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The Pentahelix Approach to Oral-Systemic Health Integration: A Policy Framework for Academic-Primary Care Partnerships in Transitional Health Systems

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ABSTRACT

Background: Dentistry has long been separated from primary medical care, which sustains preventable oral-systemic multimorbidity in low- and middle-income transitional health systems.

Objective: To quantify structural bottlenecks in oral-systemic care and formulate an evidence-informed Pentahelix policy framework centered on academic-primary care partnerships.

Methods: This secondary analysis combined four open-access sources not linked at the person or system level: national indicators for 192 World Health Organization member states (129 transitional economies); a Ghanaian physician survey (n=146); Nepalese dental outpatient records (n=211); and an international expert survey on e-oral health terminology (n=29). Analyses used a geometric composite index, HC3-robust regression, logistic regression, and bootstrap mediation.

Results: The Pentahelix Oral-Systemic Integration Index, which includes income-related indicators, was lower in transitional than in high-income systems (46.88±16.09 vs. 71.13±8.43; p<0.001), and the academic pillar scored lowest (37.46±16.74). Although 91.8% of physicians endorsed diabetic periodontal screening, 12.3% delivered oral counseling and 5.5% performed routine examinations. Curriculum content was associated with screening self-efficacy (adjusted odds ratio [aOR] 6.97, 95% confidence interval [CI] 2.13 to 22.81; p=0.001), and self-efficacy with counseling (aOR 27.54, 95% CI 5.59 to 135.72; p<0.001); the indirect association of interprofessional exposure with counseling was +9.38 percentage points (95% CI 1.87 to 18.34). Body mass index was associated with attachment loss (β=+0.0398 mm per kg/m²; p<0.001). An illustrative simulation of a +25-point rise in all pillars predicted oral screening rising from 69.6% to 89.9%.

Conclusion: Coordinated action across academia, government, primary care, civil society, and digital media may help narrow the oral-systemic divide.

1. Introduction

Oral diseases are among the most widespread non-communicable diseases (NCDs) worldwide, yet they remain marginal within global health governance, primary medical care delivery, and universal health coverage (UHC) financing architectures.[1,2] Current surveillance estimates show a very large burden. More than 3.5 billion people, nearly half of the world's population, suffer from active and largely preventable oral conditions, among them untreated dental caries, severe periodontitis, edentulism, and lip or oral cavity malignancies, and their combined case count surpasses that of the main NCD groups combined.[3–5] The last three decades have changed the picture. Demographic expansion, rapid urbanization, and nutrition transitions

have driven steep absolute increases in severe periodontitis and untreated caries across low- and middle-income countries (LMICs). Global Burden of Disease projections warn that severe periodontitis alone will surpass 1.5 billion prevalent cases worldwide by 2050 if fragmented clinical models persist.[4,6] Beyond localized masticatory disability, chronic pain, and psychosocial stigma, oral disorders impose a macroeconomic toll exceeding USD 710 billion annually, counting direct treatment expenditures and indirect productivity losses together. Working-age populations in transitional economies bear a disproportionate share.[7] Isolated, chairside restorative dentistry cannot reverse this trajectory. The World Health Organization (WHO) Global Strategy and Global Oral Health Action Plan (2023–2030) therefore set out a mandate to move oral healthcare away from siloed, curative interventionism and toward full integration within primary health care (PHC) and national NCD agendas by 2030.[8,9]

The biological case for integrating oral and general healthcare rests on molecular, immunological, and clinical trial evidence of bidirectional associations and syndemic interactions between periodontal inflammation and major cardiometabolic NCDs.[10,11] The local anatomy of the periodontal pocket matters here. In moderate-to-severe periodontitis, the ulcerated pocket epithelium presents a vascularized wound surface of approximately 8 to 20 cm^2 to dysbiotic subgingival biofilms dominated by proteolytic pathobionts such as Porphyromonas gingivalis, Tannerella forsythia, and Treponema denticola.[10,12] Recurrent transient bacteremia and continuous paracellular translocation of lipopolysaccharides and gingipains activate Toll-like receptors 2 and 4 and nuclear factor-kappa B signaling in hepatic, endothelial, and adipose tissues, and systemic concentrations of interleukin-1 β, interleukin-6, tumor necrosis factor-alpha, and high-sensitivity C-reactive protein stay elevated.[12–14] In type 2 diabetes mellitus, this systemic cytokine spillover induces serine phosphorylation of insulin receptor substrate-1 and worsens peripheral insulin resistance. Hyperglycemia then feeds back into the same process. It accelerates periodontal breakdown through advanced glycation end-product accumulation and receptor for advanced glycation end-products (AGE–RAGE) oxidative stress within gingival microvasculature.[11,12] A Cochrane meta-analysis reports that non-surgical subgingival periodontal instrumentation reduces glycated hemoglobin (HbA1c) by 0.43% at three to four months, an effect comparable in magnitude to adding a second-line oral hypoglycemic agent, while also attenuating endothelial dysfunction and atherosclerotic vascular inflammation.[13,15] Visceral adiposity and clinical obesity amplify periodontal connective-tissue destruction through dysregulated adipokines, including resistin, visfatin, and leptin. These pathways combine into a triangular cardiometabolic–periodontal syndemic. That syndemic calls for unified screening at the primary care frontline.[16,17]

Biological convergence has not yet reached clinical practice. Clinical translation across transitional health systems, defined here as Low-, Lower-Middle-, and Upper-Middle-Income economies undergoing simultaneous epidemiological shifts from infectious to chronic disease dominance and institutional UHC reforms, remains limited by the long-standing professional and financial separation of medicine and dentistry.[18–20] The divide is institutional as well as professional. In most transitional nations, dental education, licensure, electronic medical records, ministry directorates, and insurance benefit packages run on parallel tracks that are disconnected from family medicine and internal medicine clinics.[21–23] Patients with poorly controlled diabetes, hypertension, or metabolic obesity rarely receive basic intraoral risk screening at PHC facilities, while dental services stay concentrated in urban private practices financed mainly through regressive out-of-pocket (OOP) payments that trigger catastrophic household health expenditure or delay presentation until emergency tooth extraction is needed.[24–26] Earlier attempts to bridge the divide relied mostly on top-down ministerial guidelines or isolated continuing education workshops. These efforts routinely stall at the facility level for several reasons. Among them are misaligned capitation incentives, absent referral protocols, severe rural dental workforce shortages, low community oral health literacy, and uncoordinated digital communication channels.[21,22,25]

Overcoming multi-level implementation failure requires a move beyond dyadic ministry-clinic mandates and toward systemic multi-actor governance. In innovation and public policy theory, the Triple Helix (academia–industry–government) has evolved into Quadruple and Quintuple/Pentahelix architectures, which show that sustainable socio-technical transformation needs co-evolutionary alignment across interdependent societal spheres; the five spheres used here (academia, government and payers, healthcare delivery and health technology, civil society, media and digital ecosystem) are the authors' adaptation of the Quintuple Helix: academic knowledge institutions, government regulators and payers, healthcare delivery and health-technology enterprises, civil society and patient communities, and the media and digital information ecosystem.[27,28] The question is who carries the change. Academic–primary care partnerships are the hypothesized translational engine here. They turn biomedical discovery into routine frontline practice within this five-actor architecture. Such partnerships unite medical and dental faculties with district PHC networks through interprofessional education (IPE), shared clinical clerkships, competency-based screening protocols, and implementation research.[29–34] Empirical evidence on this question is still thin. To our knowledge, no earlier study has operationalized all five Pentahelix pillars across transitional health systems. None has tested, within a single analysis, the meso-level clinician mediation pathways and micro-level cardiometabolic–periodontal gradients that govern policy effectiveness. Drawing exclusively on four verifiable, open-access global and clinical repositories,[35–38] the present study aimed to: (1) construct a cross-national Pentahelix Oral-Systemic Integration Index (POSII) across 192 WHO member states, to diagnose structural bottlenecks in 129 transitional health systems; (2) identify multivariable determinants and competency mediation pathways governing diabetic oral screening and cross-referral among frontline physicians; (3) quantify the independent cardiometabolic–periodontal disease gradient among adult outpatients, alongside international expert consensus on e-oral health terminology; and (4) synthesize an empirically calibrated Pentahelix policy framework and counterfactual simulation roadmap for academic–primary care partnerships.

2. Methods

2.1. Study design and multi-scale open-data architecture

This was an observational, multi-scale, convergent cross-sectional policy and clinical investigation, and we followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines and the Guidelines for Accurate and Transparent Health Estimates Reporting (GATHER). Structural health-system reform acts at three levels at once: macro-policy stewardship, meso-institutional provider interfaces, and micro-clinical patient encounters. No single dataset spans all five Pentahelix spheres. We therefore linked four publicly auditable open-access datasets. Cohort A captures macro cross-national governance (*N*=192 WHO member states). Cohort B covers meso physician referral interfaces in a transitional academic-referral network (Zenodo DOI: 10.5281/zenodo.19407039; *n*=146 physicians),[35] while Cohort C holds micro outpatient cardiometabolic–periodontal clinical examinations from a transitional teaching hospital (Zenodo DOI: 10.5281/zenodo.22172178; *n*=211 adults).[36] Cohort D records global expert consensus on digital e-oral health modalities (Zenodo DOI: 10.5281/zenodo.10605383; *n*=29 international task-force panelists).[37,38] A deterministic, version-controlled Python 3.9 pipeline ran all data extraction, harmonization, composite index construction, and econometric scripts.

2.2. Macro cross-national policy panel and operationalization of the Pentahelix index (Cohort A)

To evaluate national policy readiness and structural bottlenecks, we harmonized country-level indicators across all sovereign analytical economies classified by World Bank income tier. Only WHO member states with complete epidemiological oral disease ascertainment were kept (*N*=192) Low-Income (*n*=25), Lower-Middle-Income (*n*=46), and Upper-Middle-Income (*n*=58) economies were designated a priori as Transitional

Health Systems (*n*=129). High-Income economies (*n*=63) served as the benchmark. Sixteen indicators came from programmatic REST API queries to the WHO Global Health Observatory (GHO). Topics were oral health surveillance, PHC service availability, NCD capacity, dental workforce density, and the UHC Service Coverage Index. Eight more came from World Bank Open Data. We used the most recent non-empty observation for each. Those were the domestic government health expenditure share (SH.XPD.GHED.CH.ZS), OOP health expenditure share (SH.XPD.OOPC.CH.ZS), gross tertiary and secondary enrollment (SE.TER.ENRR, SE.SEC.ENRR), internet penetration (IT.NET.USER.ZS), mobile cellular subscriptions (IT.CEL.SETS.P2), gross domestic product per capita at purchasing power parity (NY.GDP.PCAP.PP.KD), and population share aged ≥65 years (SP.POP.65UP.TO.ZS). Bibliometric data came from the OpenAlex open registry. Country-level peer-reviewed oral-systemic co-production counts were taken from it (2015–2025; *n*=341,565 indexed authorship records).

Continuous component indicators were normalized onto a bounded 0–100 scale via min–max transformation (inverting regressive OOP share as financial protection=100 − OOP% and log-transforming right-skewed publication per million population and dentist density per 10,000 population prior to scaling). Sporadic missingness in auxiliary covariates was addressed strictly via within-income-stratum median imputation while preserving observed values for all primary clinical and policy endpoints. Five domain sub-indices (0–100) were constructed corresponding to the Pentahelix architecture:[27,28] Pillar 1 (Academia and Interprofessional Knowledge Production) combined log oral-systemic research output per million population (weight 0.50), gross tertiary enrollment (0.35), and WHO-reported pre-service eHealth training in health-sciences faculties (GOE_Q018; 0.15); Pillar 2 (Government Stewardship and UHC Mandate) combined presence of dedicated oral health staff within Ministry of Health NCD units (ORALHEALTH_NCD_STAFF; 0.35), inclusion of routine and preventive oral care in the largest government UHC scheme (ORALHEALTH_UHC_PREVENTIVE; 0.30), and domestic government share of current health expenditure (0.35) (government share and out-of-pocket share are near mirror images of one financing split, so this domain partly counts a single quantity twice; see Section 4.4); Pillar 3 (Primary Care Delivery and Health-Tech Service Infrastructure) combined composite PHC availability of early oral screening (this component is also the outcome of the logistic model for PHC screening availability, so that model partly contains its outcome; see Section 4.4), basic restorative dental procedures, and urgent oral pain relief (ORALHEALTH_AVAILABILITY_SCREENING, RESTORATIVE, URGENTCARE; 0.40), log dentist density per 10,000 population (HWF_0010; 0.30), and the UHC Service Coverage Index (UHC_INDEX_REPORTED; 0.30); Pillar 4 (Civil Society, Community Literacy, and Financial Protection) combined household protection from OOP payments (0.55) and secondary educational empowerment (0.45); and Pillar 5 (Media and Digital Health Information Ecosystem) combined population internet connectivity (0.60) and mobile cellular penetration (0.40).[39,40] To capture weakest-link institutional bottlenecks predicted by multi-helix systems theory, our primary composite exposure—the Geometric POSII—was defined as the shifted geometric mean [(P1+1)(P2+1)(P3+1)(P4+1)(P5+1)]^(1/5) − 1, evaluated alongside the unweighted arithmetic mean, within-country cross-pillar standard deviation (Pentahelix Imbalance SD), and the multiplicative Academic–PHC Synergy term (P1 × P3 / 100). Internal consistency across the five pillars was verified using Cronbach's alpha.

2.3. Meso academic–primary care physician interface cohort (Cohort B)

We also asked why national policy mandates stall at the clinical frontline. To answer this, we analyzed individual-level records from 146 medical practitioners. They were Family Medicine and Internal Medicine residents, medical officers, and specialists who practiced at Korle Bu Teaching Hospital or its affiliated primary-referral ambulatory clinics in Accra, Ghana (Zenodo DOI: 10.5281/zenodo.19407039, Creative Commons Attribution 4.0 International [CC BY 4.0])[35].

Bidirectional periodontitis–diabetes pathophysiological knowledge was measured with a 5-point composite index (0–5) created by the authors, and its internal consistency was not assessed. The index summed affirmative answers across five clinical domains, namely periodontitis as a recognized diabetes complication, elevated risk of severe periodontitis in diabetes, the deleterious impact of gingival inflammation on glycemic control, heightened periodontal susceptibility under poor glycemic control, and the glycemic benefit of periodontal therapy. Academic–primary care partnership exposures were inclusion of oral health in undergraduate medical curricula, affiliation of the physician's medical university with a dental school, interprofessional clinical rotation or observation alongside dentists or dental hygienists, and physical proximity to a dental clinic or school. Proximate psychological and behavioral outcomes included physician self-efficacy in conducting diabetic oral health screening. Active provision of in-office diabetic oral counseling was another. Proactive routine intraoral examination at initial or follow-up visits was recorded. The final outcomes were endorsed facility barriers and physician demand for policy guidelines and patient educational media.

2.4. Micro clinical outpatient and digital e-oral health consensus cohorts (Cohorts C and D)

To verify patient-level oral-systemic multimorbidity and social gradients in a transitional setting, we analyzed de-identified clinical periodontal examination records. These covered 211 consecutive adult dental outpatients evaluated at a tertiary teaching hospital in Bharatpur, Nepal, between February and July 2025 (Zenodo DOI: 10.5281/zenodo.22172178, CC BY 4.0)[36]. Anthropometric assessment grouped body mass index (BMI = weight [kg] / height [m]^2) into underweight (<18.5 kg/m^2), normal (18.5–24.9 kg/m^2), overweight (25.0–29.9 kg/m^2), and obese (≥30.0 kg/m^2) categories. Socioeconomic status (low, middle, high) was recorded too. So was daily toothbrushing frequency (<2/day vs. ≥2/day). Calibrated clinical periodontal parameters were the Silness–Löe Plaque Index and full-mouth Bleeding on Probing (BOP, %). Mean and Maximum Probing Pocket Depth (PPD, mm) were measured. So were Mean and Maximum Clinical Attachment Loss (CAL, mm). The Community Periodontal Index (CPI, 0–3) and clinical periodontitis case status completed the list. We also wanted to describe expert agreement on the terminology of digital modalities relevant to Pillar 3 and Pillar 5 integration. For this, we analyzed survey responses from 29 international digital oral health experts on e-oral health terminology convened by the International Association for Dental, Oral, and Craniofacial Research (IADR) e-Oral Health Network Terminology Task Force (Zenodo DOI: 10.5281/zenodo.10605383, CC BY 4.0)[37,38]. The responses quantified framework inclusion consensus and operational definition agreement. Ten primary-care connective modalities were rated, among them e-referral, teledentistry, m-oral health, store-and-forward imaging, tele-triage, e-health records, and e-learning.

2.5. Statistical, econometric, and counterfactual simulation analysis

Descriptive distributions were summarized as means ± standard deviations (SD) for approximately Gaussian variables. Medians with interquartile ranges (IQR) described skewed workforce densities, and binomial proportions were given as exact percentages with 95% Wilson score confidence intervals (CI). Cross-stratum comparisons in Cohort A used Welch's unequal-variance t-test, the Mann–Whitney U test, the four-group Kruskal–Wallis H test, and Pearson's chi-squared test. Multivariable continuous outcomes were estimated by ordinary least squares (OLS) with MacKinnon–White HC3 heteroskedasticity-consistent covariance matrices. These outcomes were the macro Oral-Systemic Burden Index, premature NCD mortality (ages 30–70 years), untreated permanent caries prevalence (adjusted for log GDP PPP per capita and demographic aging share aged ≥65 years to prevent epidemiological transition confounding), and micro-clinical Mean CAL and BOP% (adjusted for BMI, age, sex, socioeconomic status, brushing frequency, and Plaque Index). Multicollinearity was audited with variance inflation factors (VIF < 5.0 threshold). Binary policy and clinical outcomes were modeled by multivariable logistic regression fitted by maximum likelihood (Newton–Raphson algorithm). They were national PHC early oral screening availability,

physician screening self-efficacy, active diabetic oral counseling, and outpatient periodontitis. We reported adjusted odds ratios (aOR), 95% Wald CIs, McFadden pseudo-R^2, and receiver operating characteristic area under the curve (AUC). Fisher's exact test audited variables with quasi-complete separation. In Cohort B, non-parametric bootstrap mediation (2,000 resamples with percentile 95% CIs) quantified the indirect probability effect of interprofessional dental clinical rotation on active diabetic oral counseling, transmitted through physician screening self-efficacy (Model 2 had 18 counseling events for six predictors, so its estimates are imprecise and may be affected by sparse-data bias). Calibrated parameter vectors from Cohort A were then applied to 129 transitional economies across five counterfactual policy scenarios: Baseline (S0), Siloed Academia +25 points (S1), Siloed Primary Care +25 points (S2), Academic–PHC Dyad +25 points (S3), and Balanced Five-Pillar Pentahelix Reform +25 points capped at 100 (S4). Sensitivity analyses compared Geometric against Arithmetic POSII aggregation and audited complete-case versus income-stratum-imputed specifications. A final check verified the stability of Wilson binomial confidence bounds under sparse event counts. Statistical significance was defined by two-sided p-values <0.05; no adjustment for multiple comparisons was applied, and secondary analyses are exploratory.

2.6. Ethical considerations

This investigation drew on publicly archived, fully de-identified macro-epidemiological indicators (WHO GHO, World Bank, OpenAlex) and on open-access datasets distributed under permissive CC BY 4.0 licenses on Zenodo[35–37], each of which had obtained prior institutional ethics board approval and informed participant consent within its primary collection protocol. The work followed the Declaration of Helsinki (2013 revision). International regulations on secondary research with anonymized public-domain datasets were also observed, and participants were never contacted directly. No identifiable private health information was involved. The study therefore qualified for institutional ethical exemption, and full data provenance transparency was maintained.

3. Results

3.1. Macro-structural deficits and Pentahelix asymmetry across transitional health systems

The analysis covered 192 WHO member states with complete epidemiological oral disease surveillance. Of these, 129 economies (67.2%) met criteria for transitional health systems. They comprised 25 Low-Income, 46 Lower-Middle-Income, and 58 Upper-Middle-Income nations, set against 63 High-Income reference systems (Table 1). The five-pillar POSII showed strong internal psychometric coherence across nations (Cronbach's α=0.850), which shows that the five pillar scores covary across countries, as expected when most components track national income. The gap to wealthier systems was wide. Transitional systems trailed High-Income benchmarks by 24.25 points in Geometric POSII (46.88 ± 16.09 vs. 71.13 ± 8.43, Welch t=−13.70, p=3.91 × 10^{-30}). The income gradient was steep and monotonic. Low-Income systems scored 27.48 ± 8.47, Lower-Middle-Income systems 41.77 ± 11.13, and Upper-Middle-Income systems 59.29 ± 10.51 (Kruskal–Wallis H=133.10, p=1.16 × 10^{-28}, Figure 1A–B).

Table 1. Cross-national Pentahelix Oral-Systemic Integration Index (POSII) pillar scores, primary health care readiness, workforce density, and disease burden across 192 WHO member states.*

Domain / Indicator	Low-Income (*n*=25)	Lower-Middle (*n*=46)	Upper-Middle (*n*=58)	All Transitional† (*n*=129)	High-Income‡ (*n*=63)	*p*-value§
P1: Academia & Interprof. R&D (0–100)	23.28 ± 11.39	31.85 ± 13.89	48.03 ± 13.96	37.46 ± 16.74	66.68 ± 12.66	<0.001
P2: Government & UHC Mandate (0–100)	56.05 ± 22.77	64.39 ± 19.78	77.69 ± 16.30	68.75 ± 20.68	80.60 ± 19.21	<0.001
P3: Primary Care & Health-Tech (0–100)	34.70 ± 21.16	44.26 ± 18.68	70.20 ± 14.15	54.07 ± 22.84	80.19 ± 15.84	<0.001
P4: Civil Society & Fin. Protection (0–100)	37.84 ± 15.59	48.22 ± 17.12	58.23 ± 14.31	50.71 ± 17.32	71.20 ± 9.43	<0.001
P5: Media & Digital Ecosystem (0–100)	16.44 ± 8.06	38.60 ± 12.50	53.69 ± 12.04	41.09 ± 18.02	63.14 ± 4.55	<0.001
Arithmetic POSII Score (0–100)	33.66 ± 8.18	45.46 ± 10.13	61.57 ± 8.81	50.42 ± 14.25	72.36 ± 7.92	<0.001

Domain / Indicator	Low-Income (*n*=25)	Lower-Middle (*n*=46)	Upper-Middle (*n*=58)	All Transitional† (*n*=129)	High-Income‡ (*n*=63)	*p*-value§
Geometric POSII Score‖ (0–100)	27.48 ± 8.47	41.77 ± 11.13	59.29 ± 10.51	46.88 ± 16.09	71.13 ± 8.43	<0.001
PHC Early Oral Screening, % (95% CI; *n*=120 with data)	50.0 (30.7 to 69.3)	55.8 (41.1 to 69.6)	89.1 (78.2 to 94.9)	70.0 (61.3 to 77.5)	85.5 (73.8 to 92.4)	0.024
MoH Oral–NCD Staff, % (95% CI; *n*=122 and 59 with data)	62.5 (42.7 to 78.8)	68.2 (53.4 to 80.0)	77.8 (65.1 to 86.8)	71.3 (62.7 to 78.6)	78.0 (65.9 to 86.6)	0.334
Dentists per 10,000, median (IQR)	0.06 (0.02–0.13)	0.31 (0.12–1.26)	2.56 (1.23–5.26)	0.99 (0.13–2.75)	7.01 (4.25–8.82)	<0.001
Out-of-Pocket Health Share, %	42.90 ± 19.52	37.25 ± 21.11	31.98 ± 18.32	35.92 ± 19.86	19.92 ± 10.60	<0.001
Severe Periodontitis (≥15 y), %	19.80 ± 6.16	19.04 ± 8.16	16.79 ± 7.03	18.18 ± 7.36	18.98 ± 5.89	0.418
Untreated Permanent Caries (≥5 y), %	31.75 ± 3.53	31.52 ± 3.95	32.54 ± 5.01	32.03 ± 4.39	32.73 ± 4.78	0.329
Age-Std. Diabetes Prevalence, %¶	7.10 ± 2.49	9.50 ± 3.43	11.45 ± 4.53	9.96 ± 4.14	8.89 ± 4.76	0.132
Premature NCD Mortality (30–70 y), %	23.18 ± 4.96	21.91 ± 6.26	18.97 ± 5.06	20.88 ± 5.74	12.56 ± 6.35	<0.001

*Values are reported as mean ± standard deviation unless otherwise specified; harmonized from World Health Organization Global Health Observatory (GHO), World Bank Open Data, and OpenAlex (2015–2025). †Transitional health systems encompass all Low-, Lower-Middle-, and Upper-Middle-Income economies. ‡High-Income economies serve as the benchmark reference stratum. §Comparisons between All Transitional and High-Income strata using Welch's two-sample t-test (continuous means), Mann–Whitney U test (medians), or Pearson's chi-squared test (proportions); four-group Kruskal–Wallis test for Geometric POSII yielded H=133.10 ($p=1.16 \times 10^{-28}$). ‖Geometric POSII penalizes cross-pillar structural bottlenecks across the five helices (internal consistency Cronbach's α=0.850). ¶Age-standardized prevalence of diabetes mellitus among adults aged ≥18 years. Abbreviations: CI, Wilson confidence interval; Interprof., interprofessional; IQR, interquartile range; MoH, Ministry of Health; NCD, non-communicable disease; PHC, primary health care; POSII, Pentahelix Oral-Systemic Integration Index; R&D, research and development; UHC, universal health coverage; WHO, World Health Organization.

Separating the five helices revealed an institutional asymmetry that helps explain why nominal global oral health declarations often falter during domestic implementation. Pillar 2 (Government Stewardship and UHC Mandate) reached the highest mean score in transitional systems (68.75 ± 20.68). Dedicated oral health staff assigned to national NCD units were reported by 71.3% (95% CI: 62.7 to 78.6) of transitional ministries, a proportion statistically indistinguishable from High-Income ministries (78.0%, 95% CI: 65.9 to 86.6, p=0.334). The intervals correspond to 87 of 122 transitional and 46 of 59 high-income countries with available data (derived from the printed intervals) Pillar 1 told a rather different story. Academia and Interprofessional Knowledge Production was the single weakest pillar across transitional health systems (37.46 ± 16.74 vs. 66.68 ± 12.66 in High-Income economies, p<0.001), followed by Pillar 5 (Media and Digital Ecosystem: 41.09 ± 18.02), Pillar 4 (Civil Society and Financial Protection: 50.71 ± 17.32), and Pillar 3 (Primary Care and Health-Tech Infrastructure: 54.07 ± 22.84). Workforce scarcity and regressive health financing widened this gap. Transitional nations had a median of just 0.99 dentists per 10,000 population (IQR: 0.13–2.75), a seven-fold shortfall compared with 7.01 per 10,000 (IQR: 4.25–8.82, p<0.001) in High-Income nations. In Low-Income countries it fell to 0.06 per 10,000. Households paid 35.92 ± 19.86% of current health expenditures out of pocket, compared with 19.92 ± 10.60% in High-Income systems (p<0.001). Early oral disease screening in public PHC facilities remained unavailable in 30.0% of all transitional economies and 50.0% of Low-Income nations. These settings also carried about 1.7 times the premature 30–70-year NCD mortality burden of High-Income countries (20.88 ± 5.74% vs. 12.56 ± 6.35%, p<0.001). Severe periodontitis (18.18 ± 7.36% vs. 18.98 ± 5.89%, p=0.418) and untreated permanent caries (32.03 ± 4.39% vs. 32.73 ± 4.78%, p=0.329) did not differ between the two groups (Table 1).

Placing transitional nations on the Academic–Primary Care coupling plane (Figure 1C) revealed four governance archetypes (Synergistic Dyad Benchmark, Ivory-Tower–Clinic Chasm, Service-First/Low Academic R&D and Dual Structural Deficit Trap, Figure 1C) with possible policy relevance. Upper-middle-income exemplars such as Brazil (POSII 70.5, P1 = 64.0, P3 = 89.1), Thailand (POSII 70.6, P1 = 52.8, P3 = 73.3), and Malaysia (POSII 68.0, P1 = 59.5, P3 = 83.0) sit in the upper-right Synergistic Dyad Benchmark quadrant. This position may reflect decades of deliberate institutional coupling. Brazil integrated multi-

professional oral health teams into the community-anchored Family Health Strategy, and Thailand built a universal primary-care dental benefit package backed by rural mandatory academic service.[18,23,24,41] Ghana and Nepal show the opposite pattern. Ghana (POSII 50.2, MoH NCD staff present and P2 = 88.7, yet P3 = 28.9, PHC oral screening unavailable, and severe periodontitis 29.3%) and Nepal (POSII 41.1, MoH NCD staff present and P2 = 76.4, yet P3 = 25.3, PHC screening unavailable, and diabetes prevalence 10.6%) exemplify an Ivory-Tower–Clinic and Policy-on-Paper Chasm. In this pattern, ministerial staffing and university training fail to reach peripheral primary care clinics. Indonesia (POSII 55.7, P1 = 51.2, P3 = 67.0, severe periodontitis 19.6%) holds an intermediate transitional position. Broad *Puskesmas* primary-care infrastructure exists there, but national oral–NCD directorate coordination remains fragmented (MoH oral–NCD joint staffing absent), which points to the need for formal multi-helix alignment.[21,40]

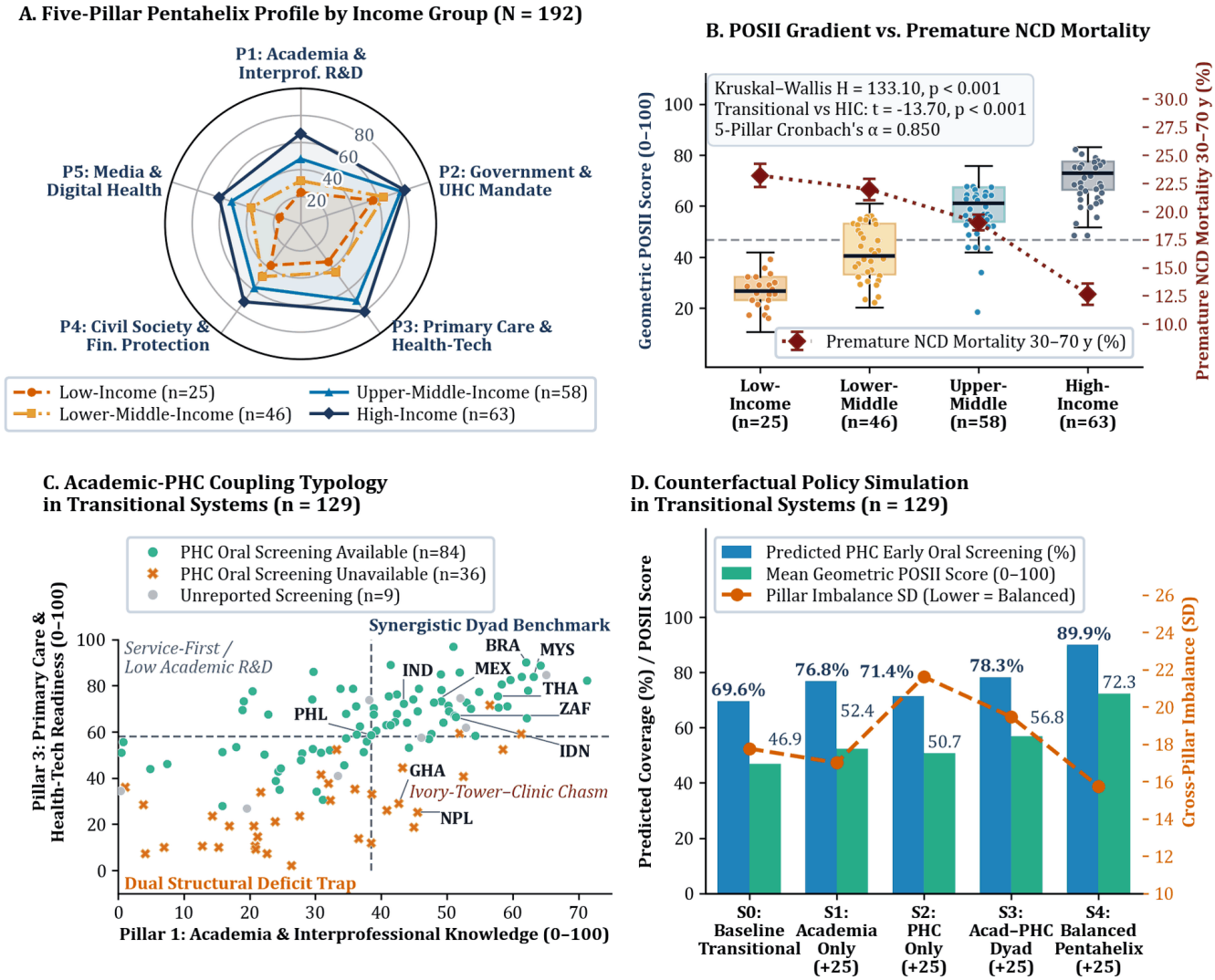


Figure 1. Cross-national Pentahelix structural profile, income gradient, coupling typology, and counterfactual policy simulation across World Health Organization member states (*N*=192). (A) Five-pillar radar profile across Low-Income (*n*=25), Lower-Middle-Income (*n*=46), Upper-Middle-Income (*n*=58), and High-Income (*n*=63) health systems demonstrating Pillar 1 (Academia, mean 37.46) as the deepest structural deficit in transitional economies. (B) Box-and-jitter distribution of Geometric Pentahelix Oral-Systemic Integration Index (POSII) juxtaposed against premature non-communicable disease (NCD) mortality (ages 30–70 years). (C) Academic–Primary Care coupling quadrant across 129 transitional systems stratified by primary health care (PHC) early oral screening availability. (D) Counterfactual policy simulation comparing siloed single-pillar reforms (S1, S2), dyadic Academic–PHC reform (S3), and full balanced Pentahelix integration (S4).

3.2. Econometric determinants of primary care screening and counterfactual policy simulation

The transitional cohort (n=120 countries with non-missing PHC screening status) was analyzed with a multivariable logistic regression that included all five Pentahelix dimensions. The model achieved acceptable apparent (in-sample) discrimination for national PHC early oral screening availability (McFadden pseudo-R^2=0.121, AUC=0.737). Adjusted odds ratios were above 1 for four predictors, but every confidence interval included 1. These were civil financial protection (P4 per 10 points: aOR 1.27, 95% CI: 0.98 to 1.66, p=0.075), dental workforce log-density (aOR 1.33, 95% CI: 0.62 to 2.83), academic capacity (P1 per 10 points: aOR 1.19, 95% CI: 0.81 to 1.74), and government stewardship (P2 per 10 points: aOR 1.13, 95% CI: 0.90 to 1.42). Multivariable HC3 OLS models of epidemiological disease burden showed no harmful collinearity (all VIFs 1.13–4.50). In these models, macroeconomic purchasing power (log GDP PPP per capita) independently lowered untreated permanent dental caries globally (β=−1.41 percentage points, HC3 95% CI: −2.28 to −0.53, p=0.002). It also lowered premature 30–70-year NCD mortality within transitional systems (β=−2.35 percentage points, HC3 95% CI: −4.31 to −0.38, p=0.020, R^2=0.197). Cross-national Academic–PHC Synergy showed a modest positive cross-sectional association with reported untreated caries prevalence (β=+0.074, p=0.021). This pattern may reflect diagnostic ascertainment, although this explanation was not tested. Transitional countries with active university–PHC oral screening detect subclinical carious lesions. Those lesions stay systematically under-recorded in low-surveillance settings.[3,9] A counterfactual simulation across all 129 transitional economies (Figure 1D) gave smaller predicted gains for single-sector reforms in this illustrative scenario analysis. Siloed PHC expansion alone (+25 points in P3, Scenario S2) worsened cross-pillar structural imbalance (SD rising from 17.76 to 21.61). It moved predicted PHC screening only slightly, from 69.6% to 71.4%, whereas siloed academic reform (Scenario S1) raised it to 76.8% (Figure 1D), close to the 78.3% of Scenario S3. Pairing Academic and PHC reform (Scenario S3) raised predicted screening to 78.3% (POSII 56.81). Synchronized five-pillar Pentahelix reform (Scenario S4) lifted predicted PHC screening coverage to 89.9% (POSII 72.32), compressed structural imbalance to 15.73, and lowered predicted premature NCD mortality from 20.88% to 20.28% (0.60 percentage points, about one-tenth of the between-country SD of 5.74).

3.3. Meso-level physician knowledge–action chasm and competency pathways in academic–primary care networks

Cohort B (Zenodo 10.5281/zenodo.19407039; n=146 physicians; mean age 34.71 ± 5.06 years; 43.8% female; 31.5% Family Medicine and 68.5% Internal Medicine)[35] described the behavioral and institutional bottleneck that may block oral-systemic integration in a transitional care network (Figure 2A). Frontline physicians showed high theoretical awareness of bidirectional periodontitis–diabetes pathobiology. Their mean composite knowledge score was 4.03 ± 1.52 out of 5.00. Specifically, 87.0% recognized heightened periodontal susceptibility in poorly controlled diabetes, and 82.9% knew that diabetes elevates severe periodontitis risk. Periodontitis was identified as a formal diabetes complication by 80.1%. In addition, 78.8% recognized that periodontal therapy improves glycemic control, and 74.7% acknowledged worse blood glucose control in patients with gingival inflammation. Referral attitudes were similarly favorable, with 91.8% (95% CI: 86.2 to 95.2) agreeing that diabetic patients require periodontal screening and dental referral. Most respondents (95.9%, 95% CI: 91.3 to 98.1) practiced near an accessible dental clinic or school. Finally, 79.5% (95% CI: 72.2 to 85.2) had graduated from a university with an affiliated dental school.

Table 2. Multivariable logistic regression models of physician oral-screening self-efficacy and active in-office diabetic oral health counseling in a transitional academic-primary care network (n=146).*

Explanatory Variable / Pentahelix Mechanism	Model 1: Screening Self-Efficacy† aOR (95% CI)	Model 1 p-value	Model 2: Active Diabetic Counseling‡ aOR (95% CI)	Model 2 p-value
Oral health in medical curriculum (Yes vs. No)	6.97 (2.13 to 22.81)	0.001	0.43 (0.08 to 2.39)	0.336
Interprofessional dental clinical rotation (Yes vs. No)	1.88 (0.71 to 4.98)	0.203	1.64 (0.38 to 7.07)	0.504

Explanatory Variable / Pentahelix Mechanism	Model 1: Screening Self-Efficacy† aOR (95% CI)	Model 1 *p*-value	Model 2: Active Diabetic Counseling‡ aOR (95% CI)	Model 2 *p*-value
Affiliated university dental school (Yes vs. No)	1.42 (0.40 to 5.13)	0.589	—§	—§
Oral-screening self-efficacy‖ (Confident vs. Unsure/No)	—	—	27.54 (5.59 to 135.72)	<0.001
Bidirectional PD–DM knowledge score (per 1-pt, 0–5)	1.12 (0.81 to 1.55)	0.502	1.15 (0.70 to 1.88)	0.586
Clinical department (Family vs. Internal Medicine)	0.40 (0.15 to 1.06)	0.067	0.52 (0.12 to 2.30)	0.385
Model fit & discrimination diagnostics¶	McFadden R^2=0.157; AUC=0.749	—	McFadden R^2=0.287; AUC=0.847	—

*Analyzed from open-access physician dataset Fiifi-Yankson & Ohene-Marfo (Zenodo DOI: 10.5281/zenodo.19407039; *n*=146 physicians: 31.5% Family Medicine, 68.5% Internal Medicine; mean age 34.71 ± 5.06 years). †Dependent variable: physician confidence in performing oral health screening for patients with diabetes (26.7%, 95% CI: 20.2 to 34.4). ‡Dependent variable: provision of in-office oral health counseling to diabetic patients (12.3%, 95% CI: 7.9 to 18.6). §Nearby dental facility/school availability (95.9%, 140/146) exhibited zero counseling events among the 6 physicians without a nearby dental facility (quasi-complete separation; exact Fisher test *p*=1.00) and was excluded from multivariable maximum-likelihood estimation to preserve finite variance. ‖Non-parametric bootstrap mediation (2,000 resamples) estimated an indirect association from interprofessional clinical rotation through screening self-efficacy to active diabetic counseling (indirect probability effect=+9.38 percentage points, 95% bootstrap CI: +1.87 to +18.34). ¶Area under the receiver operating characteristic curve (AUC) and McFadden pseudo-R^2 report apparent (in-sample) rank discrimination; no out-of-sample validation was performed. Abbreviations: aOR, adjusted odds ratio; AUC, area under the curve; CI, confidence interval; DM, diabetes mellitus; PD, periodontal disease.

Despite near-universal theoretical endorsement and physical co-location, clinical execution dropped sharply along an institutional competency gradient (Figure 2A). Some oral health exposure in medical school was reported by 60.3% (95% CI: 52.2 to 67.8), yet only 43.8% (95% CI: 36.0 to 51.9) rated that training as fair-to-very-good. Merely 21.2% (95% CI: 15.4 to 28.6) had ever completed an interprofessional clinical rotation or patient-care observation with dentists or dental hygienists. Accordingly, only 26.7% (95% CI: 20.2 to 34.4) felt confident performing an oral health screening on diabetic patients. Just 12.3% (95% CI: 7.9 to 18.6) provided in-office diabetic oral health counseling. Proactive intraoral examinations at initial or routine visits were rare (5.5%, 95% CI: 2.8 to 10.4). Multivariable logistic regression (Table 2, Figure 2B) estimated associations of curriculum, partnership exposure and self-efficacy with screening and counseling in this 86-percentage-point endorsement-to-practice gap. Passive university co-existence with a dental school did not significantly improve physician screening self-efficacy (aOR 1.42, 95% CI: 0.40 to 5.13, *p*=0.589), whereas structured inclusion of oral health within the medical curriculum was associated with nearly seven-fold higher odds of it (aOR 6.97, 95% CI: 2.13 to 22.81, *p*=0.001; Model 1 apparent AUC=0.749). Physicians with interprofessional dental clinical exposure reported more than double the crude screening confidence of unexposed peers (45.2% vs. 21.7%; crude Fisher exact *p*=0.012, not significant after adjustment: aOR 1.88, 95% CI 0.71 to 4.98, *p*=0.203, Table 2). Their active counseling prevalence was nearly double as well (19.4% vs. 10.4%). In Model 2 (AUC=0.847, McFadden pseudo-R^2=0.287), physician screening self-efficacy was the dominant proximate determinant of active diabetic oral counseling (aOR 27.54, 95% CI: 5.59 to 135.72, *p*<0.001), whereas theoretical knowledge score alone was not independently associated with counseling (aOR 1.15, 95% CI: 0.70 to 1.88, *p*=0.586). A 2,000-resample non-parametric bootstrap mediation analysis followed. It estimated a positive indirect association of interprofessional dental clinical exposure with active counseling through screening self-efficacy; because the exposure-to-self-efficacy odds ratio was not significant (aOR 1.88, 95% CI 0.71 to 4.98), the indirect estimate should be read cautiously (indirect probability effect=+9.38 percentage points, 95% CI: +1.87 to +18.34).

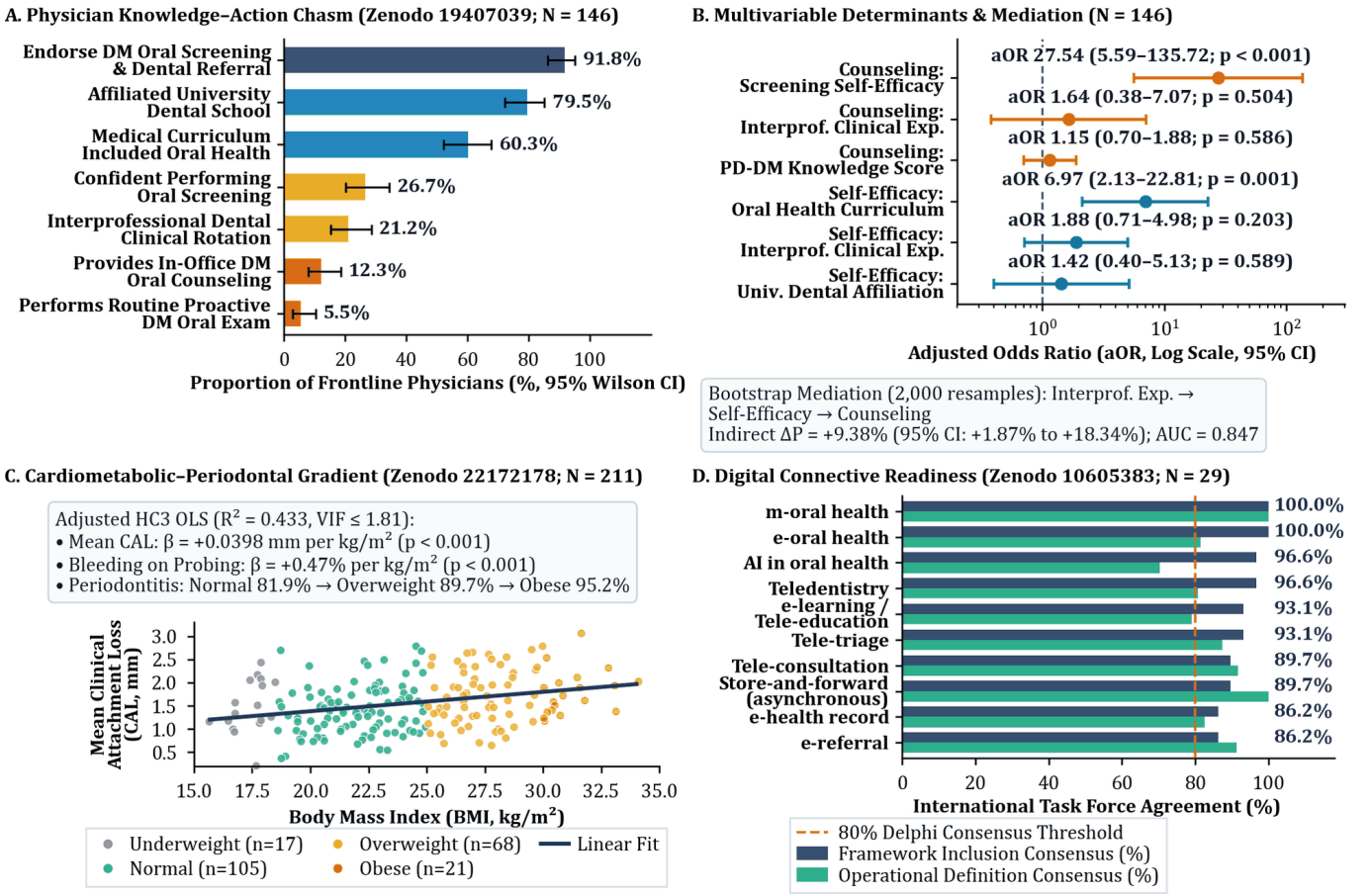


Figure 2. Multi-scale empirical results across meso-provider, micro-clinical, and digital e-oral health cohorts. (A) Frontline physician knowledge-to-action cascade in a transitional referral network (Zenodo 10.5281/zenodo.19407039; *n*=146) showing 95% Wilson confidence intervals. (B) Multivariable logistic regression forest plot (log scale) and 2,000-resample bootstrap mediation confirming screening self-efficacy as the decisive bridge between academic training and active diabetic oral health counseling. (C) Micro-clinical cardiometabolic gradient between body mass index (BMI) and mean clinical attachment loss (CAL) among adult outpatients (Zenodo 10.5281/zenodo.22172178; *n*=211; HC3 $p<0.001$). (D) International consensus readiness for digital connective modalities (Zenodo 10.5281/zenodo.10605383; *n*=29).

The authors mapped the reported barriers onto the five Pentahelix spheres; this mapping is interpretive, and the survey did not measure the spheres. These findings do not test single-pillar reform models. The most prevalent barrier was patients not mentioning dental symptoms during medical consultations (59.6%), which reflects low community oral-NCD health literacy and normalizing of gingival bleeding within Pillars 4 and 5, where asymptomatic periodontitis progresses silently until advanced tooth mobility occurs.[19,42] Physician uncertainty about what type of oral examination to perform ranked second (49.3%). This may point to didactic-only medical education that lacks hands-on interprofessional clinical assessment in Pillar 1.[29–31] Two barriers tied for third place at 31.5% each. These were the absence of formal institutional screening and referral guidelines (Pillar 2 regulatory stewardship failure) and the lack of interdisciplinary communication channels with dentists (Pillar 3 health-tech interoperability failure). Skepticism regarding scientific evidence (2.1%) or clinical necessity (0.7%) was virtually nonexistent. Translational readiness appeared high, with most frontline physicians requesting continuing oral-systemic education (94.5%), interprofessional collaboration (93.8%), formal incorporation of oral health specialists into diabetes management teams (93.8%), standardized referral guidelines (91.8%), and patient-facing educational media (87.7%).

3.4. Micro-clinical cardiometabolic–periodontal gradient and digital connective consensus

Analysis of Cohort C (Zenodo 10.5281/zenodo.22172178; *n*=211 adult outpatients in Nepal; mean age 41.19 ± 8.92 years; 47.9% female; mean BMI 24.27 ± 4.02 kg/m²)[36] described periodontal status in adults attending a dental outpatient clinic in Nepal; a clinic-attending sample does not allow population prevalence to be inferred (Table 3; Figure 2C). Overall clinical periodontitis prevalence reached 86.3% (95% CI: 81.0 to 90.3). Severe periodontal pocketing (CPI score 3) affected 45.0% (95% CI: 38.5 to 51.8). Overweight or obesity was present in 42.2% (95% CI: 35.7 to 48.9) of patients, 22.7% (95% CI: 17.6 to 28.9) belonged to low socioeconomic households, and 42.7% (95% CI: 36.2 to 49.4) practiced suboptimal toothbrushing (<2 times/day). Across BMI strata, periodontitis prevalence, irreversible attachment loss, pocket depth, and gingival bleeding rose from normal-weight to obese adults. Normal-weight adults had 81.9% periodontitis, Mean CAL 1.42 mm, Mean PPD 2.41 mm, and BOP 23.6%. Overweight adults had 89.7%, Mean CAL 1.70 mm, Mean PPD 2.60 mm, and BOP 26.5%. Obese adults had 95.2%, Mean CAL 1.79 mm, Mean PPD 2.90 mm, and BOP 28.7%. A multivariable HC3 OLS regression controlled for age, sex, socioeconomic status, brushing frequency, and local Plaque Index (R^2=0.433, adjusted R^2=0.416, all VIFs ≤ 1.81). In this model, higher BMI remained associated with greater attachment loss after adjustment for the Plaque Index of both Mean CAL (β=+0.0398 mm per kg/m², HC3 95% CI: +0.0235 to +0.0561, $p=2.86 \times 10^{-6}$) and active gingival bleeding (BOP β=+0.47% per kg/m², HC3 95% CI: +0.20 to +0.73, p<0.001). Chronological age (CAL β=+0.0286 mm/year, p<0.001) and plaque biofilm (CAL β=+0.3096 mm/unit, p=0.033, BOP β=+11.97%/unit, p<0.001) were also determinants. Multivariable logistic models showed a concordant directional elevation in clinical periodontitis (aOR 2.20, 95% CI: 0.90 to 5.35, p=0.082) and severe CPI-3 pocketing (aOR 1.68, 95% CI: 0.95 to 2.95, p=0.072) among overweight/obese adults.

Table 3. Micro-clinical multivariable HC3 regression of mean clinical attachment loss (CAL) on cardiometabolic and behavioral predictors among adult dental outpatients (*n*=211).

Predictor†	Mean CAL β (mm)	95% HC3 CI	*p*-value	Hypothesized interpretation (not measured in these data)
Body mass index (per 1 kg/m² increase)	+0.0398	+0.0235 to +0.0561	<0.001	Adipokine-mediated systemic TNF-α/IL-6 amplification (BOP β=+0.47%/kg/m², p<0.001)
Age (per 1 year increase)	+0.0286	+0.0197 to +0.0375	<0.001	Cumulative life-course alveolar connective-tissue attachment loss
Dental plaque index (per 1-unit score)	+0.3096	+0.0245 to +0.5946	0.033	Dysbiotic subgingival biofilm trigger (BOP β=+11.97%, p<0.001)
Low socioeconomic status (vs. Middle/High)	−0.1114	−0.2495 to +0.0267	0.113	Outpatient care-seeking selection; BOP significantly altered (p=0.046)
Male sex (vs. Female)	+0.0785	−0.0487 to +0.2057	0.225	Non-significant after controlling for plaque and BMI (all VIF ≤ 1.81)
Suboptimal brushing (<2/day vs. ≥2/day)	+0.0813	−0.0459 to +0.2085	0.209	Attenuated by clinical plaque index adjustment (Model R^2=0.433)

Data: adult dental outpatients, Bharatpur, Nepal (Gupta, Zenodo doi:10.5281/zenodo.22172178).[35] †Ordinary least squares regression with MacKinnon–White HC3 heteroskedasticity-consistent standard errors predicting Mean CAL (mm); R^2=0.433, adjusted R^2=0.416; maximum VIF=1.81. Abbreviations: BMI, body mass index; BOP, bleeding on probing; CAL, clinical attachment loss; CI, confidence interval; IL, interleukin; OLS, ordinary least squares; TNF, tumor necrosis factor; VIF, variance inflation factor.

Cohort D (Zenodo 10.5281/zenodo.10605383; *n*=29 international IADR e-Oral Health Task Force experts)[37,38] recorded that more than 85% of the 29 experts agreed that each of the ten modalities belongs within the e-oral health terminology framework; this reflects agreement on terms and definitions, not evidence of feasibility, effectiveness or low-bandwidth performance in primary care (Table 4; Figure 2D). Agreement for m-oral health was unanimous at 100.0%. This held for framework inclusion (95% CI: 88.3 to 100.0) and for operational definition (95% CI: 87.5 to 100.0). E-oral health followed, with 100.0% inclusion for the framework. Teledentistry reached 96.6% (95% CI: 82.8 to 99.4), as did artificial intelligence triage tools (96.6%). Tele-triage reached 93.1% (95% CI: 78.0 to 98.1), and e-learning/tele-education for continuing provider training reached 93.1% as well. Asynchronous store-and-forward clinical photography/radiography

scored 89.7% for inclusion and 100.0% for definition consensus, while synchronous tele-consultation scored 89.7%. Structured bidirectional e-referral obtained 86.2% for inclusion and 91.3% for definition consensus. Interoperable e-health records obtained 86.2% as well. Dentists are scarce in many LMIC districts (median 0.99 dentists per 10,000 in Cohort A). There, smartphone-based m-oral health literacy and asynchronous store-and-forward tele-triage, paired with closed-loop e-referral, allow primary-care physicians and nurses to risk-stratify diabetic and obese patients without placing an on-site dental chair in every rural outpost.[39,40,43,44]

Table 4. Pentahelix policy framework matrix with baseline gaps from Cohorts A and B and digital consensus benchmarks from Cohort D (*n*=29).

Pentahelix helix‡	Baseline Gap§	Digital Enabler‖	5-Yr Policy KPI¶	Institutional Academic–Primary Care Partnership Lever
Helix 1: Academia (Dental & Medical Schools)	POSII P1: 37.46; IPE: 21.2%	e-Learning: 93.1% (78.0 to 98.1)	100% IPE & OSCE mandate	Co-designed 2-minute diabetic/CVD oral exam OSCE & district PHC clinical clerkships
Helix 2: Government (MoH & UHC Payer)	No guidelines: 31.5%; OOP: 35.9%	e-Health record: 86.2% (69.4 to 94.5)	PHC screening ≥89.9%	Joint MoH Oral–NCD directorate, capitation cross-referral KPI, UHC scaling/ART tier
Helix 3: Primary Care & Health-Tech Industry	Routine exam: 5.5%; 0.99 dent/10k	e-Referral: 86.2%; Tele-triage: 93.1%	≥60% closed-loop referral	Bidirectional NCD–dental e-referral, asynchronous store-and-forward (89.7%), SDF/ART kits
Helix 4: Civil Society & Community Networks	Patient silence: 59.6%	Tele-consult: 89.7% (73.6 to 96.4)	OOP share <20% of CHE	Community health worker (*kader*) oral-NCD literacy & diabetic peer-navigation clubs
Helix 5: Media & Digital Info-Ecosystem	P5 score: 41.09; Edu demand: 87.7%	m-Oral health: 100.0% (88.3 to 100.0)	≥80% public awareness	Culturally tailored m-oral health reminders, sugar/tobacco counter-marketing, anti-stigma media

‡Operational policy matrix synthesized across Cohorts A–D. §Empirical baseline bottlenecks observed in Cohort A (*n*=129 transitional countries) and Cohort B (*n*=146 physicians). ‖Proportion of international Delphi experts endorsing framework inclusion (with 95% Wilson CI) in Cohort D (Uribe, Scheerman & Mariño, Zenodo doi:10.5281/zenodo.10605383; *n*=29 IADR Task Force panelists); the agreement concerns terminology, not feasibility.[36,37] ¶Counterfactual target anchored to Scenario S4 (balanced +25-point Pentahelix reform across transitional systems; illustrative simulation). Abbreviations: ART, atraumatic restorative treatment; CHE, current health expenditure; CVD, cardiovascular disease; IPE, interprofessional education; KPI, key performance indicator; MoH, Ministry of Health; NCD, non-communicable disease; OOP, out-of-pocket; OSCE, objective structured clinical examination; PHC, primary health care; POSII, Pentahelix Oral-Systemic Integration Index; SDF, silver diamine fluoride; UHC, universal health coverage.

4. Discussion

4.1. Pathobiological plausibility: the bidirectional periodontal–cardiometabolic inflammatory loop

From a dental science and clinical pathobiology standpoint, the convergent signals across Cohorts A, B, and C show why isolating oral care from NCD primary care sustains a self-amplifying inflammatory feedback loop. Our micro-clinical analysis found that each 5 kg/m² increment in BMI added ~0.20 mm of mean clinical attachment loss and ~2.35 percentage points of gingival bleeding, after adjustment for the Plaque Index. This may be compatible with mechanistic evidence on adipose biology, in which hypertrophic visceral adipocytes are proposed to secrete pro-inflammatory adipokines (TNF-alpha, IL-6, resistin, visfatin) and reactive oxygen species. These hyper-prime polymorphonuclear neutrophils within the gingival crevice.[12,16] Primed neutrophils release excess matrix metalloproteinases (MMP-8, MMP-9) and receptor activator of nuclear factor-kappa B ligand (RANKL). Collagenous periodontal ligament degradation and osteoclastic alveolar crest resorption then accelerate, even under moderate microbial challenge.[10,14] Ulcerated periodontal pockets (CPI ≥2–3) were observed in 86.3% of Cohort C outpatients. Once such pockets form, persistent hematogenous dissemination of Gram-negative endotoxins feeds back into systemic insulin resistance, glycemic instability, and atherogenesis.[11,13,14] Breaking this loop does not need costly surgical infrastructure in resource-constrained PHC clinics. Several low-cost options exist for these clinics. Chairside non-surgical periodontal debridement, silver diamine fluoride (SDF) caries arrest, atraumatic restorative treatment (ART), and targeted behavioral biofilm control are low-cost adjuncts that suit PHC clinics; among them, only non-surgical periodontal therapy has evidence of lowering HbA1c (ref 15), and the effect of the others on systemic markers is not established.[8,15,45–47]

4.2. A staged Pentahelix policy framework for academic–primary care partnerships in transitional health systems

Synthesizing our empirical findings across all four datasets yields a three-phase Pentahelix Policy Framework anchored by academic–primary care partnerships (Table 4). The first step concerns Helix 1 (Academia). Medical, nursing, and dental faculties should dismantle segregated pre-service silos, because passive campus co-location with a dental school failed to build physician screening confidence (aOR 1.42; p=0.589). Curricular integration performed better in this respect: it was associated with higher odds of screening self-efficacy (aOR 6.97), and self-efficacy was in turn associated with active counseling (aOR 27.54). The curriculum itself was not independently associated with counseling (aOR 0.43, 95% CI 0.08 to 2.39).[29–31] Universities should consider competency-based IPE modules that train medical and family-practice trainees in a standardized two-minute non-mirror intraoral risk check (assessing gingival bleeding, tooth mobility, purulence, mucosal lesions, and self-reported pain), verified via Objective Structured Clinical Examinations (OSCEs). Joint longitudinal clerkships in district PHC centers should accompany these modules. Suitable sites include Indonesian *Puskesmas*, Ghanaian Community-Based Health Planning and Services zones, and Nepalese municipal health posts.[33,40]

The second step concerns Helix 2 (Government Regulators and UHC Payers). Ministries must convert symbolic NCD staffing, present in 71.3% of transitional systems, into operational clinical governance and financial protection.[18,21,48] National diabetes and cardiovascular clinical practice guidelines should mandate annual periodontal risk screening and bidirectional referral. This would directly resolve the 31.5% guideline vacuum identified in Cohort B. National social health insurers should reform PHC capitation formulas to include a quality-linked oral-NCD cross-referral indicator, and they should reimburse basic preventive periodontal therapy, fluoride varnish, SDF, and ART so that households are shielded from the 35.92% OOP financing burden documented in Cohort A.[23,26,45] The third step concerns Helix 3 (Primary Care Delivery and Health-Tech Industry). Co-designed health-information vendors and public IT agencies should embed lightweight e-referral triggers (86.2% Delphi consensus) and asynchronous store-and-forward smartphone intraoral triage (89.7% consensus) directly into chronic-disease registries. Doing so would eliminate the 31.5% interdisciplinary communication barrier between physicians and district dentists.[38–40,43,44]

The fourth step concerns Helix 4 (Civil Society and Community Networks). Patient silence regarding oral symptoms during diabetes visits (59.6% in Cohort B) was the single largest frontline barrier. Overcoming it requires empowering community health workers (CHWs / *Posbindu PTM kader*), diabetes peer-support associations, and local civil organizations to administer validated self-reported periodontal screening questionnaires and to navigate low-income patients toward subsidized PHC dental slots.[20,32,42,49] The fifth step addresses Helix 5 (Media and Digital Information Ecosystem). Public broadcasters, local journalists, and telecom platforms should partner with academic faculties to deploy culturally adapted m-oral health messaging (100.0% Delphi consensus; demanded by 87.7% of Cohort B physicians), and such messaging would de-normalize bleeding gums and expose bidirectional diabetes–gum links. It would counter aggressive commercial marketing of cariogenic ultra-processed sugars, tobacco, and areca nut products across transitional markets.[42,48] The strategy unfolds over a five-year horizon. Phase I (Months 1–12) covers a ministerial joint desk, OSCE curriculum reform, and a paper/electronic diabetes oral-triage checklist. Phase II (Months 13–36) covers interoperable e-referral, UHC preventive periodontal reimbursement, and CHW and m-oral health rollout. Phase III (Months 37–60, Years 4–5) covers national scale-up, audited via POSII dashboards. This synchronized strategy is proposed as a pathway toward higher PHC oral screening; the 89.9% figure is the output of an illustrative simulation and not a validated target.

4.3. Health financing alignment, capitation governance, and equity protection in transitional UHC reforms

A key health-policy insight from our cross-national and clinical synthesis is that interprofessional education and digital referral architectures cannot sustain behavior change when the underlying health-purchasing mechanisms actively penalize preventive integration.[18,23,26] Public PHC clinics across most LMIC transitional systems receive flat, unadjusted per-capita capitation transfers. These pool medical and basic dental budgets without ring-fenced incentives for chronic disease co-management. Hospital and private dental providers operate under fee-for-service tariffs skewed toward late-stage prosthetic or surgical procedures.[7,23,34,50] The incentive problem is easy to see. Under unadjusted capitation, a diabetic periodontal assessment or chairside subgingival scaling consumes scarce clinician minutes and consumable supplies without incremental facility reimbursement, which creates rational economic inertia toward passive non-screening or symptomatic extraction. Referral brings a second, separate problem for patients. When diabetic or hypertensive patients are sent outside public PHC clinics without benefit-package portability, regressive OOP co-payments average 35.92% of current health expenditure across our 129 transitional economies and 42.90% in Low-Income states, and these payments induce high referral drop-out and deepen socioeconomic health inequities in accordance with the inverse care law.[19,25,26] Aligning purchasing incentives under the Pentahelix framework therefore calls for blended payment reform. One element is risk-adjusted PHC capitation, paired with explicit pay-for-coordination micro-incentives tied to documented closed-loop oral–NCD e-referrals. The other is zero-copayment UHC entitlement for annual periodontal debridement among registered diabetes and cardiovascular patients. Hypothecated excise taxes on sugar-sweetened beverages, tobacco, and areca nut products could partially self-finance this investment.[17,42,46,51]

Sustainable academic–primary care partnerships further require formalized bilateral governance compacts. The parties would be ministries of health, ministries of higher education, district health offices, and professional medical–dental councils.[29,32,33] Historically, academic dental hospitals in transitional economies reward faculty mainly for specialized tertiary procedures and laboratory publications, and community-oriented primary-care implementation receives far less credit there, a pattern reflected in the low Pillar 1 translational score (37.46 ± 16.74) documented in Cohort A. The proposed remedy is both straightforward and feasible. We suggest accredited 'Academic Primary Care Oral-Systemic Teaching Hubs' within district health networks. Dental residents, family-medicine trainees, primary-care nurses, and CHWs would co-manage shared panels of diabetic, obese, and hypertensive patients there. Rural service capacity would grow in dentist-scarce districts (median 0.99 per 10,000). The hubs would also generate continuous real-world implementation data embedded within national health information platforms.[24,33,39] Joint accreditation standards across medical and dental licensing boards would let transitional nations ensure that every graduating primary-care physician possesses verified diagnostic self-efficacy, which was the factor most strongly associated with active counseling in Cohort B (aOR 27.54, 95% CI 5.59 to 135.72).

4.4. Methodological strengths, epidemiological surveillance nuances, and study limitations

A principal strength of this investigation is its transparent, fully reproducible triangulation of four open-access global, provider, patient, and expert-consensus datasets. This design allowed macro-policy architecture, meso-clinician mediation, and micro-pathobiological gradients to be tested together, without relying on proprietary or unverified survey estimates. Limitations remain, and they need careful interpretation. First, all four component cohorts employ cross-sectional observational designs. Definitive causal inference regarding longitudinal trajectories is therefore precluded. Bootstrap mediation and age- and GDP-adjusted HC3 regressions do not establish causal pathways, but they cannot replace temporal data, so quasi-experimental stepped-wedge cluster trials or longitudinal panel evaluations are still needed as subsequent WHO Global Oral Health Action Plan

monitoring waves become available between 2026 and 2030.[9,45] Second, Cohorts B and C derive from single-institution academic-referral catchments in Ghana and Nepal, respectively. Both represent prototypical Lower-Middle-Income transitional health systems characterized by high NCD multimorbidity and constrained dental workforce ratios, yet external generalizability to rural non-teaching health posts still requires multi-country primary-care network validation. Third, Cohort C had no biochemical assays. HbA1c and serum C-reactive protein were not measured alongside BMI. Further limitations are that the index shares income-related components with the income strata it is compared across, that Cohorts B and C come from different countries and are not linked to the national scores, that physician outcomes are self-reported with only 18 counseling events, that Cohort C comprises clinic attenders, that Pillar 3 contains the component that is the outcome of the screening model, that Cohort D concerns terminology, and that no multiplicity adjustment was applied. Cross-national WHO caries estimates also remain sensitive to differential diagnostic surveillance intensity across income tiers. Future implementation research should embed prospective trials of Academic–PHC Pentahelix hubs. These trials would track two clinical endpoints (glycemic HbA1c reduction and periodontal pocket closure) alongside household catastrophic expenditure incidence.

5. Conclusion

Ministerial directives and didactic biomedical awareness alone cannot bridge this divide. The historical separation of oral healthcare from general medicine persists in transitional health systems. Across 129 transitional economies, the academic pillar had the lowest mean score among the five pillars in transitional systems. At the clinical frontline, physician awareness in theory does not become diabetic oral counseling or referral unless it is operationalized through competency-building interprofessional education and screening self-efficacy, and a higher BMI was independently associated with greater attachment loss after adjustment for the Plaque Index. A synchronized Pentahelix policy framework offers an equity-oriented blueprint. That blueprint is proposed as scalable and may help advance universal oral-systemic health by 2030, centered on co-located academic–primary care partnerships, supported by UHC preventive financing, closed-loop digital e-referral, community health-worker navigation, and m-oral health media literacy.

Declarations

Declaration of generative AI and AI-assisted technologies in the writing process

The authors confirm that no generative artificial intelligence (AI) tools were used at any stage of preparing this manuscript.

Author contributions (CRediT)

Z.D.: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft. R.H.: Conceptualization, Supervision, Validation, Data curation, Writing – review & editing. M.A.: Investigation, Visualization, Project administration, Writing – review & editing. All authors reviewed and approved the final version of the manuscript.

Conflict of interest

The authors declare no commercial, financial, or institutional conflicts of interest.

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Ethical approval and informed consent

This study analyzed only publicly archived, fully de-identified indicators and open-access datasets, each of which obtained ethics approval and informed consent in its primary collection protocol. The study qualified for institutional ethical exemption.

Consent for publication

Not applicable; no identifiable individual data are reported.

Data availability

All datasets analyzed in this study are openly accessible: Cohort A was harmonized from the WHO Global Health Observatory (ghoapi.azureedge.net/api), World Bank Open Data (api.worldbank.org/v2) and OpenAlex (api.openalex.org); Cohort B, Cohort C and Cohort D are archived at Zenodo

(doi:10.5281/zenodo.19407039, doi:10.5281/zenodo.22172178 and doi:10.5281/zenodo.10605383). The harmonized CSV files and analytical Python scripts are archived in the accompanying replication repository.

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