	1.95 (1.79-2.12)	<0.0001	Ref	1.20 (1.01-1.43)	1.45 (1.19-1.76)	0.0022
Occupational Exposures^	Ref	1.11 (0.96-1.27)	1.17 (1.03-1.33)	0.05	Ref	1.44 (1.16-1.79)	1.35 (1.02-1.79)	0.0046
Percutaneous Injuries^	Ref	0.97 (0.80-1.19)	1.07 (0.89-1.29)	0.53	Ref	1.50 (1.10-2.06)	1.29 (0.85-1.97)	0.07
Attentional Failures	Ref	1.59 (1.51-1.69)	2.21 (2.09-2.33)	<0.0001	Ref	1.37 (1.25-1.49)	1.71(1.51-1.93)	<0.0001

All models are adjusted for age, gender, BMI, specialty, and cohort. P-values are obtained from likelihood ratio tests.

^Also adjusted for hours of patient care in the month.

Appendix Table 2.

The adjusted association between exceeding 80 weekly work hours and adverse safety outcomes stratified by cohort.

	Weekly Work Hours 2002–2007			Weekly Work Hours 2014–2017		
	≤80	>80	p-value	≤80	>80	p-value
Crashes	Ref	1.24 (1.04–1.49)	0.02	Ref	1.40 (1.09–1.79)	0.001
Crashes leaving work	Ref	non-estimable		Ref	1.30 (0.88–1.94)	0.19
Near-crashes	Ref	1.80 (1.69–1.93)	<0.0001	Ref	1.68 (1.50–1.87)	<0.0001
Occupational Exposures^	Ref	1.22 (1.10–1.35)	0.0002	Ref	1.58 (1.38–1.82)	<0.0001
Percutaneous Injuries^	Ref	1.21 (1.03–1.42)	0.02	Ref	1.59 (1.28–1.96)	<0.0001
Attentional Failures	Ref	1.79 (1.73–1.85)	<0.0001	Ref	1.52 (1.44–1.60)	<0.0001

All models are adjusted for age, gender, BMI, and specialty. P-values are obtained from likelihood ratio tests.

^Also adjusted for hours of patient care in the month.

Appendix Tables 3A and 3B:

The adjusted association between increasing weekly work hours and adverse safety outcomes stratified by cohort.

	Weekly Work Hours				
A: 2002–2007	**≤60**	**>60 & ≤70**	**>70 & ≤80**	**>80**	**p-valuve**
Crashes	Ref	1.47 (1.12–1.94)	1.42 (1.10–1.84)	1.59 (1.24–2.02)	0.0007
Crashes leaving work	Ref		non-estimable		
Near-crashes	Ref	1.39 (1.25–1.53)	1.72 (1.56–1.89)	2.45 (2.23–2.69)	<0.0001
Occupational Exposures	Ref	1.25 (1.06–1.47)	1.75 (1.52–2.01)	1.88 (1.65–2.15)	<0.0001

	Weekly Work Hours				
A: 2002–2007	**≤60**	**>60 & ≤70**	**>70 & ≤80**	**>80**	**p-valuve**
Percutaneous Injuries	Ref	1.10 (0.85–1.43)	1.45 (1.17–1.80)	1.63 (1.33–2.00)	<0.0001
Attentional Failures	Ref	1.66 (1.56–1.76)	2.12 (2.01–2.24)	2.83 (2.68–2.98)	<0.0001

	Weekly Work Hours				
B: 2014–2017	**≤60**	**>60 & ≤70**	**>70 & ≤80**	**>80**	**p-value**
Crashes	Ref	1.01 (0.83–1.22)	1.05 (0.86–1.27)	1.42 (1.09–1.85)	0.13
Crashes leaving work	Ref	1.36 (1.00–1.86)	1.37 (1.00–1.89)	1.60 (1.04–2.46)	0.07
Near-crashes	Ref	1.33 (1.22–1.45)	1.52 (1.39–1.65)	2.12 (1.88–2.40)	<0.0001
Occupational Exposures	Ref	1.29 (1.13-1.46)	1.60 (1.41-1.81)	2.23 (1.91-2.61)	<0.0001
Percutaneous Injuries	Ref	1.20 (0.97–1.49)	1.36 (1.11–1.67)	2.05 (1.61–2.61)	<0.0001
Attentional Failures	Ref	1.29 (1.25–1.34)	1.52 (1.47–1.58)	1.94 (1.83–2.05)	<0.0001

All models are adjusted for age, gender, BMI, and specialty. P-values are obtained from likelihood ratio tests

Appendix Tables 4A and 4B.

The demographics of the study sample compared to the characteristics of first-year residents nationally.

A	**Study Sample**	**ACGME National Data**		
	2014–2017 (n=9,778)	**2014–2015 (n=28,220)**	**2015–2016 (n=29,074)**	**2016–2017 (n=30,381)**
Age	28.7±3.2	30.6	30.6	30.7
Female Gender	48%	44%	44%	44%
Specialty *				
Internal Medicine	25%	34%	34%	34%
Family Medicine	12%	13%	13%	13%
Pediatrics	11%	11%	11%	10%
General Surgery and surgical specialties	10%	13%	13%	13%
Emergency Medicine	7%	7%	7%	7%
Obstetrics/Gynecology	5%	5%	5%	5%
Psychiatry	4%	5%	5%	5%
Anesthesiology	4%	3%	4%	3%
Other (including combined)	15%	9%	8%	10%

B	**Study Sample**	**ACGME National Data**
	2002–2007 (n=6,211)	**2007–2008 (n=36,012)**
Age	28.9±3.9	Not Reported
Female Gender	56%	41%
Specialty *		
Internal Medicine	24%	31%
Family Medicine	11%	10%
Pediatrics	14%	10%

B	Study Sample	ACGME National Data
	2002–2007 (n=6,211)	2007–2008 (n=36,012)
General Surgery and surgical specialties	11%	9%
Emergency Medicine	7%	4%
Obstetrics/Gynecology	6%	3%
Psychiatry	4%	5%
Anesthesiology	1%	4%
Other (including combined)	20%	22%

* Percentage of residents in each specialty. Percentages may not add to 100 due to rounding.

Reporting practices may explain some differences in the demographic characteristics of our study sample compared to residents nationally. Our baseline questionnaire was administered immediately upon entry of residency. The timing of age information in the national data is not known. The lower prevalence of reported internal medicine residents in our study may be explained by the reporting of planned specialty rather than preliminary or transitional year. National PGY-1 specific demographic information is not available for years prior to 2007.

Appendix Table 5.

Temporal trends in motor vehicle crashes in the USA.

Year	Crashes	Licensed Drivers	Rate per Driver per Year
2002	6,315,708	194,295,633	0.032505661
2003	6,327,955	196,165,667	0.032258219
2004	6,181,027	198,888,912	0.031077786
2005	6,159,350	200,548,972	0.030712449
2006	5,973,213	202,810,438	0.029452197
2007	6,024,008	205,741,845	0.02927945
2008	5,810,846	208,320,601	0.027893766
2009	5,505,180	209,618,386	0.026262868
2010	5,419,445	210,114,939	0.025792764
2011	5,337,829	211,874,649	0.025193335
2012	5,615,045	211,814,830	0.026509216
2013	5,686,891	212,159,728	0.026804762
2014	6,064,284	214,092,472	0.028325536
2015	6,296,134	218,084,465	0.028870163
2016	7,276,838	221,711,918	0.03282114

Average 2002–2007: 0.0308 crashes per driver per year.

Average 2014–2016: 0.0300 crashes per driver per year.

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CLINICAL SIGNIFICANCE

- First-year resident physician safety improved after the 2011 ACGME work hour limit.
- The 2011 ACGME work hour limit was associated with increased sleep duration and significantly lower risk of motor vehicle crashes, near-crashes, percutaneous injuries, and attentional failures.
- Extended duration shifts and prolonged weekly work hours were associated with an increased risk of adverse safety outcomes before and after work hour reform.

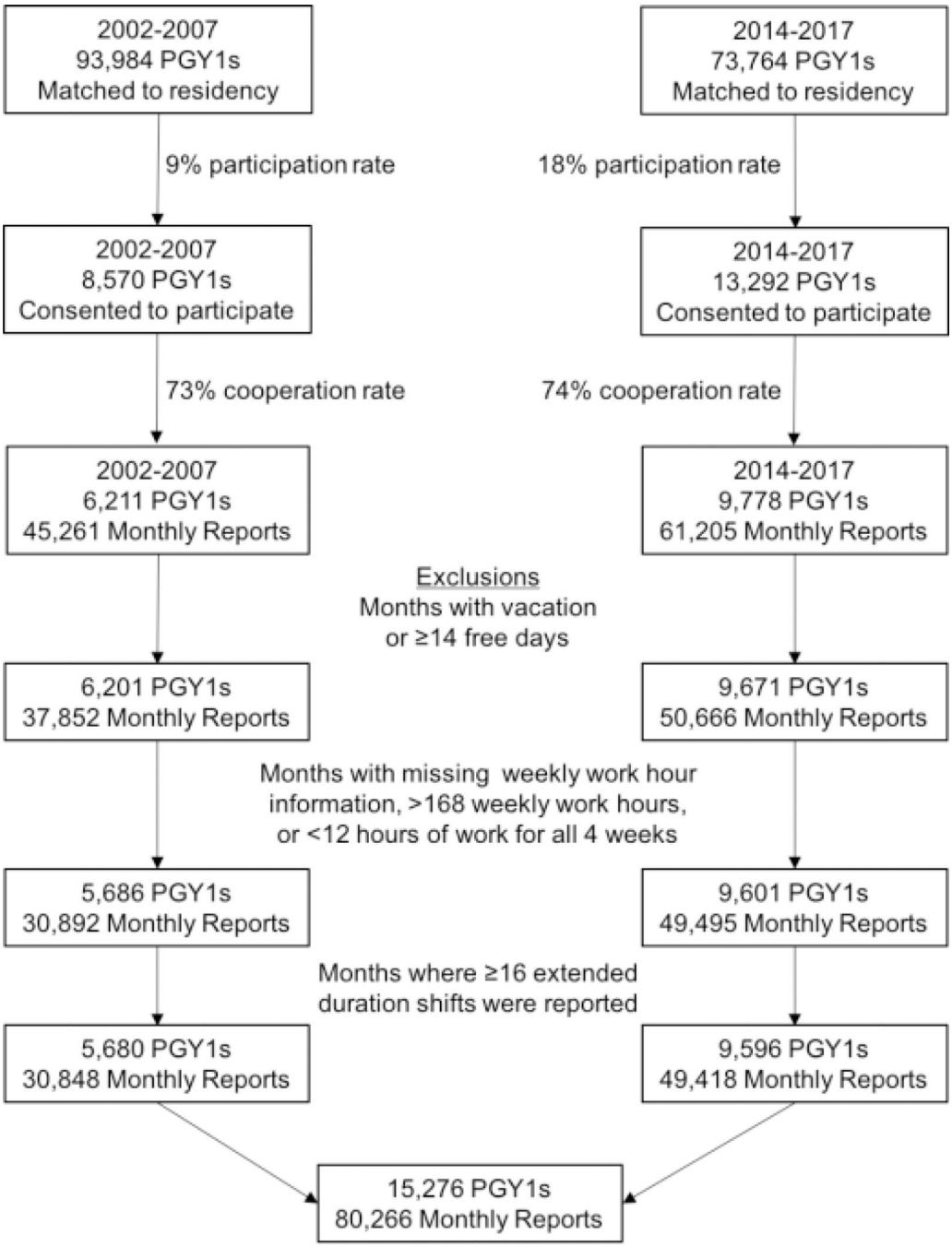

Figure 1.
Participation in the study and exclusion criteria.

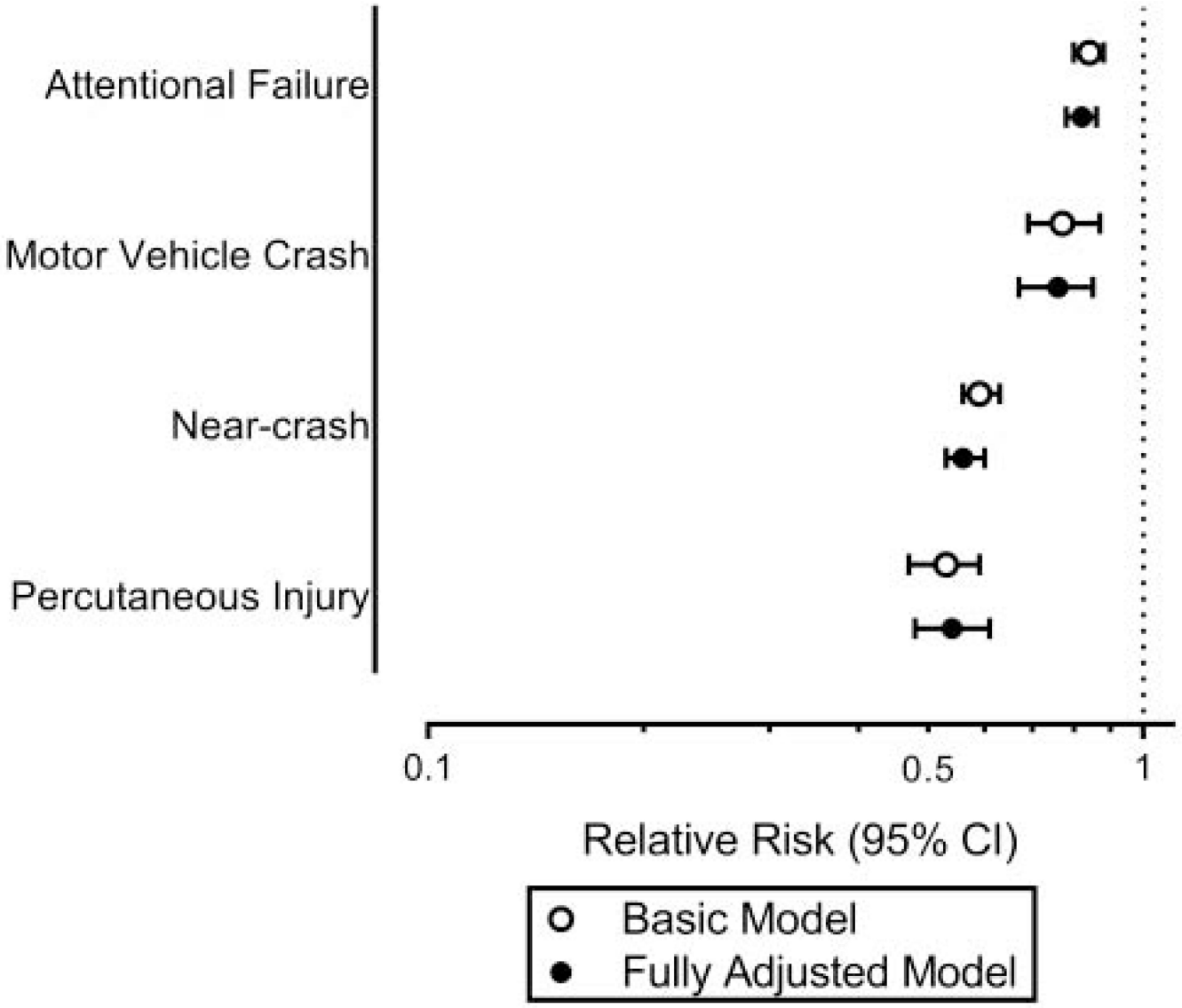

Figure 2.

The risk of adverse safety outcomes for first-year resident physicians who contributed data after implementation of the 16-h 2011 ACGME work-hour limit relative to first-year resident physicians who contributed data from 2002–2007.

Basic models for attentional failures, motor vehicle crash, and near crash include cohort as the only independent variable. The basic model for percutaneous injuries is adjusted for hours in patient care. The fully adjusted models for attentional failures, motor vehicle crash, and near crash are adjusted for age, gender, BMI, and specialty. The fully adjusted model for percutaneous injury is adjusted for all previously mentioned variables, as well as hours in patient care. All models are generalized linear models. Attentional failures and near-crashes use a Poisson distribution with a log link. All other models use a binomial distribution with a logit link function.

Table 1.

Demographic characteristics of the study sample

Baseline Characteristics	2002–2007 n=5,680	2014–2017 n=9,596	p-value
Age	28.9±3.9	28.7±3.2	0.01
Female gender n(%)	3,206 (56%)	4,641 (48%)	<0.001
Unknown	32 (1%)	668 (7%)	
Mean body mass index	24.5±4.1	24.1±4.0	<0.001
Specialty n(%) *			<0.001
Internal Medicine	1,366 (24%)	2,358 (25%)	
Family Practice	643 (11%)	1,125 (12%)	
Pediatrics	790 (14%)	1,080 (11%)	
General Surgery and surgical specialties	643 (11%)	934 (10%)	
Emergency Medicine	369 (7%)	687 (7%)	
Obstetrics/Gynecology	364 (6%)	509 (5%)	
Psychiatry	251 (4%)	422 (4%)	
Anesthesiology	30 (1%)	430 (4%)	
Other (including combined)	1,129 (20%)	1,402 (15%)	
Unknown	95 (2%)	649 (7%)	
Monthly Characteristics	n=30,848	n=49,418	
Weekly work hours	71.1±18.5	62.1±17.0	<0.001
Hours engaged in patient care	49.6±19.6	49.3±19.3	0.40
Additional weekly work hours related to program	3.7±4.3	5.0±6.3	<0.001
Extended duration shifts per month	3.9±3.4	0.2±1.2	<0.001
Nightly sleep duration	6.47±1.2	6.72±1.1	<0.001
Sleep duration on extended duration shifts	2.52±1.5	1.86±1.9	<0.001

Plus-minus values are means ± SD. Rank sum tests were used to compare age and body mass index. Wilcoxon chi square tests were used to compare gender and specialty. Univariate generalized linear regression models adjusted for clustering of individual responses were used to compare monthly characteristics.

Table 2.

The incidence of adverse safety outcomes before and after the 16-h 2011 ACGME work-hour limit.

	2002–2007			2014–2017				
	Months*	Outcomes	Rate per Person-Year	Months*	Outcomes	Rate per Person-Year	Incidence Rate Ratio	p-value
Crashes	28,428	565	0.238	47,241	736	0.187	0.78	<0.001
Police-Reported Crashes	28,428	130	0.055	47,241	167	0.042	0.77	0.03
Crashes on commute	28,428	243	0.103	47,241	277	0.070	0.69	<0.001
Near-crashes	28,428	7,999	3.377	47,241	7,813	1.985	0.59	<0.001
Occupational Exposures	30,155	2,942	1.171	47,946	2,840	0.711	0.61	<0.001
Percutaneous Injuries	30,155	884	0.352	47,946	682	0.173	0.49	<0.001
Attentional Failures	30,848	92,557	36.005	49,418	123,070	29.885	0.83	<0.001

*Months where participants reported zero hours of patient care are excluded for assessment of outcomes occurring in the patient care setting (medical errors and occupational exposures). Crash and near-crash months are limited to participants who reported having a valid driver's license and commuting to work. Attentional failures include all months of data. P-values were obtained from generalized log-linear regression models.

Table 3.

A sensitivity analysis comparing the relationship between the 2011 ACGME policy and resident safety outcomes overall compared to those with supporting documentation.

	Overall	p-value	With Supporting Documentation	p-value
Crashes	RR 0.76 (0.67–0.85)	<0.0001	RR 0.76 (0.67–0.87)	<0.0001
Occupational Exposures^	RR 0.57 (0.52–0.61)	<0.0001	RR 0.46 (0.42–0.50)	<0.0001

All models are adjusted for age, gender, BMI, and specialty. P-values are obtained from likelihood ratio tests.

^ Also adjusted for hours of patient care in the month

Table 4.

The adjusted association between weekly work hours, extended duration shifts, and adverse safety outcomes.

			Weekly Work Hours (WWH)			Extended Duration Shifts (EDS)				Combined categorical WWH and EDS				
	n cases	n person months	≤80	>80		None	1–4	≥5		≤80 WWH No EDS	≤80 WWH ≥1 EDS	>80 WWH No EDS	>80 WWH ≥1 EDS	
Crashes	1,301	75,669	Ref	1.30 (1.12–1.51)	*	Ref	1.20 (0.98–1.48)	1.53 (1.27–1.86)	†	Ref	1.37 (1.13–1.64)	1.35 (1.06–1.73)	1.56 (1.27–1.92)	†
Crashes leaving work	520	75,669	Ref	1.59 (1.29–1.97)	*	Ref	1.35 (0.99–1.84)	1.91 (1.45–2.51)	†	Ref	1.45 (1.10–1.92)	1.35 (0.92–1.97)	2.20 (1.64–2.95)	†
Near-crashes	15,812	75,669	Ref	1.76 (1.67–1.87)	†	Ref	1.37 (1.27–1.48)	1.82 (1.70–1.95)	†	Ref	1.42 (1.32–1.53)	1.69 (1.52–1.88)	2.27 (2.10–2.45)	†
Occupational Exposures	5,782	78,101	Ref	1.50 (1.38–1.62)	†	Ref	1.18 (1.05–1.33)^	1.25 (1.12–1.40)^	*	Ref	1.26 (1.13–1.41)	1.67 (1.46–1.90)	1.66 (1.48–1.86)	†
Percutaneous Injuries	1,576	78,101	Ref	1.47 (1.30–1.66)	†	Ref	1.14 (0.96–1.37)^	1.19 (1.00–1.41)^		Ref	1.20 (1.01–1.43)	1.66 (1.36–2.02)	1.57 (1.32–1.87)	†
Attentional Failures	215,627	80,266	Ref	1.68 (1.63–1.73)	†	Ref	1.49 (1.42–1.56)	2.05 (1.96–2.14)	†	Ref	1.59 (1.52–1.67)	1.54 (1.46–1.63)	2.40 (2.29–2.50)	†

All models are adjusted for age, gender, BMI, specialty, and cohort. P-values are obtained from likelihood ratio tests.

^ Also adjusted for hours of patient care in the month.

† p-value<0.001

* p-value=0.001.

Table 5.

The adjusted association between increasing weekly work hours and adverse safety outcomes.

	Weekly Work Hours				
	≤60	>60 & ≤70	>70 & ≤80	>80	p-valuve
Crashes	Ref	1.14 (0.97–1.33)	1.17 (1.00–1.37)	1.42 (1.20–1.68)	<0.001
Crashes leaving work	Ref	1.51 (1.16–1.95)	1.56 (1.21–2.01)	2.12 (1.64–2.76)	<0.001
Near-crashes	Ref	1.35 (1.27–1.45)	1.59 (1.50–1.70)	2.30 (2.14–2.47)	<0.001
Occupational Exposures	Ref	1.27 (1.15–1.41)	1.66 (1.52–1.82)	1.99 (1.80–2.19)	<0.001
Percutaneous Injuries	Ref	1.15 (0.98–1.36)	1.41 (1.22–1.64)	1.78 (1.53–2.07)	<0.001
Attentional Failures	Ref	1.39 (1.34–1.43)	1.70 (1.65–1.75)	2.27 (2.20–2.35)	<0.001

All models are adjusted for age, gender, BMI, specialty, and cohort. P-values are obtained from likelihood ratio tests