China's Physician-Scientist Paradox: Structural Features of Research Continuity and Implications for Global Training Systems

Yaming Liu[1], Chunmeng Jiang[1], Zhiyu Liu[2*]

[1]Department of Gastroenterology and Hepatology, The Second Hospital of Dalian Medical University, Dalian Medical University, Dalian, Liaoning Province, China

[2]Department of Urinary Surgery, The Second Hospital of Dalian Medical University, Dalian Medical University, Dalian, Liaoning Province, China

***Corresponding author:**

Dr. Zhiyu Liu,

No. 467 Shahekou District, Dalian, Liaoning Province, China 116023

E-mail: Liu.Zhiyu@outlook.com

Lead Contact:

Dr. Yaming Liu,

E-mail: yaming0856@gmail.com

Conflict-of-interest statement

The authors have declared that no conflict of interest exists.

Graphic Abstract

Structural features associated with research continuity in physician-scientist training

Structured evidence synthesis of physician-scientist training in China and selected comparator systems, based on 90 primary empirical studies, including 73 providing direct physician-scientist evidence and 17 providing supportive residency-context evidence. Across heterogeneous training pathways and career stages, protected research opportunity, mentorship and transition support, funding continuity, and early-career support recurred across the evidence as structural features relevant to sustained research engagement. Standardized residency represents a clinically intensive stage in which maintaining research engagement may be challenging, while the transition from structured training toward research independence is conceptualized as a recurrent structural vulnerability—the "missing middle." Implementation of continuity-supporting mechanisms varies across systems, institutions, programs, and career stages. Collectively, the synthesis supports research continuity as an organizing framework for physician-scientist development and identifies candidate structural mechanisms for prospective evaluation. These relationships represent evidence-bounded structural associations and conceptual synthesis rather than causal effects, empirically estimated attrition trajectories, or national performance rankings.

Abstract:

Physician-scientists link clinical investigation with biomedical discovery, yet sustaining research engagement across training and early career remains challenging. We conducted a structured evidence synthesis of physician-scientist training in China and selected comparator systems. PubMed and Web of Science searches covering 2010-2025 yielded 3,639 records; after deduplication, screening, and adjudication, 90 primary empirical studies were included, comprising 73 with direct physician-scientist evidence and 17 with supportive residency-context evidence. Research exposure varied across pathways and programs. Chinese residency studies documented substantial training burden, while formal protected research time was not consistently identified in reviewed residency settings, positioning residency as a plausible constraint on research continuity without establishing causality. The transition from structured training toward research independence also emerged as a recurrent vulnerability involving discontinuities in protected research opportunity, mentorship, and career-development support. Across systems, protected research opportunity, transition support, funding continuity, and early-career support recurred as structural features, with implementation varying by system, institution, program, and career stage. These findings support research continuity as an organizing framework and identify structural mechanisms warranting prospective evaluation rather than universal prescription.

Keywords: physician-scientist; clinician-scientist; medical education policy; research training; research continuity; residency training; career transition.

Introduction

Physician-scientists connect clinical investigation with biomedical discovery and therapeutic innovation, yet sustaining this workforce remains challenging across biomedical systems (1-10). Across specialties and pathways, discontinuities in research opportunity, mentorship, funding, and career-development support have been repeatedly identified as barriers to sustained research engagement.

China provides an informative setting because its medical education system encompasses heterogeneous pathways within a rapidly evolving clinical and academic environment. Research exposure ranges from predominantly clinical training to integrated and research-intensive programs (11-13), while training duration, credentialing, institutional setting, and educational objectives also vary (14-17). However, heterogeneous definitions, populations, follow-up periods, and outcomes preclude nationally representative physician-scientist conversion rates, direct China-US conversion-rate comparisons, or national estimates of geographic disparities in physician-scientist production.

This heterogeneity raises a broader question: whether physician-scientist development is best characterized by training capacity and pathway structure alone or also by continuity of research opportunity across career stages. Expansion of training pathways does not ensure that research engagement can be maintained through clinically intensive and transitional periods; research exposure, protected research opportunity, mentorship, transition support, and funding continuity may therefore be more informative across the training trajectory than as isolated program characteristics.

We therefore conducted a structured evidence synthesis of physician-scientist training in China, supported by a reproducible search and study-level evidence audit, with selected US and European systems used for structural comparison. Rather than estimating causal effects, national career-conversion rates, or system rankings, we examined recurring structural features relevant to sustained research engagement and their evidentiary limits.

Results

1. Research exposure differs across training pathways and is associated with subsequent research engagement

Chinese medical pathways differ in duration, structure, and research exposure. The conventional "5+3" pathway—5 years of undergraduate medical education plus 3 years of standardized residency—is clinically oriented, with research exposure varying across institutions and stages. Chinese trainee studies document heterogeneous access to research opportunities and mentorship, whereas selected integrated or research-intensive programs report greater research participation in selected cohorts (11, 18, 19). Other physician-scientist settings likewise vary in the timing and structure of research exposure (20-23) (Figure 1 and Table 1).

MSTP and MD–PhD studies document substantial subsequent participation in research and academic medicine (24), while cohort evidence associates postgraduate research experience with later full-time faculty appointment (25). Heterogeneous populations, program structures, and outcome preclude direct quantitative comparison with Chinese pathways or pathway-specific career-conversion estimates. Overall, sustained research exposure and protected opportunities recur in association with subsequent research engagement, without establishing independent effects.

2. Standardized residency is characterized by substantial training burden and constrained research opportunity

Chinese residency-context studies document substantial demands during standardized residency training (STSR). At Peking Union Medical College Hospital 100/159 residents (62.2%) met the

study-defined burnout criterion (26). In a separate multicenter cohort of 563 trainees, 35.9% reported working > 60 hours/week and 71.05% had at least one burnout dimension (27). These observations characterize the studied training environments but do not directly measure physician-scientist attrition or scholarly productivity (28-32).

Formal protected research periods were not consistently identified in the reviewed Chinese STSR policy and training evidence (33-37), and nationally representative, denominator-transparent estimates of resident scholarly output were not identified. The evidence therefore documents substantial training burden and inconsistent protected research opportunity without establishing effects on publication productivity or physician-scientist attrition (Figure 2).

3. The transition to research independence emerges as a recurrent structural vulnerability

Across the physician-scientist literature, transition from formal clinical or research training toward independent investigation was repeatedly associated with challenges involving protected research opportunity, mentorship, funding continuity, competing clinical responsibilities, and academic progression; comparable stage-specific attrition rates were unavailable (38-41). These recurring challenges were conceptualized as a "missing middle" between structured training and research independence, but the evidence does not establish this transition as the quantitatively highest-risk career stage (42-45) (Figure 3).

Comparator programs and targeted interventions provide examples of protected research periods, formal mentorship, salary or research support, and staged career-development mechanisms (41, 43, 45-49). Targeted interventions have also been developed to support specific transition points,

including fellowship applications among predoctoral physician-scientist (50). Individual programs report research engagement, academic progression, or retention outcomes, but heterogeneous designs do not establish a universally effective model.

4. Access to structural support varies across institutions, programs, and career stages

Research opportunities, career intentions, and physician-scientist outcomes vary across institutions, specialties, programs, and trainee populations (51-58). Research-intensive programs more often reported formal mentorship, dedicated research opportunities, or structured career-development support, whereas other settings report limited access. The evidence did not permit nationally representative quantification of physician-scientist training infrastructure within China.

Coordinated frameworks integrating protected research opportunity, mentorship, funding continuity, and transition support were not consistently identified at national scale in the reviewed Chinese evidence (59). Individual institutions and programs nevertheless document local research training and mentorship, indicating heterogeneity rather than universal absence (11, 19, 60). Financial considerations across the broader literature include educational debt, research funding, salary support, and research resources, but nationally representative China-specific evidence remains limited.

5. Cross-system synthesis identifies recurring structural features associated with research continuity

Across the evidence, protected or dedicated research opportunities, sustained mentorship, transition mechanisms, and financial or institutional support recur in association with research engagement, academic progression, or continued research-oriented careers (24, 25, 41, 51, 55). Selected US, German, and other European programs document these mechanisms at specific career stages (16, 41, 45, 61-67), while selected Chinese programs document local structural research exposure and mentorship (19, 60). Implementation varies across systems and programs and harmonized longitudinal outcome data remain limited; cross-system comparison was therefore restricted to documented structural features rather than national performance rankings (Figure 4 and Table 2).

Discussion

This synthesis identifies research continuity as a useful organizing framework for physician-scientist development. Research exposure varies across pathways and programs, sustained research opportunities recur with subsequent research engagement, Chinese residency studies document substantial training burden without establishing physician-scientist attrition, and the transition toward research independence represents a recurrent vulnerability involving protected research opportunity, mentorship, funding, and career-development support (7-10, 24, 25, 41, 45, 51).

The findings shift attention from training structure or research exposure alone toward whether research engagement can be maintained across career stages. Early research experience may be followed by clinically intensive periods with limited protected opportunity, whereas mentorship, dedicated research periods, and transition support may help preserve engagement. Thus, the relevant distinction is not simply between “research” and “clinical” pathways but between continuous and intermittent research opportunity. This interpretation is consistent with heterogeneous evidence linking research training and mentorship with subsequent engagement, without establishing independent causal effects (21, 25, 51, 68-71).

Residency illustrates this challenge. In Chinese cohorts, 62.2% of residents in one institutional study met the burnout criterion (26); in another cohort, 35.9% worked > 60 hours/week and 71.05% had at least one burnout dimension (27). These observations do not measure physician-scientist attrition or productivity, but together with the inconsistent identification of formal protected research periods, they describe conditions in which sustained research activity may be

difficult. Residency is therefore a plausible structural constraint on research continuity, not a demonstrated attrition mechanism (35-37).

A related vulnerability is the transition from structured training toward research independence—the "missing middle." Recurring challenges include protected research opportunity, mentorship, financial or salary support, competing clinical responsibilities, and progression toward independent roles (72). Their recurrence supports transition-stage vulnerability but not a highest attrition rate; comparable longitudinal data were unavailable. The term therefore denotes a conceptual synthesis rather than an estimated attrition trajectory (73-76).

Cross-system comparison suggests that the relevant question is not whether a system is "strong" or "weak," but where and how continuity-supporting mechanisms are implemented. Selected US, German, European, and Chinese programs document protected research opportunities, mentorship or transition support, or dedicated funding at particular stages, but implementation varies substantially. These observations describe structural approaches rather than national rankings or uniformly continuous support (59, 61-67).

The evidence therefore supports prospective evaluation rather than universal prescription. Candidate mechanisms include designated research opportunities, longitudinal mentorship, structured transition support, and funding or salary support across defined transitions. Future studies should assess sustained research participation, protected research time, scholarly activity, academic appointment, research-career retention, and competitive funding progression (77-80).

For China, longitudinal cohorts using standardized definitions of research engagement, protected opportunity, funding progression, and physician-scientist career status are a priority.

Limitations

Several limitations warrant consideration. Heterogeneity in populations, training stages, program structures, exposures, and outcomes precluded pooled estimates or direct quantitative comparison across systems, and physician-scientist definitions varied. Of 90 primary studies, 17 provided supportive residency-context rather than direct physician-scientist evidence. Failure to identify a coordinated mechanism does not establish universal absence, particularly where implementation may be local or unpublished; cross-system comparisons therefore describe documented approaches rather than comprehensive national assessments. The "missing middle" is a conceptual synthesis, not an estimated attrition trajectory. Finally, predominantly observational, cross-sectional, or program-evaluation evidence does not establish causal effects.

Conclusion

Physician-scientist development depends not only on research training but also on sustaining research engagement across career stages. Protected research opportunity, mentorship and transition support, funding continuity, and early-career support recur as relevant structural features, while residency and transition toward research independence represent plausible vulnerability. These findings provide an evidence-bounded framework for prospective evaluation of continuity-supporting mechanisms rather than a universal training model**.**

Methods

Study Design

This structured evidence synthesis incorporated policy and program analysis to examine physician-scientist training systems, with China as the primary setting and selected international systems used for structural comparison. We focused on recurrent, potentially modifiable features relevant to continuity of research engagement rather than pooled or causal effects because populations, designs, exposures, and outcomes were heterogeneous. Prespecified structural domains were research exposure and protected research opportunity, funding continuity, transition support, and early-career support; policy and program documents characterized formally specified structures without implying causality.

Evidence sources and literature search

Evidence came from national policy and statistical sources, institutional or program materials, and peer-reviewed literature (1, 10, 33, 51, 59, 73, 81-83). PubMed and Web of Science (WoS) were searched on August 19–20, 2026, for publications from January 1, 2010, through December 31, 2025. Six prespecified searches addressed physician-scientist training and career pathways, physician-scientist and residency training in China, and protected research time, mentorship, funding, transition, retention, and early-career support. PubMed searches used Title/Abstract fields and a publication-date restriction; WoS searches used Topic (TS=) queries restricted to 2010–2025. Article and Review types were retained at retrieval for sensitivity and citation chaining, but reviews without original analyzable data were not primary evidence. Complete strategies and counts are in Supplemental Table S1.

The searches retrieved 3,639 records. Deterministic deduplication by valid DOI, valid PMID, and normalized exact title yielded 2,094 unique publications; 1,755 met the publication-year rule. Screening identified 211 candidates, and bibliographic reconciliation left 210 for eligibility assessment. Ninety publications formed the primary empirical evidence base; 12 additional sources were retained for contextual or policy interpretation, and 108 were excluded for prespecified reasons (Supplemental Table S1). Additional references cited for general background or conceptual framing were not part of the adjudicated analytic corpus and therefore were not included in these study-disposition counts.

Eligibility and evidence classification

Primary studies evaluated a defined population, program, or career stage and reported evidence relevant to training structure, research exposure, protected research time, workload, mentorship or transition support, funding continuity, research engagement or productivity, or physician-scientist career outcomes (26-32, 34-37, 84-89). Studies directly addressing physician-scientist or clinician-scientist development were classified as direct evidence. Standardized-residency studies without direct physician-scientist outcomes were classified as supportive residency-context evidence when they described workload, training demands, or related conditions potentially relevant to research engagement; they were not treated as direct evidence of physician-scientist productivity or attrition. Within the adjudicated analytic corpus, reviews, commentaries, policy analyses, and official documents without original analyzable data were retained only for contextual or structural interpretation and were not counted as primary empirical evidence.

The final corpus comprised 90 empirical publications: 73 direct and 17 supportive residency-context studies. Full text was reviewed for 89 included studies; one study was assessed from its indexed abstract, with extraction limited to explicitly reported information.

Evidence extraction and provenance

We extracted bibliographic information, setting, design, population and sample size, training stage, structural domain, exposure or program characteristic, outcome definition, quantitative findings, limitations, and figure/table relevance. Numerical findings retained original populations, denominators, exposures, and outcome definitions and were not treated as directly comparable across heterogeneous studies. Study-level extraction and permitted use are documented in Supplemental Table S2; figure-and-table provenance, coding rationale, and interpretation limits are in Supplemental Table S3 (18, 90-98). Overlapping publications were retained for distinct outcomes or analyses but not treated as independent replications; denominators were not combined.

Operational structural domains

The synthesis examined four domains: (1) research exposure and protected research opportunity; (2) funding continuity; (3) transition support; and (4) early-career support. Training duration and pathway structure were contextual characteristics (2, 23, 46, 47, 63, 64, 68, 99-105). Protected research time was formally designated time with reduced clinical or service obligations for research. Funding continuity was financial or salary support spanning a defined training or career-transition interval rather than isolated project funding. A structured transition mechanism linked formal training to progression toward research independence and incorporated at least two

of the following: protected research time, formal mentorship, salary or research support, or staged career-development support. The Chinese "5+3" pathway was defined as 5 years of undergraduate medical education plus 3 years of standardized residency; integration with professional master's training was identified separately when documented.

Quantitative and structural synthesis

No meta-analysis was performed. Quantitative evidence was summarized as source-specific observations with original denominators and outcome definitions; heterogeneous estimates were not combined into synthetic national or cross-national rates (10, 25, 65, 73, 75, 82). Structural implementation was classified as Present, Partial, or Not identified. *Present* indicated that a mechanism meeting the definition was documented; *Partial* indicated implementation limited to selected institutions, programs, specialties, or career stages; *Not identified* indicated that no coordinated mechanism meeting the definition was identified and did not imply universal absence. Categories described implementation, not quality, effectiveness, or national performance, and no ordinal rankings were assigned. Major claims were mapped to supporting evidence and interpretation limits; observational evidence was not interpreted causally. Figure and table elements used the same provenance framework (Supplemental Tables S2 and S3).

Statistics

No meta-analysis or inferential statistical analysis was performed. Quantitative findings were reported as source-specific observations using the original populations, denominators, and outcome definitions.

Study approval

Not applicable.

Data availability

All data were derived from publicly available sources cited in the article. Search strategies, study-level extraction and classification, and figure/table provenance are provided in Supplemental Tables S1–S3; quantitative graphical values are provided in the Supporting Data Values XLS file. No new participant-level data were generated.

Authors' contributions

ZL, CJ and YL conceived the study. YL wrote the main manuscript text and prepared tables and figures. All authors read and approved the final manuscript.

AI disclosures

The authors used ChatGPT (OpenAI; GPT-5.6 Luna) and DeepSeek (DeepSeek AI) in August–September 2026 to assist with language editing, consistency checks, and reference proofreading. The graphical abstract was created by the authors using BioRender on August 29-31, 2026, based on their own conceptualization of the study findings, with AI-assisted suggestions informing the layout. All AI-assisted outputs were critically reviewed by the authors, who verified relevant factual claims against the original sources. The authors take full responsibility for the integrity and accuracy of all content presented in this article, including content developed with AI assistance.

Funding support

Introduced Talent Research Start-up Fund of the Second Hospital of Dalian Medical University (No. YJRS202501; awarded to Dr. Yaming Liu).

Acknowledgements

Not applicable.

References

1. Brass LF, Akabas MH, Burnley LD, et al. Are MD-PhD programs meeting their goals? An analysis of career choices made by graduates of 24 MD-PhD programs. *Acad Med.* 2010;85(4):692–701.
2. Ahn J, Donegan DJ, Lawrence JT, et al. The future of the orthopaedic clinician-scientist: part II: Identification of factors that may influence orthopaedic residents' intent to perform research. *J Bone Joint Surg Am.* 2010;92(4):1041–6.
3. Ogdie A, Shah AA, Makris UE, et al. Barriers to and Facilitators of a Career as a Physician-Scientist Among Rheumatologists in the US. *Arthritis Care Res (Hoboken).* 2015;67(9):1191–201.
4. Vyas JM, and Armstrong KA. Physician-Scientist to Research-Engaged Physician-What Is in a Name? *JAMA Netw Open.* 2024;7(9):e2433123.
5. Kelly DP. Replenishing the physician-scientist pipeline in the post-late bloomer era. *J Clin Invest.* 2024;134(1).
6. Morel PA, and Ross G. The physician scientist: balancing clinical and research duties. *Nat Immunol.* 2014;15(12):1092–4.
7. Collins KL. Physician-scientist development: a new category for supporting all stages of the physician-scientist pipeline. *JCI Insight.* 2024;9(5).
8. Yeravdekar RC, and Singh A. Physician-Scientists: Fixing the Leaking Pipeline - A Scoping Review. *Med Sci Educ.* 2022;32(6):1413–24.
9. Milewicz DM, Lorenz RG, Dermody TS, et al. Rescuing the physician-scientist workforce: the time for action is now. *J Clin Invest.* 2015;125(10):3742–7.

10. Andriole DA, Grbic D, Yellin J, et al. MD-PhD Program Graduates' Engagement in Research: Results of a National Study. *Acad Med.* 2021;96(4):540–8.

11. Wang G. Training and Retaining Physician–Scientists in Dermatology: China. *JID Innov.* 2022;2(1):100080.

12. Eley DS, and Wilkinson D. Building a teaching-research nexus in a research intensive university: rejuvenating the recruitment and training of the clinician scientist. *Med Teach.* 2015;37(2):174–80.

13. Heffron AS, Braun KM, Allen-Savietta C, et al. Gender Can Influence Student Experiences in MD-PhD Training. *J Womens Health (Larchmt).* 2021;30(1):90–102.

14. Tie H, Luo Y, and Chen D. Thinkings on the reform of medical education system in China. *Med Educ Online.* 2024;29(1):2302677.

15. Hsieh CR, and Tang C. The multi-tiered medical education system and its influence on the health care market-China's Flexner Report. *Hum Resour Health.* 2019;17(1):50.

16. Barnett-Vanes A, Ho G, and Cox TM. Clinician-scientist MB/PhD training in the UK: a nationwide survey of medical school policy. *BMJ Open.* 2015;5(12):e009852.

17. Pepin ME, Souder JP, Weaver AN, et al. Fostering a diverse regional community of physician-scientist trainees. *J Natl Med Assoc.* 2022;114(3):251–7.

18. Xu L, Zhou J, Fan C, et al. Current status of medical research among undergraduate medical students in China: a nationwide questionnaire survey. *Front Med (Lausanne).* 2025;12:1593233.

19. Wan M, Liu S, Zhu J, et al. Challenges of senior 8-year-program medical students' scientific research in China: A multicenter questionnaire-based study. *Medicine (Baltimore).* 2022;101(10):e29026.

20. Spaniol K, and Geerling G. [MD PhD programs: Providing basic science education for ophthalmologists]. *Ophthalmologe.* 2015;112(6):488–93.

21. Stefely JA, Theisen E, Hanewall C, et al. A physician-scientist preceptorship in clinical and translational research enhances training and mentorship. *BMC Med Educ.* 2019;19(1):89.

22. Brass LF, Fitzsimonds RM, and Akabas MH. Gaps between college and starting an MD-PhD program are adding years to physician-scientist training time. *JCI Insight.* 2022;7(6).

23. Galderisi A, Bressan S, Da Dalt L, et al. Nurturing the next generation of pediatric physician scientists: the Padova Physician Scientist Research Training for pediatric residents. *Eur J Pediatr.* 2024;183(4):1567–70.

24. Harding CV, Akabas MH, and Andersen OS. History and Outcomes of 50 Years of Physician-Scientist Training in Medical Scientist Training Programs. *Acad Med.* 2017;92(10):1390–8.

25. Andriole DA, and Jeffe DB. Predictors of full-time faculty appointment among MD-PhD program graduates: a national cohort study. *Med Educ Online.* 2016;21:30941.

26. Zhang Y, Chu X, Sha Y, et al. Survey of job burnout and depression in standardized residency training programs in China. *Medicine (Baltimore).* 2019;98(35):e16890.

27. Geng H, Tan F, Deng Y, et al. High rate of burnout among residents under standardized residency training in a tertiary teaching hospital of middle China: Results from a cross-sectional survey. *Medicine (Baltimore).* 2020;99(27):e20901.

28. Bo H, Zhang DH, Zuo TM, et al. Survey and analysis of the current state of residency training in medical-school-affiliated hospitals in China. *BMC Med Educ.* 2014;14:111.

29. Hou J, He Y, Zhao X, et al. The effects of job satisfaction and psychological resilience on job performance among residents of the standardized residency training: a nationwide study in China. *Psychol Health Med.* 2020;25(9):1106–18.

30. Sun X, Zhang M, Lu Z, et al. Turnover intention and related factors among resident physicians in China under the standardised residency training programme: a cross-sectional survey. *BMJ Open.* 2022;12(4):e061922.

31. Liu Z, Yao Q, Wang P, et al. The price of pressure: nationwide survey on lifestyle disturbances, occupational burnout and compromised perceived-competency among radiology residents in China. *Front Public Health.* 2024;12:1472397.

32. Su P, Zhu X, Zheng X, et al. Unveiling the hidden struggles: A cross-sectional study on the mental health crisis among Chinese medical residents. *Medicine (Baltimore).* 2025;104(46):e45500.

33. Sun T, and Wang Y. Standardized training for resident doctors in China. *J Biomed Res.* 2014;28(3):155–6.

34. Zhang J, Han X, Yang Z, et al. Radiology residency training in China: results from the first retrospective nationwide survey. *Insights Imaging.* 2021;12(1):25.

35. Chen Q, Li M, Wu N, et al. A survey of resident physicians' perceptions of competency-based education in standardized resident training in China: a preliminary study. *BMC Med Educ.* 2022;22(1):801.

36. Deng K, Huang C, Liu W, et al. Assessment of the Family Medicine Residency Training Environment in Guangdong, China, Based on the PHEEM: A Cross-Sectional Study. *Fam Med.* 2025;57(9):640–7.

37. Zhu H, Zhang C, Li N, et al. Satisfaction survey on graduates of standardised training for resident doctors in Guizhou Province, China. *BMJ Open.* 2024;14(10):e085789.

38. Bills JL, Davidson M, and Dermody TS. Effectiveness of a clinical intervention for MD/PhD students re-entering medical school. *Teach Learn Med.* 2013;25(1):77–83.

39. Pietrobon A, Cook EK, Yin C, et al. International training considerations of Canadian Clinician-Scientist Trainees - A national survey. *Clin Invest Med.* 2020;43(4):E2–7.

40. Gallagher EJ, Rockey DC, Kontos CD, et al. Pearls of wisdom for aspiring physician-scientist residency applicants and program directors. *JCI Insight.* 2022;7(6).

41. Rincon-Torroella J, Feghali J, Antar A, et al. The Johns Hopkins Physician-Scientist Training Program to Enhance Institutional Retention and Entry Into Academic Positions: An Evaluation of Program Effectiveness and Outcomes. *Acad Med.* 2025;100(1):63–71.

42. Chakraverty D, Jeffe DB, and Tai RH. Transition Experiences in MD-PhD Programs. *CBE Life Sci Educ.* 2018;17(3):ar41.

43. Steinman RA, Proulx CN, and Levine AS. The Highly Structured Physician Scientist Training Program (PSTP) for Medical Students at the University of Pittsburgh. *Acad Med.* 2020;95(9):1373–81.

44. Pepin ME, Kamal Y, Reisman BJ, et al. Making the match and breaking it: values, perceptions, and obstacles of trainees applying into physician-scientist training programs. *BMC Med Educ.* 2023;23(1):763.

45. Dearolf CR, Lee JS, Pickett CL, et al. The National Institutes of Health Lasker Clinical Research Scholars Program: A Decade of Launching Clinician-Scientist Careers. *Acad Med.* 2025;100(1):57–62.

46. Modrek AS, Tanese N, Placantonakis DG, et al. Breaking Tradition to Bridge Bench and Bedside: Accelerating the MD-PhD-Residency Pathway. *Acad Med.* 2021;96(4):518–21.

47. Maddry JK, Mallory A, Arana AA, et al. Establishment of the Clinician-Scientist Investigator Opportunity Network to Develop Military Medical Research Leaders. *Mil Med.* 2024;189(3-4):e864–e70.

48. Calhoun A, Herrington OD, Leckman JF, et al. Supporting Clinician-Scientist Development in Child Psychiatry: A Four-Domain Model for Individual or Programmatic Self-Reflection. *Front Psychiatry.* 2021;12:651722.

49. Emala CW, Sr., Tawfik VL, Lane-Fall MB, et al. The Anesthesiology Physician-Scientist Pipeline: Current Status and Recommendations for Future Growth-An Initiative of the Anesthesia Research Council. *Anesth Analg.* 2023;137(4):728–42.

50. Fitzsimonds RM, Gorelick FS, and Kazmierczak BI. Interventions to support fellowship application success among predoctoral physician-scientists. *JCI Insight.* 2024;9(5).

51. Skinnider MA, Twa DDW, Squair JW, et al. Predictors of sustained research involvement among MD/PhD programme graduates. *Med Educ.* 2018;52(5):536–45.

52. Jeffe DB, Andriole DA, Wathington HD, et al. Educational outcomes for students enrolled in MD-PhD programs at medical school matriculation, 1995-2000: a national cohort study. *Acad Med.* 2014;89(1):84–93.

53. Martinez-Strengel A, Samuels EA, Cross J, et al. Trends in U.S. MD-PhD Program Matriculant Diversity by Sex and Race/Ethnicity. *Acad Med.* 2022;97(9):1346–50.

54. Brass LF, and Akabas MH. More women than ever are entering MD-PhD programs. What lies ahead for them? *JCI Insight.* 2024;9(22).

55. Kwan JM, Daye D, Schmidt ML, et al. Exploring intentions of physician-scientist trainees: factors influencing MD and MD/PhD interest in research careers. *BMC Med Educ.* 2017;17(1):115.

56. von Kaeppler EP, Akabas MH, Brass LF, et al. MD-PhD graduates remain underrepresented in orthopaedic surgery: National MD-PhD Program Outcome Survey update. *J Orthop Res.* 2020;38(10):2181–8.

57. Brass LF, Tomaiuolo M, Wallace A, et al. Admissions to MD-PhD programs: how well do application metrics predict short- or long-term physician-scientist outcomes? *JCI Insight.* 2025;10(7).

58. Rowell TR, Redd RA, Neuberg DS, et al. Mind the gap: Expediting gender parity in MD-PhD admissions. *JCI Insight.* 2020;5(4).

59. Li P, Zhao J, Wang J, et al. Advancing Physician-Scientist Training in China - Challenges, Gaps, and Future Directions. *N Engl J Med.* 2025;393(9):836–8.

60. You X, and Wu W. Assessing the impact of Medical Education's Innovation & Entrepreneurship Program in China. *BMC Med Educ.* 2024;24(1):519.

61. Scherlinger M, Bienvenu TCM, Piffoux M, et al. [MD-PhD trainings in France: overview and future directions, from the French MD/PharmD-PhD students association << AMPS >>]. *Med Sci (Paris).* 2018;34(5):464–72.

62. Dos Santos Rocha A, Scherlinger M, et al. Characteristics and opinions of MD-PhD students and graduates from different European countries: a study from the European MD-PhD Association. *Swiss Med Wkly.* 2020;150:w20205.

63. Tapernoux M, Vermij S, Metzger G, et al. The Swiss National MD-PhD Grants Programme: an analysis of the career trajectories of grant recipients between 1992 and 2021. *Swiss Med Wkly.* 2024;154(7):3615.

64. Roghmann MC, Schimmenti LA, Williams CS, et al. An Analysis of Curricular Structures in MD-PhD Programs in the United States. *Acad Med.* 2025;100(1):72–7.

65. Hendriks B, and Reinhart M. What are the chances? Clinician scientist; career pathways in Germany. *BMC Med Educ.* 2023;23(1):642.

66. Dos Santos Rocha A, Combescure C, and Negro F. The MD-PhD program in Geneva: a 10-year analysis of graduate demographics and outcomes. *BMC Med Educ.* 2020;20(1):425.

67. Englmaier VA, Maier-Wenzel AK, Liekfeld A, et al. [Academics in ophthalmology : An analysis of the gender distribution at German university hospitals and the Clinician Scientist Program]. *Ophthalmologie.* 2025;122(2):91–9.

68. Twa DDW, Skinnider MA, Squair JW, et al. Cross-sectional-derived determinants of satisfaction with physician-scientist training among Canadian MD/PhD graduates. *PLoS One.* 2017;12(9):e0185218.

69. Harris JP, and Edstrom OE. Factors Influencing a Clinician-Scientist Career Path in Otolaryngology. *Laryngoscope.* 2022;132(8):1555–60.

70. Berger A, Matloubian M, Shah NP, et al. The Molecular Medicine Investigation Unit: Linking Patient Care and Scientific Inquiry in Physician-Scientist Training. *J Grad Med Educ.* 2020;12(1):92–7.

71. Jones AC, McCaw TR, Seay RL, et al. Paradigm shift: outcomes from a physician-scientist undergraduate pathway program. *BMC Med Educ.* 2025;25(1):244.

72. Rhee KY, Emala CW, Gallagher EJ, et al. Paving the physician-scientist career path: from grassroots gathering to national forum. *JCI Insight.* 2025;10(7).

73. Brass LF, and Akabas MH. The national MD-PhD program outcomes study: Relationships between medical specialty, training duration, research effort, and career paths. *JCI Insight.* 2019;4(19).

74. Marr MC, Heffron AS, and Kwan JM. Characteristics, barriers, and career intentions of a national cohort of LGBTQ+ MD/PhD and DO/PhD trainees. *BMC Med Educ.* 2022;22(1):304.

75. Akabas MH, and Brass LF. The National MD-PhD Program Outcomes Study: career paths followed by Black and Hispanic graduates. *JCI Insight.* 2024;9(9).

76. Gotian R, and Andersen OS. How perceptions of a successful physician-scientist varies with gender and academic rank: toward defining physician-scientist's success. *BMC Med Educ.* 2020;20(1):50.

77. Parker K, Burrows G, Nash H, et al. Going beyond Kirkpatrick in evaluating a clinician scientist program: it's not "if it works" but "how it works". *Acad Med.* 2011;86(11):1389–96.

78. Chao DL, Schiffman JC, and Gedde SJ. Characterization of a clinician-scientist cohort in ophthalmology: a demographic analysis of k grant awardees in ophthalmology. *Ophthalmology.* 2013;120(10):2146–50.

79. Kwan JM, Noch E, Qiu Y, Toubat O, et al. The Impact of COVID-19 on Physician-Scientist Trainees and Faculty in the United States: A National Survey. *Acad Med.* 2022;97(10):1536–45.

80. Ghosh-Choudhary S, Carleton N, Nouraie SM, et al. Predoctoral MD-PhD grants as indicators of future NIH funding success. *JCI Insight.* 2022;7(6).

81. Jeffe DB, and Andriole DA. A national cohort study of MD-PhD graduates of medical schools with and without funding from the National Institute of General Medical Sciences' Medical Scientist Training Program. *Acad Med.* 2011;86(8):953–61.

82. Akabas MH, and Brass LF. The national MD-PhD program outcomes study: Outcomes variation by sex, race, and ethnicity. *JCI Insight.* 2019;4(19).

83. Liu X, Feng J, Liu C, et al. Medical Education Systems in China: Development, Status, and Evaluation. *Acad Med.* 2023;98(1):43–9.

84. He Y, Qian W, Shi L, et al. Standardized residency training: An equalizer for residents at different hospitals in Shanghai, China? *Int J Health Plann Manage.* 2020;35(2):592–605.

85. Wang P, Zhang J, Chen Y, et al. The satisfaction with radiology residency training in China: results of a nationwide survey. *Insights Imaging.* 2022;13(1):196.

86. Yang X, Zheng D, Wan P, et al. Standard ophthalmology residency training in China: an evaluation of resident satisfaction on training program in Guangdong Province. *BMC Med Educ.* 2023;23(1):550.

87. Luo S, Zhang Y, Wang P, et al. The moderating role of resilience in the association between workload and depressive symptoms among radiology residents in China: results from a nationwide cross-sectional study. *Eur Radiol.* 2024;34(1):695–704.

88. Xue D, Yang H, Zheng J, et al. A study on transition shock among first-year residents in China: survey data based on latent profile analysis. *Front Med (Lausanne).* 2025;12:1716120.

89. Wang M, Liu M, Wang J, et al. Prevalence and correlates of perceived stress and psychological health among residents receiving standardized training: a multicenter cross-sectional survey study in China. *BMC Public Health.* 2025;25(1):4325.

90. Byrne MM, Lossos IS, and Koniaris LG. What is the institutional financial impact of an MD-PhD program without extramural funding? *Teach Learn Med.* 2010;22(1):56–9.

91. Bills JL, VanHouten J, Grundy MM, et al. Validity of the Medical College Admission Test for predicting MD-PhD student outcomes. *Adv Health Sci Educ Theory Pract.* 2016;21(1):33–49.

92. Siebert AL, Chou S, Toubat O, et al. Factors associated with underrepresented minority physician scientist trainee career choices. *BMC Med Educ.* 2020;20(1):422.

93. Martinez-Flisser G, Flisser A, Castro-Guerrero MA, et al. Measuring student satisfaction as the first assessment of the Program of Combined Studies in Medicine, an MD/PhD-like program of the Faculty of Medicine, National Autonomous University of Mexico. *BMC Med Educ.* 2020;20(1):446.

94. Ommering BWC, van Blankenstein FM, and Dekker FW. First steps in the physician-scientist pipeline: a longitudinal study to examine the effects of an undergraduate extracurricular research programme. *BMJ Open.* 2021;11(9):e048550.

95. Simpson RL, Cornfield DN, and Burris JE. Novel Prescriptions From Medical Schools for Physician-Scientist Training and Engagement in the Twenty-First Century. *Acad Med.* 2021;96(4):512–5.

96. Ayedun A, Agbelese V, Curry L, Gotian R, et al. Perspectives on National Institutes of Health Funding Requirements for Racial and Ethnic Diversity Among Medical Scientist Training Program Leadership. *JAMA Netw Open.* 2023;6(5):e2310795.

97. Duncan AF, Sukra L, Portugues A, et al. Building a Physician-Scientist Pathway for Underrepresented Medical Students Through a Summer Research Experience. *Acad Med.* 2024;99(10):1099–103.

98. Yang Z, Chen W, Li R, et al. The value of publishing case reports for the professional development of Chinese residents: a qualitative study. *BMC Med Educ.* 2025;25(1):933.

99. Cogswell PM, Deitte LA, Donnelly EF, et al. Attitudes of Radiology Program Directors Toward MD-PhD Trainees, Resident Research Productivity, and Dedicated Research Time. *Acad Radiol.* 2018;25(6):733–8.

100. Brandt AM, Rettig SA, Kale NK, et al. Can a Clinician-Scientist Training Program Develop Academic Orthopaedic Surgeons? One Program's Thirty-Year Experience. *J Surg Educ.* 2018;75(4):1039–44.

101. Salama JK, Floyd SR, Willett CG, et al. Fostering Radiation Oncology Physician Scientist Trainees Within a Diverse Workforce: The Radiation Oncology Research Scholar Track. *Int J Radiat Oncol Biol Phys.* 2021;110(2):288–91.

102. Koman LA, Danelson KA, Jinnah A, et al. An Innovative Seven-year Physician Scientist Residency Training Program That Addresses the Shortage of Academic Surgeons. *J Surg Orthop Adv.* 2022;31(3):144–9.

103. Romero JM, Sorin M, Dankner M, et al. Gender Disparities in Academic Outcomes Among Graduates of a Canadian MD-PhD Program. *Clin Invest Med.* 2023;46(1):E4–14.

104. Obradovic A, Toubat O, Chen NW, et al. Impact of COVID-19 pandemic on physician-scientist trainees to faculty one year into the pandemic. *BMC Med Educ.* 2024;24(1):587.

105. Luigi M, Yin C, Misaghi E, et al. Training Outcomes and Satisfaction in Canadian MD/PhD and MD/MSc Programs: Findings from a National Survey. *Clin Invest Med.* 2024;47(2):12–22.

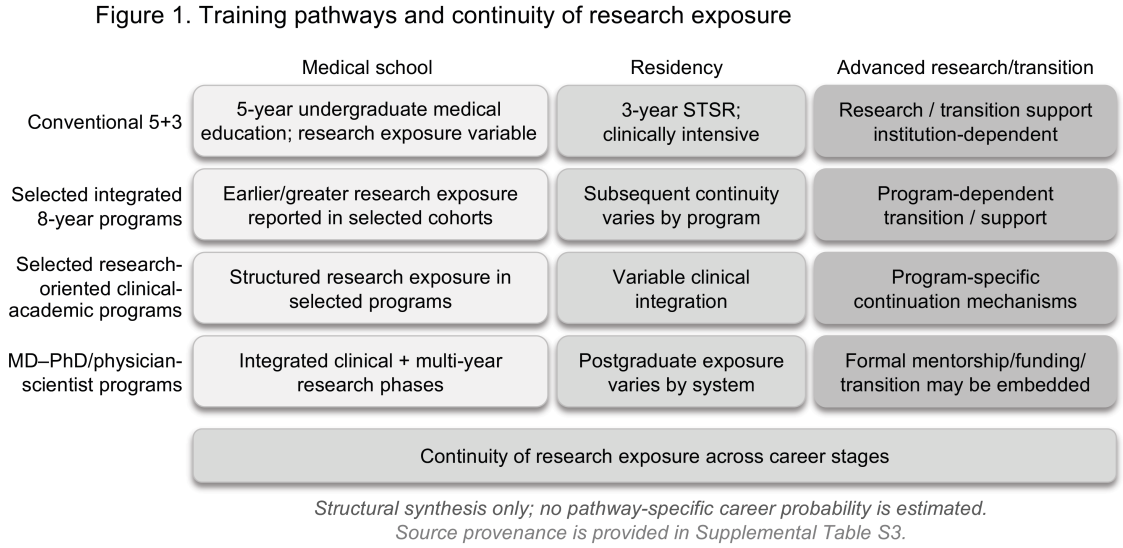


Figure 1. Structural organization of physician-scientist training pathways and research exposure.

Schematic comparison of representative pathways showing training sequence and timing/continuity of research exposure: the Chinese 5+3 pathway, selected integrated 8-year programs, selected research-oriented medical education programs, and MD–PhD/physician-scientist programs. Research exposure is a structural characteristic, not a quantitative intensity measure; the figure does not estimate pathway-specific career probabilities, productivity, or causal effects. Provenance is provided in Supplemental Table S3.

Figure 2. Source-specific residency burden and its bounded structural interpretation

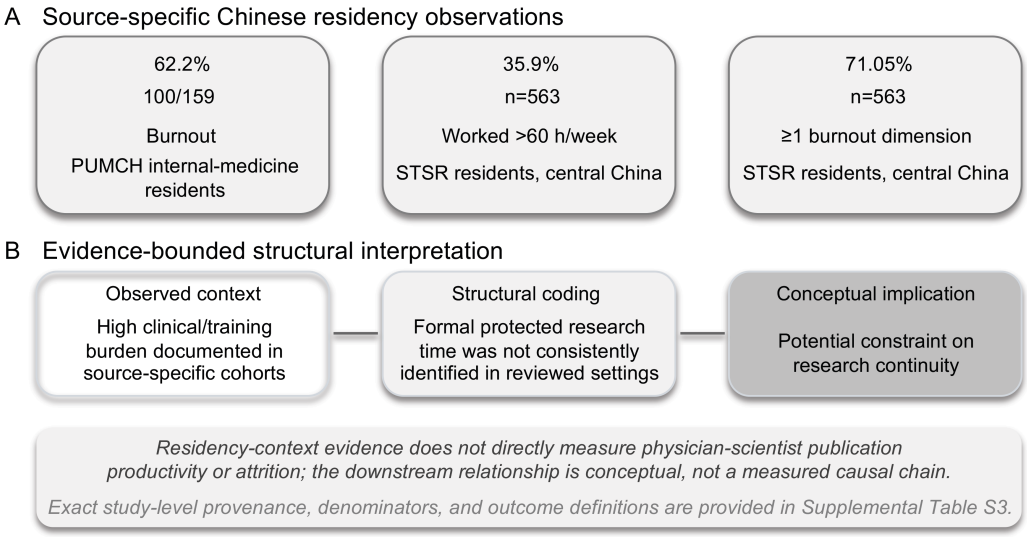


Figure 2. Source-specific workload and burnout observations during standardized residency training in China.
Supportive residency-context observations are shown for two Chinese cohorts: 100/159 residents (62.2%) met the study-defined burnout criterion; in a separate cohort of 563 trainees, 35.9% worked >60 hours/week and 71.05% had at least one burnout dimension. Values retain original denominators and definitions and are neither pooled nor nationally representative. They characterize training burden, not physician-scientist productivity, attrition, or causal effects on research continuity. Provenance is provided in Supplemental Tables S2 and S3.

Figure 3. The training-to-independence transition as a recurrent structural vulnerability

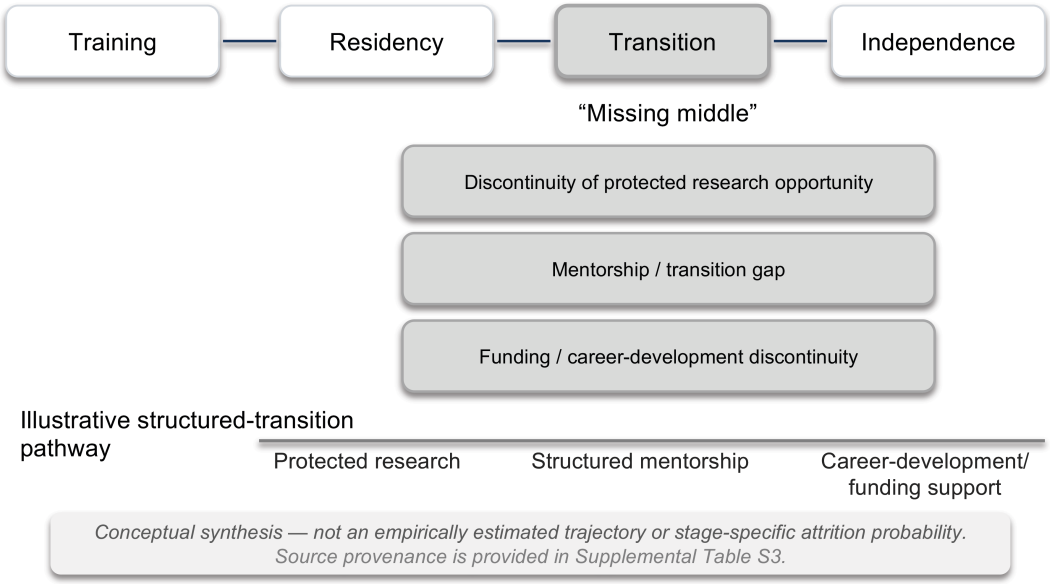
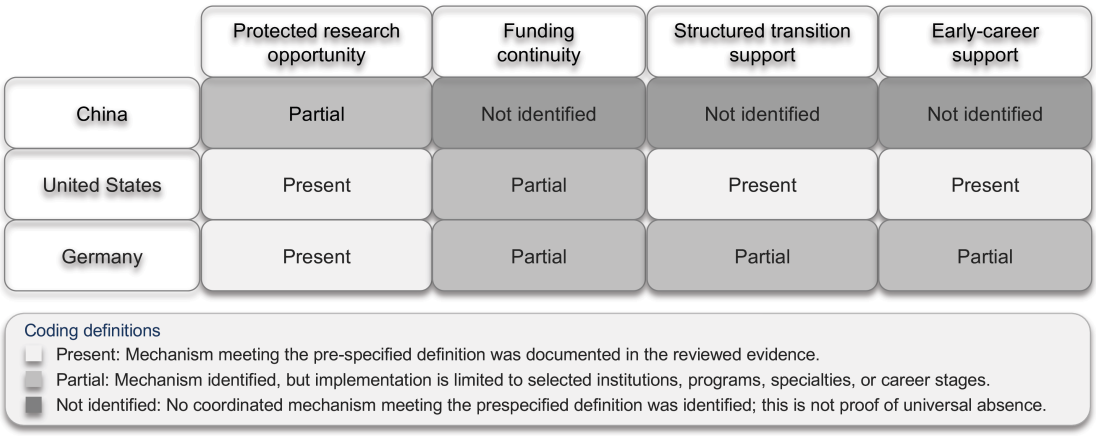


Figure 3. Conceptual model of the "missing middle" in physician-scientist development. Conceptual synthesis of recurrent vulnerabilities during transition from structured training toward research independence, including discontinuities in protected research opportunity, mentorship, funding/salary support, and career-transition mechanisms. The model is not an estimated career-progression probability or attrition trajectory and does not identify a quantitatively highest-risk stage. Supporting evidence is in Supplemental Tables S2 and S3.

Figure 4. Evidence-coded structural support mechanisms across reviewed training systems



Categories describe evidence-identified implementation and do not represent rankings of national system quality.
National-level China claims requiring policy verification should remain phrased as "not identified in the reviewed evidence."

Figure 4. Cross-system comparison of structural mechanisms supporting physician-scientist research continuity.
Evidence-coded comparison of research exposure/protected research opportunity, funding continuity, transition support, and early-career support across China and selected comparator systems. Present denotes documented implementation meeting the definition; Partial denotes implementation limited to selected institutions, programs, specialties, or career stages; Not identified denotes no coordinated mechanism identified and does not imply universal absence. Categories describe implementation, not quality, effectiveness, national performance, or ordinal ranking. Provenance is provided in Supplemental Tables S2 and S3.

Table 1. Structural characteristics of representative physician-scientist training pathways.

Training pathway	Typical structure	Research exposure	Protected research component	Transition mechanism	Evidence basis	Interpretation limit
Conventional 5+3	5 years of undergraduate medical education + 3 years of standardized residency training	Variable across reviewed settings; access to research exposure and mentorship is heterogeneous	Not consistently identified in reviewed STSR settings	No coordinated national transition mechanism identified in the reviewed evidence	Policy/contextual evidence; S2 IDs 94, 184; STSR-context S2 IDs 46, 56	No pathway-specific career probability or ordinal research-exposure ranking inferred
Selected integrated 8-year programs	Extended integrated medical training in selected Chinese programs	Research exposure documented in selected cohorts	Program-dependent	Program-dependent	S2 ID 94; policy/contextual evidence for formal program structure	Selected-program evidence; not nationally representative longitudinal career data
Selected research-oriented medical education programs	Program-specific research-oriented medical education	Structured research exposure documented in selected local programs	Program-dependent	Program-dependent	S2 ID 142	Demonstrates local implementation; does not establish national prevalence or superiority
MD–PhD / physician-scientist programs	Integrated clinical training with structured multiyear research phases	Sustained research exposure embedded in program design	Present during designated research phases; subsequent continuity varies	Variable across programs and systems	S2 IDs 2, 24, 31, 36, 180	Heterogeneous career outcomes should not be pooled into pathway-specific probabilities

S2 IDs refer to study identifiers in Supplemental Table S2. STSR, standardized residency training. “Program-dependent” denotes variation across institutions or programs. “Not consistently identified” describes the reviewed evidence and does not imply universal absence.

Table 2. Evidence-coded structural support domains across reviewed training systems.

System	Structural domain	Coding	Documented implementation	Interpretation
China	Research exposure / protected research opportunity	Partial	Structured research exposure is documented in selected programs, whereas formal protected research time was not consistently identified across the reviewed standardized residency settings.	Implementation is heterogeneous and program-dependent; Partial does not imply national coverage.
China	Funding continuity	Not identified	No coordinated stage-spanning funding mechanism meeting the prespecified definition was identified at national scale in the reviewed evidence.	Does not imply absence of local, institutional, or project-specific funding support.
China	Structured transition support	Not identified	No coordinated transition mechanism meeting the prespecified definition was identified at national scale in the reviewed evidence.	Does not imply absence of local or program-specific transition initiatives.
China	Early-career support	Not identified	No coordinated early-career support mechanism meeting the prespecified definition was identified at national scale in the reviewed evidence.	Does not imply universal absence of institution-specific early-career support.
United States	Research exposure / protected research opportunity	Present	Dedicated research periods, protected research tracks, and structured research opportunities are documented in multiple physician-scientist programs represented in the reviewed evidence.	Implementation varies across programs and institutions and should not be interpreted as universal national coverage.
United States	Funding continuity	Partial	Career-development awards and program-based funding mechanisms are documented, but continuity varies across mechanisms and career stages.	Funding mechanisms are not uniformly stage-spanning or available across all institutions and trainees.
United States	Structured transition support	Present	Physician-scientist training programs and structured career-development mechanisms provide documented support across selected transitions toward research independence.	Represents program-specific implementation rather than a single standardized national transition system.
United States	Early-career support	Present	Formal early-career mechanisms, including career-development awards and physician-scientist program support, are documented in the reviewed evidence.	Availability, eligibility, and outcomes vary; coding does not imply universal effectiveness.
Germany	Research exposure / protected research opportunity	Present	Structured Clinician Scientist Programs document protected research time during program participation.	Documented implementation in represented programs should not be generalized to all German institutions or trainees.
Germany	Funding continuity	Partial	Scholarship or program-based financial support is documented within selected Clinician Scientist Programs, while continuity beyond program participation remains incomplete.	Does not establish a continuous national funding pathway across career stages.
Germany	Structured transition support	Partial	Selected programs provide structured mentorship and career-development support during participation, but continuity across subsequent career stages remains incomplete.	Transition support is documented in selected programs rather than as a fully coordinated system-wide mechanism.
Germany	Early-career support	Partial	Program-level early-career support mechanisms are documented, but availability of positions and continued support varies across settings and career stages.	Does not establish nationally uniform early-career support or continuity.

Structural implementation was classified as Present, Partial, or Not identified using prespecified operational definitions. Present indicates that a mechanism meeting the definition was documented; Partial indicates documented implementation restricted to selected institutions, programs, specialties, or career stages; and Not identified indicates that no coordinated mechanism meeting the definition was identified in the reviewed evidence and does not imply universal absence. Categories describe documented implementation rather than program quality, effectiveness, or national performance. Detailed provenance and coding rationale are provided in Supplemental Table S3.