Supplementary appendix

Supplement to: Benoît Corriveau, Sasha Milbeck, Josien R van der Kooij, Michael Bride, Michelle Degli Esposti, Jonathan Taylor, Bernardo Meza-Torres, Catia Nicodemo, Simon de Lusignan. Actionability of general practitioner retention models using routinely collected data: a systematic review

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Appendix A – Search strategies

Table A1. Databases searched and records retrieved

Database (platform)	Date searched	Coverage	Records
PubMed (NLM)	27 Feb 2026	Inception - 27 Feb 2026	456
Embase (Ovid)	27 Feb 2026	Inception - 27 Feb 2026	660
Web of Science (Clarivate)	27 Feb 2026	Inception - 27 Feb 2026	452
Scopus (Elsevier)	27 Feb 2026	Inception - 27 Feb 2026	356
CINAHL (EBSCOhost)	27 Feb 2026	Inception - 27 Feb 2026	296

Table A2. Full search strategies

Database	PubMed
PubMed	("General Practitioners"[Mesh] OR "Physicians, Family"[Mesh] OR "Physicians, Primary Care"[Mesh] OR "General Practice"[Mesh] OR "Family Practice"[Mesh] OR "Primary Health Care"[Mesh:NoExp] OR "general practi*"[tiab] OR "primary care provider*"[tiab] OR "primary care clinician*"[tiab] OR GP[tiab] OR GPs[tiab] OR "Nurse Practitioners"[Mesh] OR "Primary Care Nursing"[Mesh] OR "Family Nursing"[Mesh] OR "nurse practitioner*"[tiab] OR "advanced practice nurse*"[tiab] OR "primary care nurse*"[tiab] OR "practice nurse*"[tiab] OR "community nurse*"[tiab] OR "community health nurse*"[tiab] OR "district nurse*"[tiab] OR "health visitor*"[tiab]) AND ("Personnel Turnover"[MeSH Terms] OR "Retirement"[MeSH Terms] OR turnover[tiab] OR attrition[tiab] OR retention[tiab] OR mobility[tiab] OR resign*[tiab] OR quit*[tiab] OR retir*[tiab] OR leav*[tiab] OR exit*[tiab] OR departure*[tiab] OR burnout[ti] OR satisfaction[ti] OR fatigue[ti] OR exhaustion[ti] OR engagement[ti]) AND ("Forecasting"[Mesh] OR "Machine Learning"[Mesh] OR "Artificial Intelligence"[Mesh] OR "Prediction Methods, Machine"[Mesh] OR predict*[tiab] OR prognos*[tiab] OR forecast*[tiab] OR model*[tiab] OR regression*[tiab] OR "multivariable"[tiab] OR "multivariate"[tiab] OR algorithm*[tiab] OR classifi*[tiab] OR "survival analysis"[tiab] OR "Cox model"[tiab] OR "decision tree*"[tiab] OR "random forest*"[tiab] OR "gradient boost*"[tiab] OR xgboost[tiab] OR "deep learning"[tiab] OR "neural network*"[tiab] OR "machine learning"[tiab] OR "risk factor*"[tiab] OR determinant*[tiab] OR association*[tiab] OR correlation*[tiab] OR longitudinal[tiab] OR cohort[tiab] OR "panel data"[tiab]) AND ("Electronic Health Records"[MeSH Terms] OR "Medical Records Systems, Computerized"[MeSH Terms] OR "Registries"[MeSH Terms] OR registry[tiab] OR "administrative data*"[tiab] OR "employment data*"[tiab] OR "workforce data*"[tiab] OR "workforce census"[tiab] OR "personnel data*"[tiab] OR "human resource*"[tiab] OR "HR data*"[tiab] OR "HRIS"[tiab] OR "human resources information system*"[tiab] OR "staff record*"[tiab] OR "workforce record*"[tiab] OR "employment record*"[tiab] OR "payroll data*"[tiab] OR "claims data*"[tiab] OR "routinely collected"[tiab] OR "routine data*"[tiab] OR "clinical log*"[tiab] OR "activity

	log*"[tiab] OR "log data"[tiab] OR "audit log*"[tiab] OR "electronic health record*"[tiab] OR "EHR"[tiab])
Web of Science	TS=("general practitioner*" OR "family physician*" OR "primary care physician*" OR "general practice" OR "family practice" OR "primary health care" OR "general practi*" OR "primary care provider*" OR "primary care clinician*" OR GP OR GPs OR "nurse practitioner*" OR "primary care nursing" OR "family nursing" OR "advanced practice nurse*" OR "primary care nurse*" OR "practice nurse*" OR "community nurse*" OR "community health nurse*" OR "district nurse*" OR "health visitor*") AND (TS=("personnel turnover" OR retirement OR turnover OR attrition OR retention OR mobility OR resign* OR quit* OR retir* OR leav* OR exit* OR departure*) OR TI=(burnout OR satisfaction OR fatigue OR exhaustion OR engagement)) AND TS=(predict* OR prognos* OR forecast* OR model* OR regression* OR "multivariable" OR "multivariate" OR algorithm* OR classifi* OR "survival analysis" OR "Cox model" OR "decision tree*" OR "random forest*" OR "gradient boost*" OR xgboost OR "deep learning" OR "neural network*" OR "machine learning" OR "artificial intelligence" OR "risk factor*" OR determinant* OR association* OR correlation* OR longitudinal OR cohort OR "panel data") AND TS=("electronic health record*" OR "computerized medical record*" OR registry OR "administrative data*" OR "employment data*" OR "workforce data*" OR "workforce census" OR "personnel data*" OR "human resource*" OR "HR data*" OR HRIS OR "human resources information system*" OR "staff record*" OR "workforce record*" OR "employment record*" OR "payroll data*" OR "claims data*" OR "routinely collected" OR "routine data*" OR "clinical log*" OR "activity log*" OR "log data" OR "audit log*" OR "electronic health record*" OR EHR)
Scopus	TITLE-ABS ("general practitioner*" OR "family physician*" OR "primary care physician*" OR "general practice" OR "family practice" OR "primary health care" OR "general practi*" OR "primary care provider*" OR "primary care clinician*" OR GP OR GPs OR "nurse practitioner*" OR "primary care nursing" OR "family nursing" OR "advanced practice nurse*" OR "primary care nurse*" OR "practice nurse*" OR "community nurse*" OR "community health nurse*" OR "district nurse*" OR "health visitor*") AND (TITLE-ABS ("personnel turnover" OR retirement OR turnover OR attrition OR retention OR mobility OR resign* OR quit* OR retir* OR leav* OR exit* OR departure*) OR TITLE (burnout OR satisfaction OR fatigue OR exhaustion OR engagement)) AND TITLE-ABS (predict* OR prognos* OR forecast* OR model* OR regression* OR multivariable OR multivariate OR algorithm* OR classifi* OR "survival analysis" OR "cox model" OR "decision tree*" OR "random forest*" OR "gradient boost*" OR xgboost OR "deep learning" OR "neural network*" OR "machine learning" OR "artificial intelligence" OR "risk factor*" OR determinant* OR association* OR correlation* OR longitudinal OR cohort OR "panel data") AND TITLE-ABS ("electronic health record*" OR "computerized medical record*" OR registry OR "administrative data*" OR "employment data*" OR "workforce data*" OR "workforce census" OR "personnel data*" OR "human resource*" OR "HR data*" OR HRIS OR "human resources information system*" OR "staff record*" OR "workforce record*" OR "employment record*" OR "payroll

	data*" OR "claims data*" OR "routinely collected" OR "routine data*" OR "clinical log*" OR "activity log*" OR "log data" OR "audit log*" OR "electronic health record*" OR EHR)
Embase	(exp general practitioner/ or exp family physician/ or exp primary care physician/ or exp general practice/ or exp family practice/ or primary health care/ or exp nurse practitioner/ or exp primary care nursing/ or exp family nursing/ or general practi*.ti,ab. or primary care provider*.ti,ab. or primary care clinician*.ti,ab. or GP.ti,ab. or GPs.ti,ab. or nurse practitioner*.ti,ab. or advanced practice nurse*.ti,ab. or primary care nurse*.ti,ab. or practice nurse*.ti,ab. or community nurse*.ti,ab. or community health nurse*.ti,ab. or district nurse*.ti,ab. or health visitor*.ti,ab.) and (exp personnel turnover/ or exp retirement/ or turnover.ti,ab. or attrition.ti,ab. or retention.ti,ab. or mobility.ti,ab. or resign*.ti,ab. or quit*.ti,ab. or retir*.ti,ab. or leav*.ti,ab. or exit*.ti,ab. or departure*.ti,ab. or burnout.ti. or satisfaction.ti. or fatigue.ti. or exhaustion.ti. or engagement.ti.) and (exp forecasting/ or exp machine learning/ or exp artificial intelligence/ or exp prediction methods/ or predict*.ti,ab. or prognos*.ti,ab. or forecast*.ti,ab. or model*.ti,ab. or regression*.ti,ab. or multivariable.ti,ab. or multivariate.ti,ab. or algorithm*.ti,ab. or classifi*.ti,ab. or survival analysis.ti,ab. or cox model.ti,ab. or decision tree*.ti,ab. or random forest*.ti,ab. or gradient boost*.ti,ab. or xgboost.ti,ab. or deep learning.ti,ab. or neural network*.ti,ab. or machine learning.ti,ab. or risk factor*.ti,ab. or determinant*.ti,ab. or association*.ti,ab. or correlation*.ti,ab. or longitudinal.ti,ab. or cohort.ti,ab. or panel data.ti,ab.) and (exp electronic health record/ or exp registry/ or registry.ti,ab. or "administrative data*".ti,ab. or "employment data*".ti,ab. or "workforce data*".ti,ab. or "workforce census".ti,ab. or "personnel data*".ti,ab. or "human resource*".ti,ab. or "HR data*".ti,ab. or HRIS.ti,ab. or "human resources information system*".ti,ab. or "staff record*".ti,ab. or "workforce record*".ti,ab. or "employment record*".ti,ab. or "payroll data*".ti,ab. or "claims data*".ti,ab. or "routinely collected".ti,ab. or "routine data*".ti,ab. or "clinical log*".ti,ab. or "activity log*".ti,ab. or "log data".ti,ab. or "audit log*".ti,ab. or "electronic health record*".ti,ab. or EHR.ti,ab.)
CINAHL	XB("general practitioner*" OR "family physician*" OR "primary care physician*" OR "general practice" OR "family practice" OR "primary health care" OR "general practi*" OR "primary care provider*" OR "primary care clinician*" OR GP OR GPs OR "nurse practitioner*" OR "primary care nursing" OR "family nursing" OR "advanced practice nurse*" OR "primary care nurse*" OR "practice nurse*" OR "community nurse*" OR "community health nurse*" OR "district nurse*" OR "health visitor*") AND XB("personnel turnover" OR retirement OR turnover OR attrition OR retention OR mobility OR resign* OR quit* OR retir* OR leav* OR exit* OR departure* OR burnout OR satisfaction OR fatigue OR exhaustion OR engagement) AND XB(predict* OR prognos* OR forecast* OR model* OR regression* OR multivariable OR multivariate OR algorithm* OR classifi* OR "survival analysis" OR "cox model" OR "decision tree*" OR "random forest*" OR "gradient boost*" OR xgboost OR "deep learning" OR "neural network*" OR "machine learning" OR "artificial intelligence" OR "risk factor*" OR determinant* OR association* OR correlation* OR longitudinal OR cohort OR "panel data") AND XB("electronic health record*" OR

	"computerized medical record*" OR registry OR "administrative data*" OR "employment data*" OR "workforce data*" OR "workforce census" OR "personnel data*" OR "human resource*" OR "HR data*" OR HRIS OR "human resources information system*" OR "staff record*" OR "workforce record*" OR "employment record*" OR "payroll data*" OR "claims data*" OR "routinely collected" OR "routine data*" OR "clinical log*" OR "activity log*" OR "log data" OR "audit log*" OR "electronic health record*" OR EHR)

Appendix B – Structured eligibility criteria

Element	Inclusion	Exclusion
Population	Community primary care clinicians (specifically, general practitioners and/or nurses, excluding trainees).	Studies that focus exclusively on hospital-based clinicians without a primary care component that it is possible to isolate.
Intervention	Studies that use multivariable modelling approaches to predict or identify determinants of workforce retention or attrition related outcomes. Studies must use routinely collected data, defined as data generated through normal clinical care or health system operations (e.g. electronic health records, claims data, administrative datasets, workforce datasets, patient registries), with at least one variable derived from such data and used as part of the analytical model (not solely for descriptive or linkage purposes). Studies using survey data are eligible if this criterion is met.	Studies that are purely descriptive and do not involve multivariable modelling.
Comparator	No comparator was required for eligibility.	
Outcome	Workforce retention or attrition related outcomes, including: • Actual departure (e.g. attrition, turnover, leaving practice/profession, non-renewal of contract, withdrawal from the professional register) • Retention, defined as participation in the workforce over a specified time period • Intended departure (e.g. intention to leave, plans to quit or retire) • Validated proxy outcomes (e.g. job satisfaction, burnout), considered only if they are explicitly conceptualised and analysed as indicators or predictors of	Studies that include outcomes unrelated to workforce retention or attrition, including attitudinal or wellbeing outcomes (e.g. job satisfaction, engagement, burnout) without measuring actual or intended workforce departure, or without being explicitly framed and justified as a proxy for departure.

	workforce departure, attrition or intended departure	
Timing	No restriction was applied to follow-up duration or prediction horizon.	—
Setting	Studies reporting predictions or associations at the individual clinician level or at aggregated levels (e.g. practice-level or regional-level). No restriction was applied by country or health system.	—

Appendix C – Data extraction grids

Table C1. Study-level data extraction grid

Domain	Variable	Description / coding instructions
General	First author	First author surname
General	Year	Year of publication
General	Title	Full study title
General	Country	Country in which the study was conducted
Aim	Study objective	Free text
Aim	Study purpose	Classify from the stated objective and intended analytic use: Association: quantifies relationships without targeting causal effects or out-of-sample prediction; Causal: estimates an intervention or exposure effect using a counterfactual design; Prediction: develops and evaluates a model for new or future observations; Mixed
Design	Study design	Cross-sectional, cohort, case-control, time-series, panel data, etc.
Design	Study period	Years or dates covered by the study
Design	Analytical approach	Main statistical or modelling approach used
Population	Clinician type	GP, nurse, pharmacist, allied health, mixed
Population	Unit of analysis	Clinician, practice, system
Population	Sample size	Number of clinicians, practices, observations, or units analysed
Outcome	Main outcome category	Turnover, attrition, retention, burnout, intention to leave, other
Outcome	System of reference	Boundary within which retention or attrition was assessed (such as a practice, facility, employer, health system, geographic area, or professional workforce)
Outcome	Outcome definition	Exact definition used by the study authors
Outcome	Outcome type	Binary, continuous, count, time-to-event
Variables	Variable extraction	*See variable-level extraction grid*
Data	Data source type	Type of data source used
Data	Data source name	Name of dataset, registry, database, or survey
Data	Linkage	Were data from two or more sources linked or combined for analysis? Yes / No / Unclear
Methods	Handling of variables	Pre-specified, data-driven selection, both
Methods	Missing data handling method	Complete case, multiple imputation, not reported, other
Methods	Missing data handling notes	Free-text description of the approach, including the extent of missingness where reported
Methods	Designated exposure	Primary intervention or exposure investigated; record “No” for studies without a designated exposure
Methods	Adjustment for confounding	Yes, multivariable model / No / Partial
Methods	Validation	None / Internal / External / NA
Results	Key quantitative results	*See variable-level extraction grid*
Interpretation	Authors’ conclusions	Free text
Actionability and usability	Stakeholder involvement in variable selection	Were decision-makers, practitioners, or patients involved in selecting variables? Yes / No / Unclear
Actionability and usability	Implementation described?	Do the authors report that the model has been deployed in a real-world operational setting? Yes / No / Unclear

Table C2. Variable-level data extraction form

Dimension	Variable	Description / coding instructions
Identification	Study ID	First author and year
Identification	Variable	Exact variable name as reported in the study
Identification	Definition	How the variable was defined and measured
D1. Level and purpose	Level of measurement	Individual (clinician) / Organisation (practice, service) / Local context (population, geography) / System/ policy
D1. Level and purpose	Domain	Clinician characteristics / Training and professional profile / Remuneration / Workload and activity / Working conditions and job design / Staffing and capacity / Patient population characteristics / Geography / Policy and regulatory context / Time
D1. Level and purpose	Concept	Harmonised construct used to group different operationalisations
D1. Level, domain and analytic role	Role of variable	Exposure of interest / Candidate (a priori, full model) / Candidate (selection-driven) / Adjustment or confounder / Mediator / Sample-split or moderator / Model-specification term / Prediction-only term
D2. Measurability	Data source name	Name of dataset
D2. Measurability	Data source type	Workforce administrative data / Health-activity data / Population or area statistics / Survey data / Other
D3. Modifiability	Potential actionability	Directly modifiable / Structurally modifiable / Not modifiable but indirectly actionable (fixed marker) / Neither modifiable nor actionable
D4. Importance	Direction of effect on retention	+ / − / null / mixed or non-linear / not reported Code direction in relation to retention: "+" indicates higher retention or lower attrition; "−" indicates lower retention or higher attrition
D4. Importance	Main outcome category	Turnover / Attrition / Retention / Burnout / Intention to leave / Other
D4. Importance	Effect size	Reported odds ratio, hazard ratio, risk ratio, regression coefficient, marginal effect or other effect estimate, with its 95% confidence interval and p value, where available

Appendix D – Risk of bias assessment

Table D1. JBI critical appraisal of included cohort studies (n=10)

Study	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11
Aars 2025	Yes	Yes	Yes	Yes	Yes	Unclear	Unclear	Yes	Yes	Yes	Yes
Dias 2023	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Marcotte 2024	Yes	Yes	Unclear	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mathews 2008	Yes	Yes	Yes	Yes	Unclear	Yes	Unclear	Yes	Yes	Yes	Yes
Palmer 2025	Yes	Yes	Yes	Unclear	Yes	Yes	Unclear	Yes	Unclear	Yes	Yes
Parisi 2023	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
Playford 2022	Yes	Yes	Unclear	Yes	Yes	No	Unclear	Yes	Unclear	Unclear	Unclear
Russell 2013	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Singer 1998	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Unclear	Yes	Yes
Skyrud 2026	Yes	Yes	Unclear	N/A	N/A	Yes	Unclear	Yes	Yes	Yes	Yes

Table D2. JBI critical appraisal of included analytical cross-sectional studies (n=4)

Study	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
Mowat 2017	Yes	Yes	Yes	Yes	Unclear	Yes	Unclear	Unclear
Parisi 2021	Yes	Yes	Yes	Yes	Yes	Yes	Unclear	Yes
Russell 2012	Yes	Yes	Unclear	Yes	Yes	Yes	Unclear	Yes
Xu 2024	Unclear	Yes	Yes	Yes	Unclear	Yes	Unclear	Unclear

Table D3. JBI critical appraisal of the included quasi-experimental study (n=1)

Study	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9
Sylling 2014	Yes	Unclear	Unclear	No	Yes	Yes	Yes	Yes	Yes

Appendix E – Studies excluded following full-text assessment

Table E1. Studies excluded following full-text assessment and reasons for exclusion

Study (author, year)	Title	Reason for exclusion
Abraham 2021	Use of multifunctional electronic health records and burnout among primary care nurse practitioners	E2
Adler-Milstein 2020	Electronic health records and burnout: Time spent on the electronic health record after hours and message volume associated with exhaustion but not with cynicism among primary care clinicians	E2
Alameddine 2012	The retention of health human resources in primary healthcare centers in Lebanon: a national survey	E4
Alameddine 2014	Measuring the job stickiness of community nurses in Ontario (2004–2010): implications for policy and practice	E6
Alameddine 2017	Investigating the job satisfaction of healthcare providers at primary healthcare centres in Lebanon: A national cross-sectional study	E2
Alamin 2022	Model Autonomy of Self-Finance Management for Primary Health Care to Enhance Workers' Satisfaction	E2
Al-Dabbagh 2022	Workload assessment of medical doctors at primary health care centers in the Duhok governorate	E2
Allan 2008	Developing a competitive advantage: Considerations from Australia for the recruitment and retention of rural and remote primary health workers	E3
Alrawashdeh 2021	Occupational burnout and job satisfaction among physicians in times of COVID-19 crisis: a convergent parallel mixed-method study	E2
Amiresmaili 2014	Factors affecting leave out of general practitioners from rural family physician program: A case of Kerman, Iran	E4
Apaydin 2025a	Secure Messages, Video Visits, and Burnout Among Primary Care Providers in the Veterans Health Administration: National Survey Study	E2
Apaydin 2025b	Burnout and Turnover Among Veterans Health Administration Primary Care Providers From Fiscal Years 2017–2021	E4
Ariste 2023	Distribution and Migration of Recent Healthcare Graduates in Canada	E6
Assefa 2016	Physician distribution and attrition in the public health sector of Ethiopia	E6
Babbott 2014	Electronic medical records and physician stress in primary care: results from the MEMO Study	E4
Bao 2024	Advances in the Application of Discrete Choice Experiments in the Field of Human Resources for Health	E3
Bester 2009	Job satisfaction and dissatisfaction of professional nurses in primary health care facilities in the Free State province of South Africa	E4
Bruhl 2020	Association of Primary Care Team Composition and Clinician Burnout in a Primary Care Practice Network	E2
Bruun 2024	Workload and GP burnout: a survey and register-based study in Danish general practice	E2
Buchan 2012	Using scenarios to assess the future supply of NHS nursing staff in England	E6
Calderon-Larranaga 2024	What can we learn from general practitioners who left Spain? A mixed methods international study	E4
De Mesa 2023	Experiences from the Philippine grassroots: impact of strengthening primary care systems on health worker satisfaction and intention to stay	E4
Ehsani-Chimeh 2018	Physicians' retention rate and its effective factors in the Islamic Republic of Iran	E1
Ejigu 2023	Motivation and job satisfaction of community health workers in Ethiopia: a mixed-methods approach	E2
Elder 2010	Health information technology and physician career satisfaction	E2

El-Jardali 2013	A national study on nurses' retention in healthcare facilities in underserved areas in Lebanon	E4
Fogarty 2014	Job satisfaction and retention of health-care providers in Afghanistan and Malawi	E4
Fuller 2025	Building a rural medical workforce: the foundations of a place-based approach to program evaluation	E1
Galbany-Estragués 2016	Migration of Spanish nurses 2009–2014. Underemployment and surplus production of Spanish nurses and mobility among Spanish registered nurses: A case study	E6
Gardner 2019	Physician stress and burnout: the impact of health information technology	E2
Goldacre 2009	Retention in the British National Health Service of medical graduates trained in Britain: Cohort studies	E1
Green 2009	Financial and work satisfaction: Impacts of participation in primary care reform on physicians in Ontario	E2
Gregory 2017	Electronic Health Record Alert-Related Workload as a Predictor of Burnout in Primary Care Providers	E2
Grigoroglou 2022	Locum doctor use in English general practice: analysis of routinely collected workforce data 2017–2020	E2
Helfrich 2014	Elements of team-based care in a patient-centered medical home are associated with lower burnout among VA primary care employees	E2
Helfrich 2017	The Association of Team-Specific Workload and Staffing with Odds of Burnout Among VA Primary Care Team Members	E2
Henrikson 2024	Inclination to pursue Veterans Health Administration for primary care practice: survey of medical residents	E4
Hernández Ledesma 2010	Job satisfaction among nurses of primary health care municipality of Pinar del Rio, 2009	E2
Holmgren 2024	Electronic Health Record Usability, Satisfaction, and Burnout for Family Physicians	E2
Humphreys 2012	Who should receive recruitment and retention incentives? Improved targeting of rural doctors using medical workforce data	E6
Hurst 2006	Primary and community care workforce planning and development	E6
Hysong 2014	Electronic alerts and clinician turnover: the influence of user acceptance	E4
Jain 2025	The Influence of Human Resource Management on Job Satisfaction among Primary Healthcare Providers: A Descriptive Study	E2
Jefferson 2026	Understanding persistent GP turnover using work and personal characteristics: a retrospective observational study	E2
Kharin 2021	First steps in forecasting the health workforce in Kazakhstan: A baseline scenario	E2
Kovács 2019	Overview of human resources for health composition in the most mobile specialty groups in Hungary	E1
Kroth 2019	Association of Electronic Health Record Design and Use Factors With Clinician Stress and Burnout	E2
Kumar 2014	A comparative study of job satisfaction among regular and staff on contract in the primary health care system in Delhi, India	E1
Laurence 2016	Improving the planning of the GP workforce in Australia: a simulation model incorporating work transitions, health need and service usage	E2
Li 2019	Contextual factors associated with burnout among Chinese primary care providers: A multilevel analysis	E2
Li 2022	Electronic medical record-related burnout in healthcare providers: a scoping review of outcomes and interventions	E3
Liu 2025	Sociodemographic characteristics, occupational characteristics, motivational factors, and job satisfaction among primary health service practitioners	E2
Lorenz 2014	The environment of professional practice and burnout in nurses in primary healthcare	E2

Lorenz 2018	Professional exhaustion, quality and intentions among family health nurses	E4
Mathews 2023	A cross-sectional study of community-level physician retention and hospitalization in rural Ontario, Canada	E6
Mbaruku 2014	What elements of the work environment are most responsible for health worker dissatisfaction in rural primary care clinics in Tanzania	E4
Menachemi 2009	The role of information technology usage in physician practice satisfaction	E2
Meredith 2015	Emotional exhaustion in primary care during early implementation of the VA's medical home transformation: Patient-aligned Care Team (PACT)	E2
Meredith 2022	Predictors of burnout among US healthcare providers: a systematic review	E1
Moisoglou 2021	Job Satisfaction in Primary Health Care in Athens, Greece: A Pilot Study	E2
Nafziger 2022	When and why do medical students drop out of extracurricular longitudinal general practice tracks?	E4
Nelson 2014	Implementation of the patient-centered medical home in the Veterans Health Administration: associations with patient satisfaction, quality of care, staff burnout, and hospital and emergency department use	E2
Ning 2023	The mediating role of job satisfaction and presenteeism on the relationship between job stress and turnover intention among primary health care workers	E4
O'Connor 2023a	Changes in electronic notification volume and primary care provider burnout	E2
O'Connor 2023b	Patient Enrollment Growth and Burnout in Primary Care at the Veterans Health Administration	E2
O'Halloran 2021	Time to retire? A register-based study of GPs' practice style prior to retirement	E2
Olson 2025	Use of Ambient AI Scribes to Reduce Administrative Burden and Professional Burnout	E1
Orava 2017	Retention of Primary Health Care Nurse Practitioners	E1
Ormiston 2025	27 Years of retention outcomes for a nine-university primary health care nurse practitioner program in Ontario, Canada	E6
Pedersen 2013	Risk of Burnout in Danish GPs and Exploration of Factors Associated with Development of Burnout: A Two-Wave Panel Study	E2
Pedersen 2014	Understanding the inverse care law: a register and survey-based study of patient deprivation and burnout in general practice	E2
Pedersen 2020	Influence of patient multimorbidity on GP burnout: A survey and register-based study in Danish general practice	E2
Pierse 2023	The retention of training doctors in the Irish health system	E1
Premji 2025	Trends colliding: Aging comprehensive family physicians and the growing complexity of their patients	E2
Quyen 2021	Job satisfaction of healthcare workers in Vietnam: A multilevel study	E1
Rezaei 2019	Factors affecting the family physicians' intention to leave the job: A case of Iran	E4
Robertson 2017	Electronic Health Record Effects on Work-Life Balance and Burnout Within the I3 Population Collaborative	E1
Rotenstein 2024	Team and Electronic Health Record Features and Burnout Among Family Physicians	E2
Sang 2024	The effect of incentive factors on turnover intention of PHC workforce in rural China-from the perspective of two-factor theory	E4
Shields 2020	Multidisciplinary approach to enhancing provider well-being in a metropolitan medical group in the United States	E6
Silva 2024	Usability of the Citizen's Electronic Record and its association with the Burnout Syndrome dimensions	E1
Simkin 2019	End-of-career practice patterns of primary care physicians in Ontario	E6

Soles 2017	Family medicine education in rural communities as a health service intervention supporting recruitment and retention of physicians: Advancing Rural Family Medicine: The Canadian Collaborative Taskforce	E3
Starfield 2007	The primary care physician workforce: Ethical and policy implications	E2
Storey 2007	Nurses working in primary and community care settings in England: Problems and challenges in identifying numbers	E2
Stults 2025	Evaluation of an Ambient Artificial Intelligence Documentation Platform for Clinicians	E1
Tajirian 2020	The influence of electronic health record use on physician burnout: Cross-sectional survey	E1
Tawfik 2024	Predicting Primary Care Physician Burnout From Electronic Health Record Use Measures	E2
Tenso 2025	Medical training program size and clinical staff productivity and turnover	E1
Toren 2012	Turnover of registered nurses in Israel: Characteristics and predictors	E4
Truelove 2008	Educational preparation as a predictor of registered nurse retention	E1
Veginadu 2024	Patterns of health workforce turnover and retention in Aboriginal Community Controlled Health Services in remote communities of the Northern Territory and Western Australia, 2017–2019	E6
Verhoef 2021	Relationship between generic and occupation-specific job demands and resources, negative work-home interference and burnout among GPs	E2
Virtanen 2008	Work stress and health in primary health care physicians and hospital physicians	E4
Waddimba 2016	Frequency of satisfaction and dissatisfaction with practice among rural-based, group-employed physicians and non-physician practitioners	E1
Wang 2024	The association between population health management tools and clinician burnout in the United States VA primary care patient-centered medical home	E2
Xu 2023	Burnout and turnover intention of primary health care providers during the COVID-19 pandemic in China	E4
Yordanov 2023	Mapping GPs' motivation - it's not all about the money: a nationwide cross-sectional survey study from Denmark	E4
Young 2001	Imbalances in the GP labour market in the UK: Evidence from a postal survey and interviews with GP leavers	E4
Yuguero 2018	Cross-sectional study of the association between healthcare professionals' empathy and burnout and the number of annual primary care visits per patient under their care in Spain	E2
Zhang 2016	Job satisfaction of urban community health workers after the 2009 healthcare reform in China: a systematic review	E3
Zhang 2021	The influence of personality, alexithymia and work engagement on burnout among village doctors in China: a cross-sectional study	E4
Zhu 2024	A Ten-year Retrospective of General Practitioner Team Construction in China	E2

Exclusion codes: *E1, wrong population (n=17); E2, wrong outcome (n=46); E3, wrong study type (n=5); E4, no routine data (n=23); E5, trainees only (n=0); and E6, no multivariable modelling (n=12)*

Appendix F – Supplementary results

Table F1: Summary of the characteristics of the 15 included studies

	Number of studies (n=15)	**References**
Total	15 (100%)	Aars et al, 2025; Dias et al, 2023; Marcotte et al, 2024; Mathews et al, 2008; Mowat et al, 2017; Palmer et al, 2025; Parisi et al, 2021; Parisi et al, 2023; Playford et al, 2022; Russell et al, 2012; Russell et al, 2013; Singer et al, 1998; Skyrud et al, 2026; Sylling et al, 2014; Xu et al, 2024
Study country		
Australia	3 (20%)	Playford et al, 2022; Russell et al, 2012; Russell et al, 2013
Brazil	1 (7%)	Dias et al, 2023
Canada	2 (13%)	Mathews et al, 2008; Mowat et al, 2017
China	1 (7%)	Xu et al, 2024
England (UK)	3 (20%)	Palmer et al, 2025; Parisi et al, 2021; Parisi et al, 2023
Norway	2 (13%)	Aars et al, 2025; Skyrud et al, 2026
USA	3 (20%)	Marcotte et al, 2024; Singer et al, 1998; Sylling et al, 2014
Clinician group		
General practitioners only	10 (67%)	Aars et al, 2025; Mathews et al, 2008; Mowat et al, 2017; Palmer et al, 2025; Parisi et al, 2021; Parisi et al, 2023; Playford et al, 2022; Russell et al, 2012; Russell et al, 2013; Skyrud et al, 2026
Primary care physicians, multiple specialties	3 (20%)	Dias et al, 2023; Marcotte et al, 2024; Singer et al, 1998
Mixed primary care workforce (physicians predominant)	2 (13%)	Sylling et al, 2014; Xu et al, 2024
Unit of analysis		
Individual clinician	12 (80%)	Aars et al, 2025; Dias et al, 2023; Marcotte et al, 2024; Mathews et al, 2008; Mowat et al, 2017; Palmer et al, 2025; Playford et al, 2022; Russell et al, 2012; Singer et al, 1998; Skyrud et al, 2026; Sylling et al, 2014; Xu et al, 2024
Practice	2 (13%)	Parisi et al, 2021; Parisi et al, 2023
GP appointment (position)	1 (7%)	Russell et al, 2013
Analytical purpose		
Association	12 (80%)	Aars et al, 2025; Dias et al, 2023; Marcotte et al, 2024; Mathews et al, 2008; Mowat et al, 2017; Palmer et al, 2025; Parisi et al, 2021; Parisi et al, 2023; Playford et al, 2022; Russell et al, 2012; Singer et al, 1998; Xu et al, 2024
Prediction	1 (7%)	Skyrud et al, 2026
Both (association and prediction)	1 (7%)	Russell et al, 2013
Quasi-experimental	1 (7%)	Sylling et al, 2014
Study design		
Retrospective cohort	10 (67%)	Aars et al, 2025; Dias et al, 2023; Marcotte et al, 2024; Mathews et al, 2008; Palmer et al, 2025; Parisi et al, 2023;

		Playford et al, 2022; Russell et al, 2013; Singer et al, 1998; Skyrud et al, 2026
Cross-sectional	3 (20%)	Mowat et al, 2017; Russell et al, 2012; Xu et al, 2024
Repeated cross-sectional	1 (7%)	Parisi et al, 2021
Interrupted time series	1 (7%)	Sylling et al, 2014
Primary workforce outcome		
Turnover	6 (40%)	Dias et al, 2023; Marcotte et al, 2024; Parisi et al, 2021; Parisi et al, 2023; Russell et al, 2013; Singer et al, 1998
Retention	6 (40%)	Mathews et al, 2008; Mowat et al, 2017; Palmer et al, 2025; Playford et al, 2022; Russell et al, 2012; Skyrud et al, 2026
Attrition	3 (20%)	Aars et al, 2025; Sylling et al, 2014; Xu et al, 2024
Outcome variable type		
Time-to-event	7 (47%)	Dias et al, 2023; Marcotte et al, 2024; Mathews et al, 2008; Russell et al, 2013; Singer et al, 1998; Skyrud et al, 2026; Sylling et al, 2014
Binary	5 (33%)	Aars et al, 2025; Mowat et al, 2017; Parisi et al, 2023; Playford et al, 2022; Xu et al, 2024
Continuous	3 (20%)	Palmer et al, 2025; Parisi et al, 2021; Russell et al, 2012
Data sources used		
Administrative - workforce	15 (100%)	Aars et al, 2025; Dias et al, 2023; Marcotte et al, 2024; Mathews et al, 2008; Mowat et al, 2017; Palmer et al, 2025; Parisi et al, 2021; Parisi et al, 2023; Playford et al, 2022; Russell et al, 2012; Russell et al, 2013; Singer et al, 1998; Skyrud et al, 2026; Sylling et al, 2014; Xu et al, 2024
Population and area statistics	6 (40%)	Marcotte et al, 2024; Parisi et al, 2021; Parisi et al, 2023; Singer et al, 1998; Skyrud et al, 2026; Sylling et al, 2014
Administrative - health activity	4 (27%)	Aars et al, 2025; Parisi et al, 2023; Singer et al, 1998; Skyrud et al, 2026
Survey	4 (27%)	Marcotte et al, 2024; Parisi et al, 2023; Playford et al, 2022; Russell et al, 2012

Table F2. Distribution of variable operationalisations by domain and level of measurement

Domain	Individual (clinician)	Organisation (practice, service)	Local context (population, geography)	System/ policy	Total, n (%)
Clinician characteristics	42				42 (24.9%)
Training and professional profile	29				29 (17.2%)
Working conditions and job design	9	17			26 (15.4%)
Workload and activity	14	4			18 (10.7%)
Geography			12		12 (7.1%)
Staffing and capacity	2	9			11 (6.5%)
Remuneration	9	1			10 (5.9%)
Patient population characteristics			9		9 (5.3%)
Time				7	7 (4.1%)
Policy and regulatory context	3		1	1	5 (3.0%)
Total, n (%)	**108 (63.9%)**	**31 (18.3%)**	**22 (13.0%)**	**8 (4.7%)**	**169 (100%)**

Table F3. Modelling role of variable operationalisations by potential actionability

Type of variable	Directly modifiable	Structurally modifiable	Not modifiable but indirectly actionable (fixed marker)	Not modifiable and non-actionable	Total, n (%)
Candidate predictor	6	27	39	6	78 (46.2%)
Confounder, mediator, or moderator	9	28	17	8	62 (36.7%)
Prediction-only term	5	6	2	4	17 (10.1%)
Exposure of interest	1	3	1	1	6 (3.6%)
Model-specification term	0	0	0	6	6 (3.6%)
Total, n (%)	**21 (12.4%)**	**64 (37.9%)**	**59 (34.9%)**	**25 (14.8%)**	**169 (100%)**

Table F4. Reported directions of association for all variable operationalisations

Concept	Studies	Operation-alisations	Favours attrition	Favours retention	Non-significant	Mixed or non-linear	No estimate reported
Directly modifiable							
Earnings level (higher)	5	5	–	3	1	–	1
Out-of-hours workload (higher)	3	4	1	2	1	–	–
Full-time status	3	3	1	1	–	–	1
Administrative work share (higher)	1	2	1	1	–	–	–
Permanent employment contract	2	2	1	–	–	–	1
Rural scholarship	2	2	–	–	1	–	1
Annual leave taken (higher)	1	1	–	1	–	–	–
Mentorship programme participation	1	1	–	–	1	–	–
Share of consultations delivered by locums (higher)	1	1	–	–	1	–	–
Subtotal (9 concepts)	**Median 2 (1-5)**	***21***	***4***	***8***	***5***	**–**	***4***
Structurally modifiable							
Team and organisational climate (better)	2	8	1	1	6	–	–
Organisation size (larger)	3	4	–	2	1	1	–
Payment model or ownership structure	3	4	1	2	–	1	–
Practice list size (larger)	4	4	1	1	–	1	1
Facility type	3	3	–	1	1	–	1
Consultation volume (higher)	2	3	–	–	1	1	1
Medical school location	3	3	–	–	2	–	1
Number of hours worked per week (higher)	3	3	1	–	1	1	–
Procedural practice	3	3	–	2	1	–	–
Professional registration	2	3	1	1	1	–	–
Regulatory restrictions on practice location	3	3	1	1	–	1	–
Shared patient lists	3	3	–	–	2	–	1
Specialty	3	3	–	–	1	1	1
Became specialist during study period	2	2	–	1	1	–	–
Hospital integration	2	2	–	2	–	–	–
Physician density (higher)	2	2	–	1	–	–	1
Profession	2	2	1	–	–	1	–
Undergraduate rural exposure	1	2	–	1	1	–	–
Billing intensity (higher)	1	1	–	1	–	–	–
Consultation length (longer)	1	1	1	–	–	–	–
Educational level (higher)	1	1	1	–	–	–	–

Major model-of-care reform exposure (PCMH)	**1**	**1**	**1**	**–**	**–**	**–**	**–**
Team workload satisfaction (higher)	**1**	**1**	**–**	**1**	**–**	**–**	**–**
Teaching activity	**1**	**1**	**–**	**1**	**–**	**–**	**–**
Working in multiple practices simultaneously	**1**	**1**	**–**	**–**	**1**	**–**	**–**
Subtotal (25 concepts)	**Median 2 (1-4)**	***64***	***10***	***19***	***20***	***8***	***7***
Not modifiable but indirectly actionable (fixed markers)							
Sex or gender (male)	**11**	**11**	**2**	**1**	**5**	**1**	**2**
Clinician age, birth cohort or career stage (older)	**8**	**9**	**–**	**1**	**2**	**5**	**1**
Rurality or remoteness	**6**	**8**	**4**	**1**	**2**	**–**	**1**
Years of service (longer)	**8**	**8**	**1**	**2**	**2**	**1**	**2**
IMG status	**6**	**7**	**4**	**–**	**2**	**–**	**1**
Pre-existing personal or family ties to the practice area	**5**	**6**	**–**	**3**	**1**	**–**	**2**
Family and household characteristics	**1**	**4**	**–**	**1**	**3**	**–**	**–**
Race or ethnicity (minority group)	**2**	**2**	**–**	**–**	**1**	**1**	**–**
Seniority rank	**2**	**2**	**1**	**–**	**–**	**1**	**–**
Type of medical school attended	**1**	**1**	**–**	**–**	**1**	**–**	**–**
Veteran status	**1**	**1**	**–**	**–**	**–**	**–**	**1**
Subtotal (11 concepts)	**Median 5 (1-11)**	***59***	***12***	***9***	***19***	***9***	***10***
Not modifiable and non-actionable							
Calendar time or period	**4**	**7**	**2**	**–**	**–**	**3**	**2**
Area deprivation (higher)	**4**	**4**	**2**	**–**	**1**	**–**	**1**
Organisation-level clustering term	**2**	**3**	**–**	**–**	**–**	**–**	**3**
Region	**3**	**3**	**–**	**–**	**–**	**2**	**1**
Patient age mix	**2**	**2**	**–**	**–**	**1**	**1**	**–**
Patient chronic-disease burden (higher)	**1**	**1**	**1**	**–**	**–**	**–**	**–**
Local unemployment rate (higher)	**1**	**1**	**–**	**1**	**–**	**–**	**–**
Patient education level (lower)	**1**	**1**	**1**	**–**	**–**	**–**	**–**
Patient sex mix (more women)	**1**	**1**	**–**	**–**	**–**	**–**	**1**
Population size (larger)	**1**	**1**	**–**	**–**	**1**	**–**	**–**
Prior quitting history	**1**	**1**	**–**	**1**	**–**	**–**	**–**
Subtotal (11 concepts)	**Median 1 (1-4)**	***25***	***6***	***2***	***3***	***6***	***8***
All tiers (56 concepts)	**15**	**169**	**32**	**38**	**47**	**23**	**29**

Table F5. Variable-outcome associations by potential actionability level, sensitivity to denominator and variable role

Potential actionability	Variable operationa-lisations, n (%)	Significant	Significant, estimated only	Significant, substantive variables only	Significant substantive, estimated only
Directly modifiable	21 (12.4%)	12/21 (57%)	12/17 (71%)	8/12 (67%)	8/11 (73%)
Structurally modifiable	64 (37.9%)	29/64 (45%)	29/57 (51%)	23/36 (64%)	23/34 (68%)
Not modifiable but indirectly actionable (fixed marker)	59 (34.9%)	21/59 (36%)	21/49 (43%)	18/42 (43%)	18/36 (50%)
Not modifiable and non-actionable	25 (14.8%)	8/25 (32%)	8/17 (47%)	4/11 (36%)	4/10 (40%)
Total	169 (100%)	70/169 (41%)	70/140 (50%)	53/101 (52%)	53/91 (58%)

"Significant" counts operationalisations with an individually statistically significant adjusted association in one clear direction in the most adjusted model. Denominators include all operationalisations or only those with a usable estimate ("estimated only"), which excludes coefficients not reported, variables not retained in the final model and model-specification terms. Substantive variables exclude operationalisations entered only as confounders, mediators, moderators or model-specification terms.

Appendix G – Changes from the registered protocol

The following refinements to the registered protocol are declared:

- Prespecified subgroup syntheses by professional group and modelling objective were not performed because no eligible study separately modelled primary-care nurse retention and only one study was primarily predictive.
- The most judgement-dependent extraction items were independently classified in full by two reviewers rather than verified in a random sample.
- The potential-actionability classification was refined from binary modifiable/non-modifiable coding to a four-level taxonomy.
- Extracted variable operationalisations were consolidated into shared concepts and categories for synthesis.
- The planned formal reporting quality assessment using RECORD and TRIPOD+AI was not undertaken and studies were appraised using JBI checklists selected by study design rather than applying PROBAST+AI to the predictive study.