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Original Article

Role of nurses in improving patient safety: Evidence from surgical complications in 21 countries

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ABSTRACT

Objectives: To analyze the role of nurse staffing in improving patient safety due to reducing surgical complications in member countries of Organization for Economic Co-operation and Development (OECD).

Methods: The number of practicing nurses' density per 1000 population and five surgical complications indicators including foreign body left in during procedure (FBL), postoperative pulmonary embolism (PPE) and deep vein thrombosis (DVT) after hip and knee replacement, postoperative sepsis after abdominal surgery (PSA) and postoperative wound dehiscence (PWD) were collected in crude rates per 100,000 hospital discharges for age group of 15 years old and over within 30 days after surgery based on surgical admission-related and all admission-related methods. The observations of 21 OECD countries were collected from OECD Health Statistics during 2010-2015 period. The statistical technique of panel data analysis including unit root test, co-integration test and dynamic long-run analysis were used to estimate the possible relationship between our panel series.

Results: There were significant relationships from nurse-staffing level to reducing FBL, PPE, DVT, PSA and PWD with long-run magnitudes of −2.91, −1.30, −1.69, −2.81 and −1.12 based on surgical admission method as well as −6.12, −14.57, −7.29, −1.41 and −0.88 based on all admission method, respectively.

Conclusions: A higher proportion of nurses is associated with higher patient safety resulting from lower surgical complications and adverse clinical outcomes in OECD countries. Hence, we alert policy makers about the risk of underestimating the impact of nurses on improving patient safety as well as the quality of health care services in OECD countries.

What is known?

- To our knowledge, there is a lack of cross-national studies to analyze the dependency of patient safety to nursing care.

What is new?

- The following study has significance in nursing by measuring the effect of nursing characteristics on reducing surgical complications in 21 OECD countries during 2010-2015 period using the statistical technique of panel data analysis.
- The findings of this study confirm that there was a significant relationship from nurse staffing to declining surgical complications in OECD countries. i.e. increasing nurse-staffing level by 1% in OECD countries is associated with a reduction of foreign body left in during procedure (FBL), postoperative pulmonary embolism (PPE) and deep vein thrombosis (DVT) after hip or knee replacement, postoperative sepsis after abdominal surgery (PSA) and postoperative wound dehiscence (PWD) by 2.9%, 1.3%, 1.7%, 2.8% and 1.1% based on surgical admission-related method and 6.1%, 14.6%, 7.3%, 1.4% and 0.9% based on all admission-related method, respectively.
- Our findings alert policy makers about the risk of underestimating the effect of nursing shortage on increasing surgical complications and adverse clinical outcomes in OECD countries.

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1. Introduction

Patient safety remains one of the core indicators for estimating quality and level of health care services globally [1]. According to the recent reports by Organization for Economic Co-operation and Development (OECD) [2,3], over 15% of total expenditures on hospital care in OECD countries have been allocated to treat preventable patient safety failures and surgical complications. As an example, by improving patient safety systematically from 2010, The United States was able to reduce approximately 28 billion USD of total health care spending resulting from developed patient safety monitoring systems as well as forceful patient safety culture [4].

As robust comparison between implementation of health care services among different OECD countries is a dominant issue to securing improvement, OECD has developed five types of adults' patient safety indicators based on surgical complications and adverse events, including failure to remove surgical foreign bodies at the end of a procedure (FBL), postoperative pulmonary embolism (PPE) and deep vein thrombosis (DVT) after hip or knee replacement, postoperative sepsis after abdominal surgery (PSA) and postoperative wound dehiscence (PWD), with the aims of monitoring and developing patient safety in OECD countries – see OECD [5]. Among OECD's patient safety indicators, FBL is classified as sentinel or an event that should never occur, whereas other adverse events cannot be totally prevented based on the high-risk nature of some medical and/or surgical procedures [5].

Although preventing adverse surgical events can be developed by using preventive measures i.e. counting instruments, effective communication between the surgical team members and methodical wound exploration in FBL, using anticoagulants and other perioperative measures in PPE and DVT [6], applying antibiotics, surpass sterile surgical techniques as well as effective postoperative care in PSA and PWD, avoidable safety failures are observed among developed countries. Evidence suggests that emergency cases, unexpected changes in surgical procedure, alterations in the surgical team and patient obesity are the most prominent issues that increase the risk of surgical complications in OECD countries [5].

As nurses play a critical role in health care services of OECD countries, the priority of this study is to measure the plausible impact of development in nursing services on improving patient safety by preventing surgical complications. To our knowledge, systematic reviews by Kane et al. [7] and Shekelle [8] have confirmed the effect of nursing characteristics associated with the level of education, experience, specialty matched with work assignments etc. on increasing patient outcomes as an efficient patient safety strategy. Moreover, the same conclusion has been drawn in multinational studies by Aiken et al. [9], Estabrooks et al. [10], Rafferty et al. [11], Van den Heede et al. [12], Aiken et al. [13], Aiken et al. [14], Cho et al. [15], Aiken et al. [16] and Amiri and Solankallio-Vahteri [17].

Across traditional studies in nursing which typically have been relied on cross-sectional data analysis, this study undertakes a new attempt to estimate the role of nursing on preventing safety failures using the technique of panel data analysis. The observations of nurse-staffing level along with surgical complications indicators were collected from OECD Health Statistics for 21 OECD countries over the period of 2010-2015.

2. Data description

The data of nursing professionals' density per 1000 population (head counts), which covered the number of practicing professional nurses who deliver clinical and medical care services directly to patients, including general care nurses, specialist nurses, clinical nurses, district nurses, nurse anesthetists, nurse educators, nurse practitioners and public health nurses, was collected as proxy for nurse staffing from OECD [18] for 21 OECD countries during 2010-2015 period. Fig. 1 depicts the amounts of nurse staffing variable in 2015 as well as the list of countries.

As a part of ongoing project by OECD with the aim of monitoring and improving patient safety in OECD countries, the observations of five indicators from OECD Health Statistics [19] including FBL, PPE, DVT, PSA and PWD were collected in crude rates per 100,000 hospital discharges for age group of 15 years old and over in both surgical admission-related and all admission-related methods during 2010-2015 period. Discharges among cases were counted in a secondary diagnosis field during the surgical admission and in other diagnosis fields during readmissions within 30 days after the surgery or 30 days from the admission date for the first surgical admission.

Statistics of FBL were measured by foreign body accidently left during a procedure together with acute reactions to foreign substance accidently left during a procedure with International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) codes 9984 and 9987 and World Health Organization's Tenth Revision, International Classification of Diseases (ICD-10-WHO) codes T81.5–6, Y61.0–9 in during surgical operation (E8710), infusion or transfusion (E8711), kidney dialysis or other perfusions (E8712), injection or vaccination (E8713), endoscopic examination (E8714), aspiration of fluid or tissue, puncture, and catheterization (E8715), heart catheterization (E8716), removal of catheter or packing (E8717) and other specified/unspecified procedures (E8718–19).

The observations of PPE and DVT were collected from hip and knee replacement surgeries with ICD-9-CM procedure codes: 387,

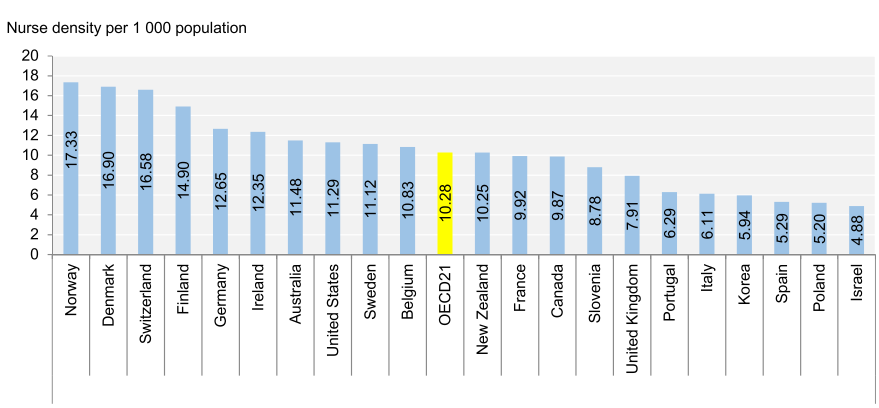

Fig. 1. Number of practicing nurses per 1000 population in 2015. Source: OECD [18].

8151 and 8153–5 and The Australian Classification of Health Interventions (ACHI): block (726) 34800–00, block (723) 35330–00, and block (723) 35330–01. PPE diagnosis codes were included ICD-9-CM: 4151, 41511, 41513 and 41519, and ICD-10-WHO: I26.0 and I26.9. DVT diagnosis codes were ICD-9-CM: 45111, 4512, 45119, 45181, 4519, 4538 and 45340–2, and ICD-10-WHO: I80.1–3, I80.8–9 and I82.8.

ICD-9-CM sepsis diagnosis codes were 0380–3, 03810–2, 03819, 78552, 78559, 9980, 99800 and 99802, and septicemia due to: 03840–4, 03849, 0388–9 and 99591–2. ICD-10-WHO diagnosis codes for PSA were A40.0–3, A40.8–9, A41.0–5, A41.8–9, R57.2, R57.8, R65.0–1 and T81.1.

Data of PWD were collected according to immunocompromised state codes available for ICD-9-CM at AHRQ Quality Indicators [20] in Appendix I and for ICD-10-WHO at Definitions for Health Care Quality Indicators (HCQID) [21] in Annex C: W-1. More details about inclusions and exclusions of surgical complications indicators can be found at HCQID [21].

The observations of five surgical complications indicators in year 2015 or nearest year as well as the list of countries are available in Figs. 2–6 and Appendix provides the same observations together with nursing staff in a fixed order. The average amounts of nurse staffing and patient safety indicators of OECD countries from 2010 to 2015 is available in Table 1. As the aim of this study is to measure the elasticities

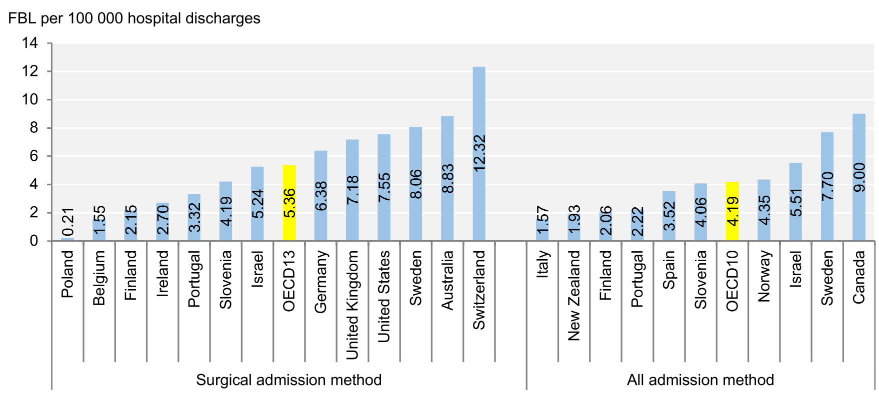

Fig. 2. Foreign body left in during procedure (FBL), 2015 (or nearest year). Source: OECD Health Statistics [19].

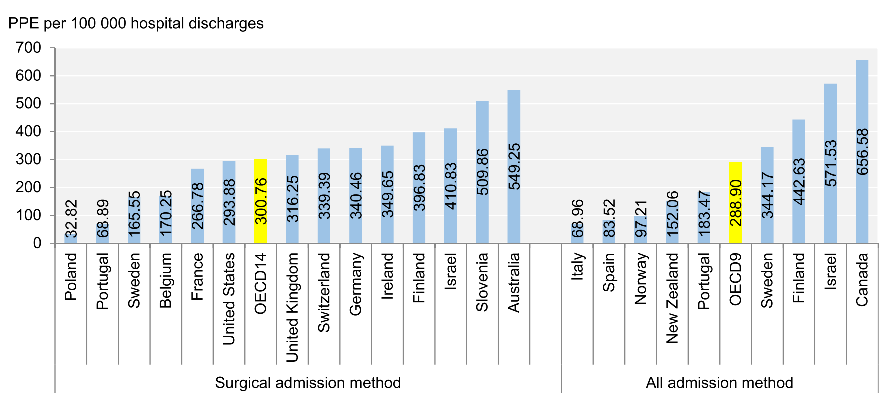

Fig. 3. Postoperative pulmonary embolism (PPE) in hip and knee surgeries, 2015 (or nearest year). Source: OECD Health Statistics [19].

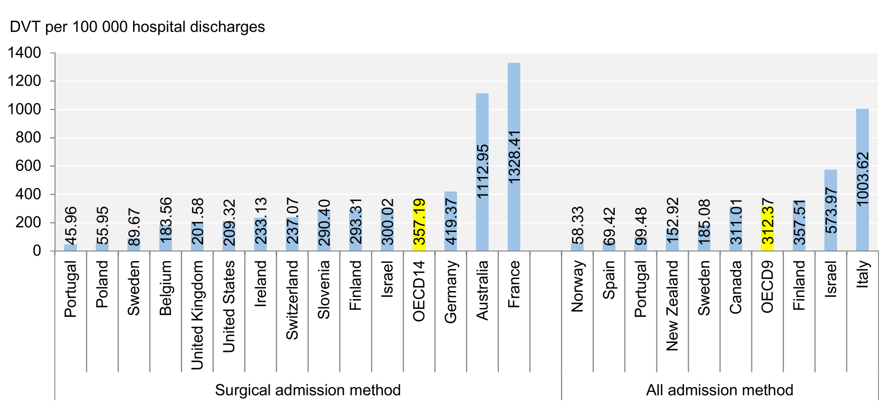

Fig. 4. Deep vein thrombosis (DVT) in hip and knee surgeries, 2015 (or nearest year). Source: OECD Health Statistics [19].

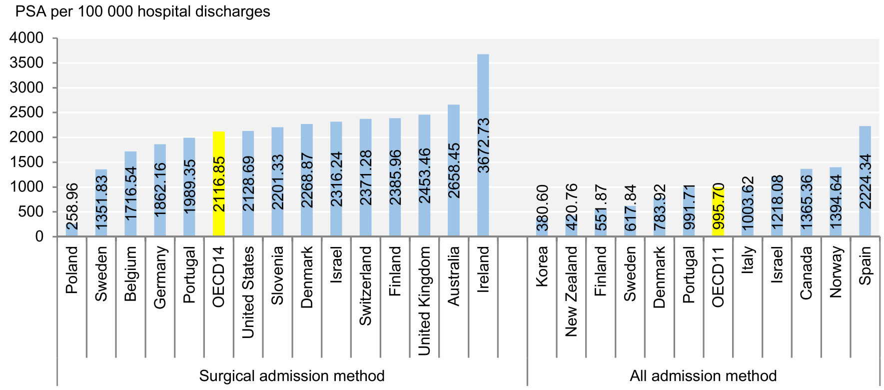

Fig. 5. Postoperative sepsis in abdominal surgeries (PSA), 2015 (or nearest year). Source: OECD Health Statistics [19].

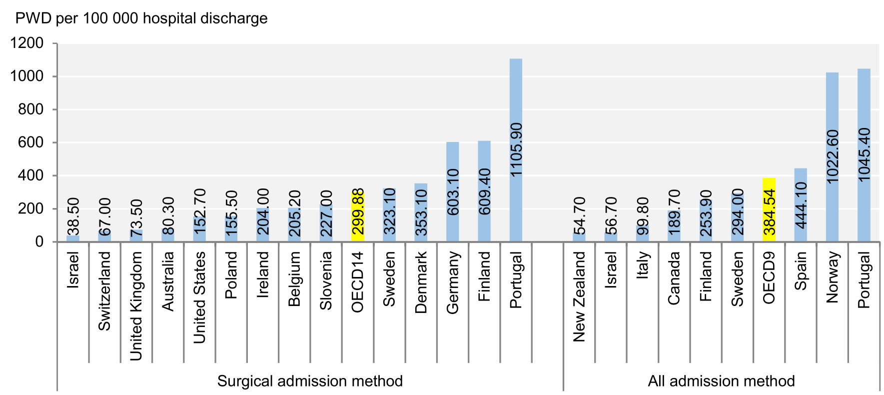

Fig. 6. Postoperative wound dehiscence (PWD), 2015 (or nearest year). Source: OECD Health Statistics [19].

of nurse staffing on reducing surgical complication indicators, the logarithm digits of series, i.e. *lnNURSE*, *lnFBL*, *lnPPE*, *lnDVT*, *lnPSA* and *lnPWD*, were used in panel data analysis and missing observations were imputed by Artificial Neural Networks (ANNs) method – for explanation of ANNs method see Dybowski and Gant [22].

3. Panel data analysis

Panel data analysis is used to analyze data collected over two dimensions for instance across time and for the same individuals. Panel data analysis is an extension of the traditional regression analysis but allowing both the fixed effects and the residual error terms to depend on the dimension indices (e.g. time and individuals). In model building or in refining the model two tests are used namely unit root test and co-integration test. The unit root test is used to test the dependency of the variables on the time and individual dimensions (time series analysis with the aim of obtaining reliable time dependencies). The co-integration test is used to assess the dependency of the residuals on time and to conclude whether there is a meaningful relationship between panel series in long-run or not. Finding co-integrated panel series opens the way to dynamic long-run analysis to measure the long-run coefficient of significant association between the panel series. In dynamic long-run analysis, different types of autoregressive models should be tested to calculate the long-run magnitude of effect between the variables [23].

Table 1
Average amounts of nurse staffing and five surgical complications indicators of OECD countries in 2010-2015.

Year	Nurse density per 1000 population	Accident rate per 100,000 hospital discharge									
		FBL		PPE		DVT		PSA		PWD	
		Surgical admission	All admission	Surgical admission	All admission	Surgical admission	All admission	Surgical admission	All admission	Surgical admission	All admission
	OECD21	OECD13	OECD10	OECD14a	OECD9	OECD14a	OECD9	OECD14b	OECD9	OECD14b	OECD11
2010	9.69	5.52	4.85	332.59	420.07	443.10	358.47	1935.46	1059.55	318.01	414.92
2011	9.79	5.54	5.16	337.59	412.66	441.76	376.18	1972.53	1074.46	328.27	416.90
2012	9.87	5.31	4.56	344.90	405.11	446.69	400.60	1840.03	1034.50	327.35	412.44
2013	10.01	5.35	4.02	321.24	330.52	403.54	304.10	1992.07	1024.67	313.24	396.22
2014	10.12	5.52	4.48	357.79	384.62	371.75	322.02	2004.58	991.37	314.16	405.51
2015	10.28	5.29	4.20	299.05	288.91	354.77	312.37	2116.84	995.70	299.86	384.54

Notes: OECD14a included France, whereas OECD14b included Denmark instead of France.

4. Panel data analysis results

4.1. Unit root test

In this article, three common types of panel-based unit root tests including Levin, Lin and Chu [24], Fisher-type tests using ADF and PP tests [25,26] used to examine stationary processes of our variables and their results are available in Table 2. As can be seen, the results of unit root tests prove that all nurse staffing series had non-stationary process, i.e. the stationarity of *lnNURSE* series were sensitive to trend presentation. Except *lnFBL* in surgical admission method and *lnPSA* in both admission-related methods, all patient safety indicators had stationary processes. Hence, co-integration analysis and dynamic long-run models would be the efficient statistical methods to investigate the plausible dependency of patient safety to nursing characteristics in OECD countries.

4.2. Co-integration test

In this step, we examine whether our variables were co-integrated, i.e. there was a meaningful relationship between them in long-run, or not. The results of Pedroni co-integration residual test [27,28] are presented in Table 3 and show that nurse staffing and all patient safety indicators were co-integrated in the long-run.

Table 2
Panel unit root test.

Null hypothesis: Unit root		level						1st difference		Conclusion
Variable	Method	Intercept		Intercept and trend		None		Intercept		
		Statistic	*P*	Statistic	*P*	Statistic	*P*	Statistic	*P*	
Surgical admission method										
lnNURSE (OECD13)	Levin, Lin & Chu t	−1.66	0.047	−6.83	0.000	5.70	1.000	−6.37	0.000	
	ADF - Fisher Chi-square	21.91	0.693	19.12	0.831	16.55	0.921	30.77	0.236	1#
	PP - Fisher Chi-square	41.57	0.027	41.24	0.029	19.81	0.800	38.45	0.054	
lnFBL	Levin, Lin & Chu t	−1.66	0.047	−6.83	0.000	5.70	1.000	−6.37	0.000	
	ADF - Fisher Chi-square	21.91	0.693	19.12	0.831	16.55	0.921	30.77	0.236	1#
	PP - Fisher Chi-square	41.57	0.027	41.24	0.029	19.81	0.800	38.45	0.054	
lnNURSE (OECD14a)	Levin, Lin & Chu t	−1.97	0.024	−6.87	0.000	6.05	1.000	−6.51	0.000	
	ADF - Fisher Chi-square	22.89	0.738	19.40	0.885	16.55	0.956	32.43	0.257	1#
	PP - Fisher Chi-square	45.29	0.020	41.27	0.050	19.81	0.871	40.11	0.064	
lnPPE	Levin, Lin & Chu t	−20.43	0.000	−53.28	0.000	−2.31	0.010	−47.93	0.000	
	ADF - Fisher Chi-square	45.93	0.017	40.81	0.055	31.13	0.311	60.29	0.000	2#
	PP - Fisher Chi-square	55.33	0.001	58.71	0.000	48.71	0.009	65.56	0.000	
lnDVT	Levin, Lin & Chu t	−0.17	0.430	−5.69	0.000	−7.93	0.000	−6.24	0.000	
	ADF - Fisher Chi-square	15.22	0.975	16.75	0.953	85.16	0.000	36.47	0.130	2#
	PP - Fisher Chi-square	21.54	0.801	26.25	0.559	103.82	0.000	37.59	0.106	
lnNURSE (OECD14b)	Levin, Lin & Chu t	−1.81	0.034	−6.93	0.000	7.03	1.000	−6.61	0.000	
	ADF - Fisher Chi-square	22.48	0.758	19.56	0.879	16.55	0.956	33.03	0.234	1#
	PP - Fisher Chi-square	43.07	0.034	41.39	0.049	19.81	0.871	40.71	0.057	
lnPSA	Levin, Lin & Chu t	1.25	0.895	−1.58	0.056	−2.02	0.021	−2.04	0.020	
	ADF - Fisher Chi-square	10.91	0.998	25.10	0.622	25.07	0.624	41.61	0.047	1#
	PP - Fisher Chi-square	14.17	0.985	46.90	0.014	35.06	0.168	47.53	0.012	
lnPWD	Levin, Lin & Chu t	−0.88	0.188	−5.53	0.000	−5.53	0.000	−6.80	0.000	
	ADF - Fisher Chi-square	18.89	0.901	23.65	0.699	43.77	0.029	40.97	0.054	2#
	PP - Fisher Chi-square	25.05	0.624	42.29	0.040	56.20	0.001	44.69	0.023	
All admission method										
lnNURSE (OECD10)	Levin, Lin & Chu t	−1.16	0.121	−6.44	0.000	4.95	1.000	−5.56	0.000	
	ADF - Fisher Chi-square	13.65	0.847	13.09	0.873	3.49	1.000	22.08	0.335	1#
	PP - Fisher Chi-square	18.88	0.529	28.58	0.096	5.11	0.999	28.99	0.087	
lnFBL	Levin, Lin & Chu t	−1.75	0.039	−10.74	0.000	−3.21	0.000	−11.94	0.000	
	ADF - Fisher Chi-square	24.38	0.226	24.44	0.223	44.78	0.001	39.01	0.006	2#
	PP - Fisher Chi-square	27.62	0.118	44.00	0.001	54.59	0.000	45.05	0.001	
lnNURSE (OECD9)	Levin, Lin & Chu t	−1.23	0.107	−6.43	0.000	4.74	1.000	−5.41	0.000	
	ADF - Fisher Chi-square	13.50	0.760	12.81	0.802	3.37	0.999	20.59	0.300	1#
	PP - Fisher Chi-square	18.86	0.400	28.53	0.054	5.05	0.998	27.51	0.069	
lnPPE	Levin, Lin & Chu t	−3.90	0.000	−5.20	0.000	−6.52	0.000	−5.97	0.000	
	ADF - Fisher Chi-square	17.01	0.522	17.82	0.467	51.85	0.000	29.35	0.044	2#
	PP - Fisher Chi-square	21.56	0.251	37.44	0.004	68.35	0.000	38.52	0.003	
lnDVT	Levin, Lin & Chu t	1.06	0.857	−4.86	0.000	−3.58	0.000	−5.12	0.000	
	ADF - Fisher Chi-square	14.58	0.690	13.20	0.779	44.86	0.000	23.88	0.159	2#
	PP - Fisher Chi-square	26.38	0.091	20.94	0.282	60.36	0.000	29.03	0.047	
lnPWD	Levin, Lin & Chu t	−1.89	0.028	−0.72	0.234	−2.55	0.005	−1.08	0.139	
	ADF - Fisher Chi-square	20.00	0.332	14.79	0.676	28.19	0.059	27.24	0.074	2#
	PP - Fisher Chi-square	26.99	0.0791	25.71	0.106	39.78	0.002	31.21	0.027	
lnNURSE (OECD11)	Levin, Lin & Chu t	−0.68	0.248	−6.64	0.000	6.57	1.000	−5.69	0.000	
	ADF - Fisher Chi-square	14.09	0.898	14.04	0.899	3.38	1.000	24.07	0.343	1#
	PP - Fisher Chi-square	20.36	0.560	31.40	0.088	5.05	0.999	31.33	0.089	
lnPSA	Levin, Lin & Chu t	−2.60	0.004	−11.53	0.000	−0.90	0.183	−9.88	0.000	
	ADF - Fisher Chi-square	17.55	0.732	25.97	0.252	27.67	0.186	39.53	0.012	1#
	PP - Fisher Chi-square	25.52	0.2725	47.45	0.001	41.95	0.006	47.35	0.001	

Notes: 1# means non-stationary process and 2# means stationary process. The optimum lag lengths chose based on Schwarz Information Criteria (SIC) from 0 to 3 to ensure that the residuals were white noise. Spectral calculations were based on automatic Newey-West for bandwidth selection and Bartlett for kernel. The existence of common *AR*(1) coefficients and trend were assumed in Levin et al. test and other tests simulated by cross-unit specific *AR*(1) coefficients with trend presentations. According to different list of countries in surgical complications indicators, different *lnNURSE* series were added in unit root test i.e. OECD14a included France, whereas OECD14b included Denmark instead of France.

Table 3
Pedroni co-integration residual test.

Null hypothesis: No co-integration		Individual intercept				Individual intercept and trend				Conclusion
Variables	Method	Non-weighted		Weighted		Non-weighted		Weighted		
		Statistic	*P*	Statistic	*P*	Statistic	*P*	Statistic	*P*	
Surgical admission method										
lnNURSE & lnFBL	Panel PP-Statistic	−3.12	0.000	−4.03	0.000	−8.78	0.000	−6.43	0.000	Co-integrated
	Panel ADF-Statistic	−2.73	0.003	−3.35	0.000	−6.00	0.000	−4.20	0.000	
	Group PP-Statistic	−4.94	0.000			−6.93	0.000			
	Group ADF-Statistic	−4.93	0.000			−6.60	0.000			
lnNURSE & lnPPE	Panel PP-Statistic	−5.38	0.000	−5.07	0.000	−14.19	0.000	−10.31	0.000	Co-integrated
	Panel ADF-Statistic	−5.29	0.000	−4.46	0.000	−8.50	0.000	−6.45	0.000	
	Group PP-Statistic	−6.54	0.000			−10.98	0.000			
	Group ADF-Statistic	−5.01	0.000			−6.51	0.000			
lnNURSE & lnDVT	Panel PP-Statistic	−5.47	0.000	−4.55	0.000	−6.83	0.000	−10.20	0.000	Co-integrated
	Panel ADF-Statistic	−4.03	0.000	−3.90	0.000	−3.36	0.000	−5.78	0.000	
	Group PP-Statistic	−4.86	0.000			−11.58	0.000			
	Group ADF-Statistic	−2.93	0.002			−5.86	0.000			
lnNURSE & lnPSA	Panel PP-Statistic	−4.68	0.000	−4.65	0.000	−27.07	0.000	−11.44	0.000	Co-integrated
	Panel ADF-Statistic	−3.89	0.000	−4.05	0.000	−12.12	0.000	−6.45	0.000	
	Group PP-Statistic	−5.02	0.000			−10.96	0.000			
	Group ADF-Statistic	−2.55	0.005			−6.74	0.000			
lnNURSE & lnPWD	Panel PP-Statistic	−4.93	0.000	−5.11	0.000	−8.27	0.000	−7.03	0.000	Co-integrated
	Panel ADF-Statistic	−4.82	0.000	−4.52	0.000	−4.33	0.000	−4.78	0.000	
	Group PP-Statistic	−5.10	0.000			−13.11	0.000			
	Group ADF-Statistic	−4.35	0.000			−6.49	0.000			
All admission method										
lnNURSE & lnFBL	Panel PP-Statistic	−0.80	0.210	−3.44	0.000	−5.39	0.000	−7.08	0.000	Co-integrated
	Panel ADF-Statistic	−0.95	0.170	−2.91	0.002	−3.43	0.000	−4.54	0.000	
	Group PP-Statistic	−4.59	0.000			−10.73	0.000			
	Group ADF-Statistic	−3.75	0.000			−7.38	0.000			
lnNURSE & lnPPE	Panel PP-Statistic	−1.13	0.128	−3.61	0.000	−8.12	0.000	−5.21	0.000	Co-integrated
	Panel ADF-Statistic	−1.15	0.123	−3.14	0.000	−5.80	0.000	−3.94	0.000	
	Group PP-Statistic	−4.52	0.000			−5.43	0.000			
	Group ADF-Statistic	−3.61	0.000			−3.20	0.000			
lnNURSE & lnDVT	Panel PP-Statistic	−2.31	0.010	−3.44	0.000	−8.61	0.000	−9.71	0.000	Co-integrated
	Panel ADF-Statistic	−1.75	0.039	−2.57	0.005	−4.35	0.000	−4.89	0.000	
	Group PP-Statistic	−4.01	0.000			−5.66	0.000			
	Group ADF-Statistic	−2.13	0.016			−2.71	0.003			
lnNURSE & lnPSA	Panel PP-Statistic	−1.88	0.030	−4.88	0.000	−9.40	0.000	−6.32	0.000	Co-integrated
	Panel ADF-Statistic	−1.63	0.051	−4.12	0.000	−5.68	0.000	−4.57	0.000	
	Group PP-Statistic	−6.38	0.000			−7.64	0.000			
	Group ADF-Statistic	−4.13	0.000			−4.20	0.000			
lnNURSE & lnPWD	Panel PP-Statistic	−7.18	0.000	−4.84	0.000	−9.39	0.000	−5.56	0.000	Co-integrated
	Panel ADF-Statistic	−5.74	0.000	−4.23	0.000	−4.37	0.000	−3.46	0.000	
	Group PP-Statistic	−5.19	0.000			−6.63	0.000			
	Group ADF-Statistic	−4.18	0.000			−2.55	0.005			

Notes: Group-statistics were calculated based on common *AR*(1) coefficients in within-dimension and cross-unit specific *AR(1)* coefficients in between-dimension. The optimum lag lengths were investigated based on SIC from 0 to 2. Spectral calculations were based on automatic Newey-West for bandwidth selection and Bartlett for kernel.

4.3. Dynamic long-run analysis

As nurse-staffing level and patient safety indicators were significantly co-integrated, long-run magnitudes of such relationships can be investigated by dynamic long-run analysis. Results of dynamic long-run panel models are available in Table 4 and verify that long-run elasticities of effect of nurse staffing has on FBL, PPE, DVT, PSA and PWD were −2.91, −1.30, −1.69, −2.81 and −1.12 in surgical admission method as well as −6.12, −14.57, −7.29, −1.41 and −0.88 in all admission methods, respectively. Thus, increasing 1% in nurse-staffing level in OECD countries is associated with a reduction in surgical complication indicators of FBL, PPE, DVT, PSA and PWD by 2.9%, 1.3%, 1.7%, 2.8% and 1.1% based on surgical admission method and 6.1%, 14.6%, 7.3%, 1.4% and 0.9% based on all admission method, respectively.

5. Discussion

There has been much interest in determining the magnitude of the effect of nurses on improving patient safety resulting from reducing surgical complications as it is considered as one of the major accomplishments of health care systems in OECD countries. To our knowledge, although the effect of nurses on reducing the risk of surgical complications, patient mortality and adverse clinical outcomes have been confirmed in previous studies, there is a lack of cross-national analysis to measure such an impact in national and global levels. This article undertook a new attempt to estimate the role of nursing care services in reducing safety failures using a widest range of available data collected from OECD Health Statistics.

The number of practicing professional nurses' density per 1000 population as the proxy of nursing characteristics along with crude rates of surgical complications per 100,000 hospital discharges for

Table 4
Dynamic long-run models.

Dependent variable	Variable	Coefficient	Std. Error	t	P	r^2	Durbin-Watson
Surgical admission method							
lnFBL	*Constant*	7.6944	3.16	2.42	0.018	0.942	1.58
	Trend	0.0131	0.02	0.51	0.605		
	lnNURSE	−2.9096	1.43	−2.03	0.046		
Long-run elasticity: −2.9096							
lnPPE	*Constant*	8.4030	1.36	6.17	0.000	0.974	1.74
	Trend	0.0141	0.01	1.19	0.235		
	lnNURSE	−1.2963	0.61	−2.10	0.039		
Long-run elasticity: −1.2963							
lnDVT	*Constant*	9.3245	1.68	5.54	0.000	0.956	1.93
	lnNURSE	−1.6907	0.74	−2.25	0.027		
Long-run elasticity: −1.6907							
lnPSA	*Constant*	13.9705	1.54	9.01	0.000	0.996	2.52
	Trend	0.0449	0.01	4.00	0.000		
	lnNURSE	−1.3830	0.48	−2.84	0.009		
	lnNURSE(-1)	0.7015	0.21	3.20	0.003		
	lnNURSE(-2)	−0.1245	0.19	−0.63	0.532		
	lnNURSE(-3)	−2.1249	0.43	−4.91	0.000		
Long-run elasticity: −1.3830 + 0.7015 + −2.1249 = −2.8064							
lnPWD	*Constant*	3.9467	2.09	1.88	0.064	0.980	2.25
	Trend	−0.0288	0.01	−1.97	0.053		
	lnPWD(-1)	0.5206	0.17	2.99	0.004		
	lnNURSE	−2.6643	1.25	−2.11	0.039		
	lnNURSE(-1)	2.1255	1.14	1.84	0.070		
Long-run elasticity: (−2.6643 + 2.1255) / (1 − 0.5206) = −1.1239							
All admission method							
lnFBL	*Constant*	9.5595	4.96	1.92	0.064	0.878	2.13
	lnFBL(-1)	0.3707	0.19	1.93	0.062		
	lnFBL(-2)	−0.3324	0.20	−1.64	0.111		
	lnNURSE	−3.8524	2.25	−1.70	0.099		
Long-run elasticity: −3.8524 / (1 − 0.3707) = −6.1223							
lnPPE	*Constant*	7.1424	5.67	1.25	0.221	0.959	2.55
	lnPPE(-1)	0.1856	0.18	1.00	0.323		
	lnPPE(-2)	0.5297	0.22	2.37	0.026		
	lnNURSE	−6.8519	3.93	−1.74	0.094		
	lnNURSE(-1)	4.2327	4.26	0.99	0.330		
Long-run elasticity: −6.8519 / (1 − 0.5297) = −14.5700							
lnDVT	*Constant*	20.5169	7.64	2.68	0.013	0.918	2.12
	lneDVT(-1)	0.0241	0.16	0.14	0.885		
	lnDVT(-2)	0.0892	0.16	0.53	0.594		
	lnNURSE	−7.2892	3.35	−2.17	0.040		
Long-run elasticity: −7.2892							
lnPSA	*Constant*	9.8644	1.50	6.57	0.000	0.920	0.96
	Trend	−0.0036	0.01	−0.26	0.794		
	lnNURSE	−1.4089	0.70	−1.98	0.051		
Long-run elasticity: −1.4089							
lnPWD	*Constant*	5.7109	1.80	3.15	0.003	0.982	2.23
	Trend	−0.0459	0.01	−3.12	0.003		
	lnNURSE	0.9044	0.67	1.33	0.190		
	lnNURSE(-1)	−0.8823	0.40	−2.19	0.035		
Long-run elasticity: −0.8823							

Notes: The optimum lag lengths were selected using SIC from 0 to 3. All dynamic long-run models were estimated by panel fixed effect method and coefficient covariance methods were ordinary, instead in *lnPWD* based on all admission method was white cross-section.

adults in surgical admission-related and all admission-related methods based on foreign body left in during procedure, post-operative pulmonary embolism and deep vein thrombosis after hip or knee replacement, postoperative sepsis after abdominal surgery and postoperative wound dehiscence were collected in 21 OECD countries over the period of 2010-2015. The statistical technique of panel data analysis was applied to study the dependency of surgical complications to nursing characteristics in the long-run.

Results of panel unit root tests argued that nurse staffing series had non-stationary process and co-integration analysis together with dynamic long-run models were the efficient statistical methods to investigate the plausible effect of nursing competencies on improving patient safety in OECD countries. Results of panel co-integration test and dynamic long-run models verified that there was a significant association between nursing characteristics and reducing surgical complications i.e. increasing 1% in nurse-staffing level in OECD countries would reduce FBL, PPE, DVT, PSA and PWD by 2.9%, 1.3%, 1.7%, 2.8% and 1.1% in surgical admission method and 6.1%, 14.6%, 7.3%, 1.4% and 0.9% in all admission method, respectively.

Overall, our findings verify the existence of a meaningful relationship from higher proportions of practicing nurses and hospital nursing characteristics to improving patient safety associated with nursing education, experience, specialty matched with work assignments, nurse working conditions, effective communication and collaborative relationships, promoting decision making among nurses and managing conflicts, improvements in the quality of nurse practice environments, the implementation of evidence-based standards and use of tools designed to drop medical error.

The limitation of this study is the lack of adding other related factors like nurse' education level, years of work experience, physician-to-patient ratio, health care expenditures and level of medical technology in our panel data analysis. As our observations were short during the study period, we were not able to add other control variables and to investigate the cross-sectional coefficients of the role of nurses on patient safety indicators in OECD countries. Thus, further research is needed to evaluate the magnitude of such an impact among different OECD countries with adding other related control variables.

6. Conclusion

Our findings conclude that improving the quality of nursing care associated with rising the level of nursing staff would be an efficient policy to reduce safety failures resulting from lower surgical complications and adverse clinical outcomes in OECD countries. Moreover, the results of this study alert policy makers about considering the risk of safety failures and patient mortality related to nursing shortages in OECD countries.

Conflicts of interest

The authors have declared that no conflicts of interest exist.

Authors' contributions

All authors contributed to the study design and drafting of the paper. Amiri has done data analysis and all authors approved the final version of article.

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Appendices. Supplementary data

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