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4 459 **APPENDICES**
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8 **Supplemental Table 1:** Provider specialty codes and healthcare provider taxonomy codes.

Type of provider	Medicare Specialty code	Label
Primary Care physician	01, 08, 11, 38	General practice, Family practice, Internal Medicine, Geriatric Medicine
Primary Care Nurse Practitioner	50 exclude 363LA2100X 363LC0200X 363LN0000X 363LN0005X 363LX0001X 363LX0106X 363LP0200X 363LP0222X 363LP1700X 363LP0808X 363LS0200X	Nurse practitioner Nurse practitioner/acute care Nurse practitioner/critical care medicine Nurse practitioner/neonatal Nurse practitioner/neonatal critical care Nurse practitioner/obstetrics & gynecology Nurse practitioner/occupational health Nurse practitioner/pediatrics Nurse practitioner/pediatrics critical care Nurse practitioner/perinatal Nurse practitioner/psychiatric & mental health Nurse practitioner/school
Primary Care Physician Assistant	97 exclude 363AS0400X	Physician Assistant Physician assistant/surgical

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Supplemental Table 2: Flow chart for study cohorts

Denominator Primary care providers	Provider type					
	Primary Care MD		NP		PA	
	N	% of previous step	N	% of previous step	N	% of previous step
1. Unique NPI numbers in 2015 Part D file from 20% Medicare sample	244,862		121,949		82,383	
2. Limited to primary care by taxonomy codes			108,995	89.4	74,428	90.3
3. Those in 50 States and DC	241,674	98.7	108,885	99.9	74,324	99.9
4. Those wrote at least 50 prescriptions in a year ^a	177,666	73.5	56,848	52.2	34,820	46.8
5. Exclude those without any E&M services	162,412	91.4	45,435	79.9	26,933	77.3
6. Those with <50% E&M service for ED	159,631	98.3	44,006	96.9	24,275	90.1
7. Those with at least 10 patients**	156,161	97.8	42,655	96.9	23,873	98.3
8. Those with at least 10 patients with completed Part D enrollment and survived after 4/1/2015**	155,335	97.3	42,309	96.1	23,754	97.9

a Using this cutoff, about 98% of providers prescribed medications to at least 10 Medicare patients in the study year.

** Assessing the percent of patients receiving high dose opioid prescriptions

*** Assessing the percent of patients receiving prolong opioid prescriptions

MD: medical doctor; NP: nurse practitioner; PA: physician assistant; E&M evaluation and management; ER: emergency department; MME: morphine milligram equivalents.

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Supplemental Table 3: Nurse Practitioner and Physician Assistant prescriptive authority²¹⁻²³ requirements for controlled substance (Schedule II-V) prescribing in 2015

<i>Nurse practitioner</i>	Legal requirements	Schedule II prescribing allowed	Schedule III-V Prescribing allowed	Can obtain DEA number
Alabama	Collaborating physician for professional oversight and direction	No	Yes	No
Arkansas	Collaborating physician for professional oversight and direction	Limited to hydrocodone-containing products (with authorization from collaborating MD)	Yes	Yes
Florida	N/A	No	No	No
Georgia	Practice under a Nurse Protocol Agreement and prescribe as delegated by a physician or protocol	No	Yes	No
Missouri	Collaborating physician for professional oversight and direction	Limited to hydrocodone-containing products (with authorization from collaborating MD)	Yes	Yes ^a
Oklahoma	Physician supervision required for prescriptive authority	No	Yes, 30-day supply	Yes
South Carolina	May prescribe according to practice agreement/protocol in place	No	Yes	No
West Virginia	Collaborating physician for professional oversight and direction	No	Yes	Yes
<i>Physician assistant</i>				
Alabama	Must practice with a supervising physician	Additional permit required	Yes	Yes
Arkansas	Must practice with a supervising physician	Limited to hydrocodone-containing products (with authorization from supervising MD)	Yes	Yes
Florida	Must practice with a supervising physician	No	Yes	Yes
Georgia	Must practice with a supervising physician	No	Yes	Yes
Iowa	Must practice with a supervising physician	May not prescribe depressants ^b	Yes	Yes
Kentucky	N/A	No	No	No
Missouri	Must practice with a supervising physician	Limited to hydrocodone-containing products (with authorization from supervising MD)	Yes	Yes
West Virginia	Must practice with a supervising physician	No	Yes, 30-day supply	Yes

467 a Prescriptions must include name of collaborating physician

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b Defined in the Iowa Code 2020, Chapter 124.206 to include amobarbital, glutethimide, pentobarbital, phencyclidine, secobarbital or the immediate precursors to any of the preceding.

Supplemental Table 4. Opioid prescribing pattern of primary care providers in the 559 primary care services areas, stratified by whether NP/PA were affiliated with primary care practices identified by social network analysis**

	Primary care MD			Primary care NP			Primary care PA		
	Total	Primary care practice		Total	Primary care practice		Total	Primary care practice	
		Yes	No ^a		Yes	No ^b		Yes	No ^b
% of patients who received any opioid	N = 31,147	N = 11,172	N = 19,975	N = 9,175	N = 3,303	N = 5,872	N = 4,983	N = 1,728	N = 3,255
Mean ± STD	16.21 ± 11.22	16.90 ± 10.22	15.82 ± 11.72	14.20 ± 18.03	17.09 ± 19.58	12.57 ± 16.87	15.63 ± 19.91	14.88 ± 18.15	16.03 ± 20.77
Median (Q1 – Q3)	14.63 (8.33 – 22.03)	15.63 (9.76 – 22.24)	14.0 (7.69 – 21.74)	8.33 (0 – 20.0)	10.87 (2.63 – 23.81)	6.90 (0 – 18.52)	9.32 (0 – 20.72)	10.00 (2.44 – 19.35)	9.09 (0 – 21.67)
>50%	1.07%	0.74%	1.25%	5.21%	7.54%	3.90%	7.59%	5.96%	8.45%
% of patients who received high dose opioids^c	N = 31,147	N = 11,172	N = 19,975	N = 9,175	N = 3,303	N = 5,872	N = 4,983	N = 1,728	N = 3,255
Mean ± STD	0.83 ± 2.66	0.82 ± 2.00	0.83 ± 2.96	0.99 ± 3.51	1.13 ± 3.40	0.91 ± 3.57	1.21 ± 4.72	1.28 ± 5.12	1.17 ± 4.50
Median (Q1 – Q3)	0 (0 – 0.48)	0 (0 – 1.04)	0 (0 – 0)	0 (0 – 0)	0 (0 – 0)	0 (0 – 0)	0 (0 – 0)	0 (0 – 0)	0 (0 – 0)
>10%	0.92%	0.52%	1.14%	2.32%	2.36%	2.30%	3.03%	2.95%	3.07%
% of patients who received long-term opioids^d	N = 30,939	N = 11,160	N = 19,779	N = 9,062	N = 3,294	N = 5,768	N = 4,941	N = 1,726	N = 3,215
Mean ± STD	4.43 ± 6.33	4.88 ± 5.32	4.18 ± 6.83	3.16 ± 7.79	3.54 ± 8.02	2.94 ± 7.65	2.94 ± 8.27	3.25 ± 8.89	2.77 ± 7.91
Median (Q1 – Q3)	2.50 (0 – 6.56)	3.61 (0 – 7.14)	1.47 (0 – 6.06)	0 (0 – 3.23)	0 (0 – 3.70)	0 (0 – 2.86)	0 (0 – 2.44)	0 (0 – 2.78)	0 (0 – 2.08)
>20%	2.61%	1.82%	3.05%	3.41%	4.01%	3.07%	3.22%	3.59%	3.02%

^aBased on Social Network Analysis, these primary care physicians were not affiliated with primary care practices. They may be primary care solo practitioners.

^bBased on Social Network Analysis, these NPs/PAs were not affiliated with primary care practices. They may be either specialist NPs/PAs or primary care solo practitioners.

^cProviders with at least 10 patients receiving any prescriptions in 2015.

^dProviders with at least 10 patients who completed Part D enrolment and were survived after 4/1/2015 in order to measure whether they received opioids for more than 90 days.

MD, medical doctor; NP, nurse practitioner; PA, physician assistant; STD, standard deviation; Q, quartile

** We identified primary care practice within each of the 20% randomly selected primary care service area (PCSA). A PCSA is an area defined by Dartmouth Atlas Healthcare for the measurement of primary care resources, utilization, and outcomes within small standardized areas based on zip codes.³⁵ We identified pairs of primary care providers in each PCSA who shared at least 30 patients, then used the Walktrap community finding algorithm to identify clusters of providers³⁶⁻³⁸ in primary care practices.²⁴⁻²⁶ Only clusters (primary care practices) in PCSAs with a modularity ≥ 0.4 , indicating a densely connected network were selected.³⁹ This methodology had positive predictive value of 84.4% for identifying MD and NP/PA pairs and good agreement in identifying primary care practices in a validation study.⁴⁰

Supplemental Table 5: Characteristics associated with high frequency, high dose, and long-term opioid prescribing by nurse practitioners (NPs) and physician assistants (PAs) to Medicare Part D enrollees in 2015, estimated from logistic regression models

	High frequency		High dose		Long-term		
	OR	95% CI	OR	95% CI	OR	95% CI	
Regulations allow Schedule II prescription^a	No	1.00	1.00		1.00		
	Yes	28.20	19.67-40.44	70.09	29.13-168.61	46.87	25.84-84.99
Patient Characteristic (every 10% increase)							
% Age older than 80 years	1.26	1.23-1.29	1.18	1.13-1.23	1.49	1.43-1.54	
% Female	1.12	1.10-1.15	1.06	1.02-1.09	1.18	1.14-1.23	
% Minority	0.86	0.84-0.88	0.84	0.81-0.86	0.87	0.85-0.90	
% Original entitlement as disabled	1.62	1.58-1.66	1.98	1.91-2.06	2.54	2.44-2.63	
% Medicaid eligible	0.95	0.93-0.97	0.81	0.79-0.84	0.83	0.80-0.85	
% HMO enrollee	0.97	0.96-0.99	0.97	0.95-1.00	1.01	0.98-1.03	
Rurality (1-unit increase)	0.82	0.80-0.83	0.79	0.77-0.82	0.94	0.92-0.97	
PCP available per 10,000	1.01	1.01-1.02	1.02	1.01-1.03	0.98	0.97-0.99	

^aStates that do not allow NPs to prescribe Schedule II opioids: Alabama, Arkansas, Florida, Georgia, Missouri, Oklahoma, South Carolina, West Virginia

States that do not allow PAs to prescribe Schedule II opioids: Alabama, Arkansas, Florida, Georgia, Iowa, Kentucky, Missouri, West Virginia.

HMO: health maintenance organization; PCP: primary care physician

Supplemental Table 6. Opioid prescription pattern by primary care providers, stratified by state regulation of NP/PA schedule II prescription authority (only for their patients who had Part A and B without HMO enrollment in 2014)

	Primary care MD			Primary care NP			Primary care PA		
		state regulation allows NP and PA to prescribe schedule II opioid ^{a,b}			state regulation allows NP to prescribe schedule II opioid ^a			state regulation allows PA to prescribe schedule II opioid ^b	
% of patients who received:	Total	Yes	No	Total	Yes	No	Total	Yes	No
Any opioid	N = 127,985	N = 101,761	N = 26,224	N = 34,175	N = 28,632	N = 5,543	N = 19,569	N = 17,012	N = 2,557
<i>Mean ± STD</i>	17.50±12.63	16.99±12.26	19.49±13.81	15.05±20.0	17.20±20.91	3.93±7.80	16.31 ± 22.21	18.12 ± 22.95	4.26 ± 10.18
<i>Median (Q1 – Q3)</i>	15.79 (8.33 – 24.32)	15.38 (8.33 – 23.60)	17.50 (9.52 – 26.86)	8.33 (0 – 20.83)	10.34 (0 – 23.53)	0 (0 – 5.00)	8.33 (0 – 21.31)	10.00 (0 – 23.53)	0 (0 – 4.17)
>50%	1.68%	1.40%	2.76%	6.55%	7.79%	0.14%	9.03%	10.24%	1.00%
High dose opioids^c	N = 127,985	N = 101,761	N = 26,224	N = 34,175	N = 28,632	N = 5,543	N = 19,569	N = 17,012	N = 2,557
<i>Mean ± STD</i>	0.94±2.94	0.94±2.86	0.91±3.25	1.17±4.47	1.39±4.84	0.03±0.52	1.28 ± 4.97	1.45 ± 5.30	0.10 ± 1.04
<i>Median (Q1 – Q3)</i>	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 – 0)	0 (0 – 0)	0 (0 – 0)	0 (0 – 0)	0 (0 – 0)	0 (0 – 0)
>10%	1.23%	1.23%	1.24%	3.05%	3.63%	<0.20%	3.54%	4.03%	<0.43%
Long-term opioids^d	N = 127,680	N = 101,518	N = 26,162	N = 34,077	N = 28,549	N = 5,528	N = 19,531	N = 16,981	N = 2,550
<i>Mean ± STD</i>	5.27±7.36	5.04±6.99	6.14±8.61	3.74±9.49	4.35±10.21	0.58±2.28	3.35 ± 9.63	3.75 ± 10.22	0.65 ± 2.65
<i>Median (Q1 – Q3)</i>	3.03 (0 – 7.94)	2.90 (0 – 7.69)	3.45 (0 – 9.09)	0 (0 – 3.57)	0 (0 – 4.76)	0 (0 – 0)	0 (0 – 1.82)	0 (0 – 2.86)	0 (0 – 0)
>20%	4.01%	3.48%	6.05%	4.50%	5.34%	<0.20%	4.20%	4.79%	<0.43%

^aStates which restricted NP authority to prescribe Schedule II opioids in 2015: Alabama, Arkansas, Florida, Georgia, Missouri, Oklahoma, South Carolina, West Virginia

^bStates which restricted PA authority to prescribe Schedule II opioids in 2015: Alabama, Arkansas, Florida, Georgia, Iowa, Kentucky, Missouri, West Virginia.

^cProviders with at least 10 patients receiving any prescriptions in 2015.

^dProviders with at least 10 patients who completed Part D enrolment and were survived after 4/1/2015 in order to measure whether they received opioids for more than 90 days.

MD, medical doctor; NP, nurse practitioner; PA, physician assistant; Rx, prescriptions; STD, standard deviation; Q, quartile.

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Supplemental Table 7: Characteristics associated with opioid overprescribing between types of provider within the same state, estimated from conditional logistic regression models (only for their patients who had Part A and B without HMO enrollment in 2014)

Type of provider	High frequency		High dose		Long-term		
	OR	95% CI	OR	95% CI	OR	95% CI	
Primary care MD	1.00		1.00		1.00		
Primary care NP	2.26	2.11-2.41	1.29	1.17-1.41	0.51	0.48-0.55	
Primary care PA	4.36	4.06-4.69	1.62	1.36-1.79	0.60	0.55-0.65	
Patient Characteristic (every 10% increase)							
% Age older than 80	1.24	1.20-1.27	1.20	1.16-1.25	1.26	1.23-1.30	
% Female	1.16	1.14-1.19	1.03	1.00-1.07	1.07	1.06-1.11	
% Minority	0.94	0.93-0.96	0.92	0.90-0.95	0.95	0.93-0.96	
% Original entitlement as disabled	1.86	1.82-1.91	2.22	2.14-2.29	2.10	2.05-2.15	
% Medicaid eligible	0.94	0.92-0.96	0.78	0.76-0.80	0.92	0.90-0.94	
% HMO enrollee	0.99	0.98-1.01	1.02	1.00-1.04	1.08	1.06-1.09	
Rurality (1-unit increase)	0.93	0.91-0.95	0.92	0.90-0.94	1.07	1.06-1.09	
PCP available per 10,000	1.01	1.00-1.01	1.02	1.01-1.02	0.98	0.97-0.98	
% >=3 comorbidity	1.22	1.20-1.24	1.15	1.13-1.18	1.03	1.01-1.04	

MD: medical doctor; NP: nurse practitioner; PA: physician assistant; HMO, health maintenance organization; PCP: primary care physician

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