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Trends in nuclear medicine service utilization at a tertiary hospital in Northwest China from 2019 to 2025: an interrupted time series analysis

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Abstract

Background: Most COVID-19 evidence concerns mature nuclear medicine services. We quantified the pandemic and reopening effects on a young, rapidly growing department in Northwest China, including the divergent recovery of diagnostic versus radioiodine (^{131}I) therapy services.

Methods: We extracted all valid nuclear medicine encounters at one tertiary hospital in Ningxia, April 2019–May 2025. Monthly counts were analyzed by segmented interrupted time series (ITS) regression with Newey–West robust standard errors, intervention points at February 2020 and January 2023 (the first full month after the December 2022 reopening), a September–November 2022 outbreak pulse, annual seasonal terms, and a Lunar New Year (CNY) indicator. ^{131}I counts from ward opening (March 2020) were modeled with Poisson and negative-binomial regression; a capacity-capped logistic counterfactual estimated forgone utilization.

Results: Of 11,831 encounters (9,033 patients), pre-pandemic volume grew 18.75/month (95% CI 15.33–22.16; P<0.0001). February 2020 reduced the slope by −16.69/month (95% CI −20.67 to −12.70; P<0.0001); the level term was not separately identifiable (−25.76; P=0.134) because it is collinear with the slope break, whereas the joint immediate effect (−42.45; 95% CI −76.52 to −8.37; P=0.015) and an explicit single-month February-2020 pulse (−101.80; P<0.0001) both indicated a large one-month collapse (observed 43 vs fitted 129.5). The 2022 pulse (−95.09; P<0.0001) and CNY (−73.90; P<0.0001) were large, whereas reopening showed no jump (−20.08; P=0.198) or slope change (−0.10; P=0.898). Adjusted ^{131}I activity fell after reopening (Poisson IRR 0.473; 95% CI 0.285–0.786; P=0.004; monthly mean 5.24 to 3.66), although the magnitude was sensitive to how the January 2023 infection wave was handled (IRR 0.40–0.68, with loss of

significance when the post period began in April 2023). In capacity-bounded scenarios the cumulative deficit was 2,833–4,682 encounters, with the monthly gap closed by early 2025.

Conclusions: The pandemic arrested a young service's growth rather than causing a persistent absolute-volume decline; recovery was heterogeneous, with elective ^{131}I therapy depressed while bone and inpatient services stabilized. Slope-based monitoring, therapy recall, and bed- and supply-contingency planning may aid recovery after systemic shocks.

Trial registration: Not applicable (retrospective observational study of administrative records).

Keywords: nuclear medicine; health services research; interrupted time series; COVID-19; service utilization; resilience; China

1. Background

The Coronavirus Disease 2019 (COVID-19) pandemic produced widespread disruption to essential health services; World Health Organization global pulse surveys documented pervasive reductions, with outpatient, routine, and elective services most affected [1]. Nuclear medicine departments were structurally vulnerable: time-sensitive examinations depend on short-lived radiopharmaceuticals from a concentrated supply base [2], and services combine outpatient imaging with inpatient therapies requiring shielded beds and multi-day admission; older patients with comorbidity, who are at greater risk of severe disease [3], may also defer non-urgent testing.

First-year studies showed large declines in nuclear medicine and cardiac imaging. The International Atomic Energy Agency's (IAEA) April 2020 survey of 256 departments found that 71% reported reduced diagnostic and 66% reduced therapeutic procedures [4], and its follow-up survey documented incomplete, geographically heterogeneous recovery [5]; recovery of cardiac testing likewise varied worldwide [6]. Single-center analyses, including the AHEPA Hospital in Greece, reported sharp category-specific reductions—technetium-

99m thyroid imaging fell 77.5% by 2021, lung-perfusion imaging rose about 71%, and overall flow had not recovered by 2023 [7]; a UK national survey corroborated modality-specific reductions [8]. We searched PubMed (last search 28 October 2026) combining "nuclear medicine", "interrupted time series" and "COVID-19" and identified no Chinese single-centre nuclear medicine ITS study; nationwide analyses nonetheless documented the wider national context: at the February 2020 nadir, all-cause visits and admissions fell by 10–71% depending on facility type and indicator, with cumulative losses of about 1,020 million visits and 28.9 million admissions by June 2020 [9]; over a longer horizon the visit-level impact attenuated and eventually disappeared, yet residual effects on bed-utilization rate, length of stay, and inpatient and outpatient costs persisted two years later, with uneven recovery across facility levels [10]. This evidence mostly concerns mature, near-steady-state departments with an immediate level drop and partial rebound [4,5–8]; less is known about how a young, rapidly growing department absorbed the shock and reopening.

China's distinct control phases—the early-2020 emergency response, dynamic-zero containment through 2020–2022, the autumn-2022 Ningxia outbreak, and the December 2022 reopening followed by the January 2023 infection wave—provide well-defined intervention points; radiology procedure-volume data likewise showed immediate reductions followed by recovery [11], and delayed oncologic care was linked to adverse outcomes in a systematic review [12]. Ningxia saw limited community transmission but two hospital-level disruptions (February 2020; September–November 2022), and the department depends on centralized ^{131}I-bed capacity and non-local radiopharmaceutical supply.

Our objectives were to (1) quantify monthly utilization from April 2019 through May 2025; (2) estimate level and slope impacts of the early pandemic, the 2022 outbreak, and the December 2022 reopening by segmented ITS; and (3) identify categories and patient types with divergent post-reopening trajectories, particularly ^{131}I therapy-related care.

2. Methods

2.1 Study design and setting

This retrospective, single-center study used ITS analysis of monthly nuclear medicine counts at the nuclear medicine department of People's Hospital of Ningxia Hui Autonomous Region, a teaching and regional-referral hospital in Yinchuan, Ningxia Hui Autonomous Region, Northwest China. The department opened in July 2019 with one SPECT/CT; an eight-bed shielded ^{131}I ward opened in March 2020; PET/CT was added in December 2024; and a second SPECT/CT in April 2025. The workforce grew from 6 staff (3 physicians, 2 technologists, 1 nurse) in 2019 to 15 (7, 4, 4) in 2023–2025.

The ledger begins in April 2019. The 19 encounters in April–June 2019 (13, 5, and 1), before the documented opening, were identifiable as installation, commissioning, and quality-control scans (including test and staff entries); they were retained in the primary analysis and excluded in sensitivity model M5.

2.2 Data source and outcome definition

De-identified records were extracted from the Hospital Information System (HIS), the radiology information/picture-archiving system, and monthly operational reports for April 2019–May 2025 (74 months); after exclusion of duplicate, cancelled, and invalid records identified by quality-control review, 11,831 valid encounters remained. The primary outcome was the monthly count of completed nuclear medicine encounters, defined operationally as one closed-loop record (order–acquisition–report) for a completed examination or therapy episode; repeat entries for the same patient, date, and examination were counted once, whereas distinct examinations on the same day were counted separately. Encounters included SPECT/CT and PET/CT imaging, radionuclide therapies, and uptake measurements. Because the ledger records encounters rather than person-time, population-based rates could not be computed and counts are analyzed as absolute volumes. Secondary outcomes were monthly

counts stratified by service category, modality, and inpatient/outpatient status. Annual counts were 538 (partial 2019), 1,523 (2020), 2,094 (2021), 1,804 (2022), 2,235 (2023), 2,506 (2024), and 1,131 (January–May 2025).

"^{131}I therapy-related encounters" is an aggregate category combining ward-based therapy administration with pre-therapy assessment and post-therapy whole-body scans; it totaled 283 in the category ledger (2020–2025), and the monthly count series—which includes one additional February 2025 post-therapy scan without a category code—totaled 284. The source system does not permit separating administration from therapy-associated imaging.

2.3 Study periods and intervention points

Intervention points were defined a priori from national and local policy records: baseline April 2019–January 2020; early-pandemic interruption from late January 2020 (Level-1 response, 23–25 January, with traffic restrictions and reduced outpatient access), modelled from February 2020, the first full month of interruption; dynamic-zero period March 2020–August 2022; a September–November 2022 local-outbreak pulse (outpatient suspension 22 September–8 October, ward closure, urgent-case transfer, graded resumption from 10 October); reopening on 7 December 2022 ("New Ten Measures"), followed by the January 2023 infection wave; December 2022 was treated as a transition month (partial-month exposure immediately before the wave), and the post-reopening period was defined a priori as January 2023–May 2025 (29 months; Table 2). The October 2021 46-day imported-case controls involved no full ward closure and were not modeled. Because the 2022 event was asymmetric, it was coded primarily as a three-month pulse and, in sensitivity analyses, as separate monthly and October–November indicators.

2.4 Statistical analysis

2.4.1 Segmented regression for total and stratified volumes

Monthly counts were analyzed with segmented linear regression, the standard ITS approach for population-level interventions [13]:

$$Y_t = \beta_0 + \beta_1 \cdot time_t + \beta_2 \cdot COVID_t + \beta_3 \cdot time_after_COVID_t + \beta_4 \cdot Pulse2022_t + \beta_5 \cdot Post_t + \beta_6 \cdot time_after_Post_t + \beta_7 \cdot \sin(2\pi t/12) + \beta_8 \cdot \cos(2\pi t/12) + \beta_9 \cdot CNY_t + \varepsilon_t$$

where *time_t* is a continuous month index; *COVID_t* and *Post_t* indicate February 2020 and January 2023 onward; *time_after_COVID_t* and *time_after_Post_t* count months thereafter; *Pulse2022_t* equals 1 for September–November 2022; sine/cosine terms capture annual seasonality; and *CNY_t* marks the Lunar New Year month—a recurring 1–2-week trough (the 2020 CNY, 25 January, immediately preceded the first intervention month). A separate March indicator was tested for the annual Two Sessions period and was not retained, because its coefficient was positive rather than negative (Results). Coefficients of interest were the baseline slope (β_1), the February-2020 level and slope changes (β_2, β_3), the pulse (β_4), and the reopening level and slope changes (β_5, β_6), reported as absolute count changes with Newey–West HAC 95% CIs and two-sided *P* values [14]; the truncation lag was set a priori at six over 74 observations, and all models were re-estimated at lags 3, 4, and 12. The same specification was fitted for outpatient, inpatient, bone, non-bone, and no-PET/CT series.

2.4.2 Segmented count models for ^{131}I activity

Because monthly ^{131}I counts were sparse and the ward opened in March 2020, ^{131}I was analyzed separately over March 2020–May 2025 (63 months) with a log-link segmented count model containing the reopening level/slope terms and the pulse and CNY indicators: Poisson (primary) and negative-binomial NB2 (overdispersion sensitivity), with incidence-rate ratios (IRRs). Because the post-reopening level term is anchored on the January 2023 infection wave, four specifications were compared: the primary model; a model adding a January–March 2023 wave indicator; a model excluding January–March 2023; and models

shifting the post-period start to April 2023 or to December 2022. Residual autocorrelation was assessed with the Ljung–Box test, and HAC standard errors were computed as a robustness check.

2.4.3 Capacity-capped counterfactual

Unconstrained linear extrapolation of the start-up slope was implausible (it exceeded 1,100 examinations/month by May 2025). Counterfactual utilization was therefore a three-parameter logistic saturation curve fitted to the ten pre-pandemic months, $CF(t) = K / (1 + \exp(-(a + b \cdot t)))$, with the capacity asymptote K treated as a scenario parameter at 230, 250, and 264/month (the last equal to the observed post-pandemic maximum, attained after the second SPECT/CT was installed); monthly gaps and cumulative deficits (counterfactual minus observed) were computed over February 2020–May 2025 and are reported as a scenario range, not as a confidence interval. The K=230 scenario is internally inconsistent with later observations (247 encounters in May 2025 exceed that ceiling), indicating that the lowest scenario overstates the deficit.

2.4.4 Sensitivity analyses and software

Eight specifications were assessed: M1 (primary, with CNY); M2 (pulse split into September/October/November indicators); M3 (October–November pulse); M4 (reopening lagged one month); M5 (excluding the April–June 2019 commissioning scans, which at monthly resolution is equivalent to restricting the baseline to July 2019 onward); M6 (explicit single-month February-2020 pulse); M7 (March/Two Sessions indicator); and M8 (break moved to January 2020). A quadratic time term ($time^2$) was additionally fitted to test whether growth was already decelerating before the pandemic. Analyses used Python 3.13.15 with statsmodels 0.14.6 (OLS with HAC covariance and Poisson/negative-binomial GLM), pandas 3.0.5, NumPy 2.4.6, and SciPy 1.18.0; significance was P<0.05. The aggregated monthly data and the analysis script are provided as Additional files 2 and 3.

2.5 Ethical approval and reporting

The study used retrospective, fully de-identified records generated during routine care and was approved by the institutional ethics committee of People's Hospital of Ningxia Hui Autonomous Region (approval no. 2025-NZR-191). The committee waived the requirement for informed consent because no identifiable personal or clinical information was analyzed and no intervention or contact with patients occurred. Reporting follows the STROBE statement for observational studies [15], and the completed checklist is provided as Additional file 1.

3. Results

3.1 Utilization, service mix, and patient characteristics

The department completed 11,831 encounters among 9,033 patients (≈1.31 encounters per patient, reflecting repeated oncologic follow-up). Females accounted for 6,381 encounters (53.9%), males 5,421 (45.8%), and sex was unrecorded in 29 (0.2%; 24 missing, 5 coded "unknown"); mean age was 57.5±15.2 years. Inpatients contributed 8,897 encounters (75.2%), outpatients 2,624 (22.2%), and 310 (2.6%) were unclassified. Bone scintigraphy dominated (7,649; 64.7%), followed by renal (1,000), thyroid (905), other (622), myocardial perfusion (408), and parathyroid (297) imaging (Table 1). Nineteen valid encounters lacked a category code (1 in 2024; 18 in January–May 2025, principally unmapped PET/CT records).

Annual volume rose from 538 (partial 2019) to 2,506 (2024), with 2020–2024 compound annual growth of 13.3%; volumes were 2,235 in 2023 (+23.9%) and 2,506 in 2024 (+12.1%), with 1,131 in January–May 2025. Mean monthly volume was 61.2 at baseline (10 months), 153.3 during the pandemic (February 2020–November 2022; 34 months), and 200.2 from December 2022 onward (30 months, including the December 2022 transition month; the three non-overlapping periods sum to the 74 analysed months). The lowest count after

January 2020 was 41 (January 2023), the lowest count of 2022 was 55 (October 2022), and the maximum was 264 (April 2025) (Figure 1).

3.2 Early-pandemic impact

Volume was 74 in January 2020, fell to 43 in February (−41.9%), and rebounded to 117 in March. The baseline slope was +18.75 examinations/month (95% CI 15.33–22.16; $P<0.0001$). The February-2020 level term was −25.76 (95% CI −59.49 to 7.97; $P=0.134$) and the slope change was −16.69/month (95% CI −20.67 to −12.70; $P<0.0001$), leaving an approximately flat early-pandemic trajectory (composite slope ≈ +2.1/month; $P=0.28$). The null level term does not imply an absence of impact: the model fitted 129.5 encounters for February 2020 against 43 observed (residual −86.5), and because the level and slope terms are collinear at the break, the single-month drop is not separately identifiable in this specification. The joint immediate effect ($\beta_2+\beta_3$) was −42.45 (95% CI −76.52 to −8.37; $P=0.015$), and an explicit single-month February-2020 pulse (M6) was −101.80 ($P<0.0001$), with the slope change attenuating to −17.06/month. A quadratic time term was negative and significant (time² −0.145; 95% CI −0.24 to −0.05; $P=0.002$), indicating that growth was already decelerating before the pandemic. The CNY month reduced volume by −73.90 (95% CI −104.32 to −43.47; $P<0.0001$); the cosine term was significant (−12.89; $P=0.012$) and the sine term was not (7.01; $P=0.242$). A March/Two Sessions indicator was positive (+26.50; $P=0.005$), providing no evidence of a March-level supply interruption.

3.3 September–November 2022 local outbreak

Volume fell from 142 (September) to 55 (October) and 71 (November)—the lowest counts of 2022—before recovering to 134 in December. The combined pulse was −95.09/month (95% CI −122.28 to −67.89; $P<0.0001$; Table 3). Monthly pulse indicators (M2, $R^2=0.791$) matched the operational timeline: −44.77 in September ($P<0.001$), −128.96 in October ($P<0.0001$), and −113.48 in November ($P<0.0001$), corresponding to entry

controls/outpatient suspension, the full ward closure, and graded resumption. The inpatient pulse reduction (−72.25/month; $P<0.0001$) exceeded the outpatient one (−21.63/month; $P<0.001$).

3.4 Reopening and post-2023 trajectory

Volume was 134 in December 2022 (transition month), dropped to 41 in January 2023—the lowest count of the whole series after January 2020—during the national infection wave, then recovered to 249 (February) and 232 (March). Both post-reopening effects were non-significant—level −20.08 (95% CI −50.65 to 10.49; $P=0.198$), slope change −0.10 (95% CI −1.65 to 1.45; $P=0.898$)—with a post-reopening composite slope of ≈ +2.0/month: reopening produced neither a jump nor a return to the pre-2020 growth rate (Figure 2). Lagging the post period by one month (M4) gave an essentially null level effect (−0.04; $P=0.999$). High-priority services normalized quickly, however: bone scintigraphy averaged 67.3/month in the disrupted fourth quarter of 2022 versus 128.7/month in the first quarter of 2023, and inpatient volume rose from 67.0 to 126.3/month over the same interval.

3.5 Stratified trajectories

The pandemic-era slope reduction was pervasive—outpatient −2.48/month, inpatient −14.31, bone −11.25, non-bone −5.44 (all $P<0.0001$)—and the pulse affected every stratum (Table 4). Post-reopening trajectories diverged: bone scintigraphy showed no significant reopening level change (+8.12; $P=0.378$) and a small negative slope change (−1.00; $P=0.043$), consistent with stabilization near capacity; non-bone services had a negative level change (−28.21; 95% CI −44.56 to −11.85; $P=0.001$) but a positive slope change (+0.90; 95% CI 0.04–1.76; $P=0.039$), indicating gradual restoration; outpatient and inpatient reopening levels were non-significant ($P=0.226$, 0.181) with flat slopes ($P=0.072$, 0.743). Excluding PET/CT left the total coefficients essentially unchanged(Table 4, last row). Descriptively, thyroid imaging fell from 235 (2021) to 82 (2024; 31 in January–May 2025),

pulmonary perfusion/ventilation rose from 16 (2020) to 61 (2024; 54 in January–May 2025), and PET/CT added 21 examinations in its launch month and 146 in January–May 2025—added capacity rather than recovered demand (Figure 3).

3.6 ^{131}I therapy-related activity: count-model analysis

Diagnostic thyroid imaging (905 examinations; outpatient, partly substitutable in the thyroid work-up) and ^{131}I therapy (an eight-bed, multi-day inpatient ward existing only since March 2020) were analyzed separately. In the Poisson model over March 2020–May 2025, pre-reopening activity rose slightly (IRR 1.024/month; 95% CI 1.002–1.046; P=0.029), but the post-reopening level fell to IRR 0.473 (95% CI 0.285–0.786; P=0.004)—about 53% lower—without a detectable recovery slope (IRR 0.973/month; P=0.066). Mean monthly activity fell from 5.24 to 3.66. The pulse (IRR 0.158; P<0.0001) and CNY (IRR 0.248; P=0.0002) produced large proportional reductions. The NB2 model was consistent (reopening IRR 0.448; 95% CI 0.243–0.828; P=0.010; slope IRR 0.972; P=0.104), with weak overdispersion evidence (P≈0.09). The magnitude of the reduction, however, depended on how the January 2023 infection wave was handled (Table 5): adding a January–March 2023 wave indicator moved the post-level IRR to 0.556 (95% CI 0.324–0.956; P=0.034; wave IRR 0.555); excluding January–March 2023 gave 0.540 (95% CI 0.332–0.877; P=0.013); starting the post period in April 2023 gave 0.675 (95% CI 0.415–1.097; P=0.112); and starting it in December 2022 gave 0.399 (95% CI 0.243–0.654; P<0.001). Across specifications the reduction therefore ranged from about 32% to 60% and lost significance when the wave months were removed from the post period. Residual autocorrelation was negligible (Ljung–Box Q=3.37, P=0.339 at lag 3; Q=4.06, P=0.668 at lag 6), and HAC standard errors left the post-level reduction significant (P<0.001). We therefore interpret the ^{131}I decline as a persistent but quantitatively uncertain reduction rather than a precisely estimated halving; its mechanism—de-intensification of low-risk differentiated thyroid cancer, referral diversion, or

bed-scheduling constraints—cannot be determined from aggregate data and is treated as hypothesis.

3.7 Sensitivity analyses

Findings were stable across the eight specifications (Table 3, Table 5, Table 6). The split-pulse (M2, R^2=0.791) and October–November (M3, pulse −115.74; R^2=0.785) codings confirmed the event with better fit, while post-reopening terms stayed non-significant; lagging the post period by one month (M4) gave an essentially null level effect (−0.04; *P*=0.999); and excluding the commissioning scans (M5), equivalent to restricting the baseline to July 2019 onward, attenuated the baseline slope as expected (+14.70, −22%) but left the pulse (−94.18) and the null post-reopening terms unchanged (R^2=0.714). An explicit February-2020 pulse (M6) was −101.80 (*P*<0.0001) and reduced the slope change to −17.06/month, confirming that the single-month collapse and the subsequent slope break are not separately identifiable in the primary specification. A March/Two Sessions indicator (M7) was +26.50 (*P*=0.005), giving no support to a March supply interruption. Moving the break to January 2020 (M8) produced a near-zero level term (−4.98; *P*=0.703) and an unchanged slope change (−16.55; *P*<0.0001), supporting February 2020 as the interruption month. Adding CNY improved fit materially (R^2=0.778 versus 0.696). HAC lag sensitivity (3, 4, 6, and 12) left the baseline slope (+18.75), the slope break (−16.69), the pulse (−95.09), and the CNY effect (−73.90) unchanged and significant, whereas the level terms remained non-significant (*P* 0.11–0.15 for the February-2020 level term and 0.17–0.24 for the post-reopening level term); the Durbin–Watson statistic (1.90) indicated no important residual autocorrelation.

3.8 Capacity-capped counterfactual

Observed volume converged to the fitted ceiling by early 2025: at May 2025 the counterfactual was 230–264/month against 247 observed (gap −17 to +17), i.e., the monthly

gap had effectively closed. Over February 2020–May 2025, however, the cumulative deficit was 2,833 (K=230), 3,926 (K=250), or 4,682 (K=264) encounters—roughly 2,800–4,700 forgone examinations, concentrated in 2020–2023. This is a scenario range, not a confidence interval: K is not estimated from the data, the K=264 anchor was observed only after capacity expansion, and the K=230 anchor is contradicted by later counts (247 in May 2025). The bounded estimate nonetheless replaces unconstrained linear extrapolation, which ignores finite scanner and bed capacity.

4. Discussion

4.1 Principal findings

Over 74 months, a young nuclear medicine department in Northwest China grew rapidly before the pandemic (+18.75 examinations/month), experienced a February 2020 collapse that is not separately identifiable as a level shift but is evident in the fitted-versus-observed gap (129.5 vs 43) and in the joint immediate effect (−42.45), a large and significant slope reduction (−16.69/month), a deep but transient autumn-2022 outbreak pulse (−95.09/month), and no detectable post-reopening jump or slope restoration. Recovery was heterogeneous: bone and inpatient services normalized toward capacity, non-bone services recovered gradually, pulmonary-perfusion and PET/CT services expanded, whereas adjusted ^{131}I therapy activity fell by roughly one-third to one-half after reopening and did not recover.

The central observation is not the persistent post-pandemic *decline* commonly reported from mature departments [4,5–8], but an **arrest of growth** in a service that had opened months before the pandemic. Absolute annual volume nonetheless continued to rise (1,523 in 2020 to 2,506 in 2024). Two caveats limit this interpretation. First, a significant negative quadratic term ($time^2$ −0.145; P=0.002) shows that growth was already decelerating before 2020, so a pandemic-induced arrest cannot be fully distinguished from natural saturation toward capacity; the baseline is also only ten months of a start-up ramp, and

excluding the first three months lowers the baseline slope from 18.75 to 14.70/month. We therefore describe an arrest of growth rather than the truncation of an established trend. Second, the capacity-capped counterfactual reconciles continued growth with forgone volume: relative to a saturation trajectory the department accumulated roughly 2,800–4,700 forgone encounters over February 2020–May 2025, but by early 2025 observed monthly volume had converged to the capacity ceiling and the monthly gap had closed. The pandemic thus delayed maturation and shifted utilization into later years rather than leaving a large permanent monthly shortfall by 2025—although this convergence partly reflects added capacity (PET/CT, the second SPECT/CT, and workforce expansion), which the observational design cannot separate from demand.

4.2 Comparison with existing evidence

The pattern is partly consistent with, and partly distinct from, international evidence. IAEA surveys and the INCAPS COVID cohort documented substantial early-2020 reductions in nuclear medicine and cardiac imaging with geographic and modality-specific variation [4,5,6], and the AHEPA single-center analysis described a large 2020 level drop followed by partial recovery, with thyroid imaging particularly affected and lung-perfusion imaging increasing [7]. We replicate the category-specific pattern—thyroid contraction, pulmonary-perfusion growth—but not the aggregate pattern: because this department was new and operating far below capacity, pandemic controls suppressed the rate at which it could scale up rather than pushing a mature volume sharply downward. Radiology case-volume data likewise documented an initial reduction followed by recovery [11]; our within-department data extend this by showing that diagnostic oncologic imaging normalized while a bed-dependent therapeutic service did not.

What this study adds to previous single-centre reports. Relative to the AHEPA analysis [7] and the UK BNMS survey [8], this study contributes: (i) a pre-pandemic baseline

and segmented slope estimates for a department that opened months before the outbreak, allowing growth arrest to be quantified rather than inferred from level changes alone; (ii) a within-department contrast between a diagnostic line that normalized and a bed-dependent therapeutic line that did not, accompanied by explicit sensitivity analyses that show how uncertain that therapeutic estimate is; and (iii) a capacity-bounded counterfactual that converts the shortfall into a scenario range instead of an unbounded linear extrapolation.

4.3 Divergence of diagnostic thyroid imaging and ^{131}I therapy

The two thyroid-related lines require separate interpretation. **Diagnostic thyroid imaging** (905 examinations) is outpatient, relatively discretionary, and partly substitutable or re-sequencable within the thyroid work-up (ultrasound, thyroid-function testing, fine-needle aspiration); its decline from 235 in 2021 to 82 in 2024 mirrors the AHEPA experience and plausibly reflects changed post-pandemic referral behavior, though indication-level data are lacking.

^{131}I therapy is a shielded-ward, admission-based service that did not exist before March 2020. The post-reopening reduction (IRR 0.473 in the primary model) was consistent in direction across distributional assumptions and HAC standard errors, but its magnitude ranged from 0.40 to 0.68 across specifications and lost significance when the post period began in April 2023 (IRR 0.675; P=0.112), because the level term is anchored on the January 2023 infection wave. Two features of this estimate deserve emphasis. First, the change is a discrete level shift at the wave month rather than a gradual decline, whereas structural explanations operate over years: the 2015 American Thyroid Association narrowing of radioiodine indications for low- and intermediate-risk disease [16]; the shift of surgical extent toward lobectomy (in the US National Cancer Database, lobectomy rates among patients with differentiated thyroid cancer and extrathyroidal extension doubled between 2010 and 2020, with total thyroidectomy becoming less likely from 2015 onward [17]); and the association

between surgeons' preference for extensive resection and hospital-level radioiodine use [18]. Because remnant ablation presupposes total thyroidectomy, a falling total-thyroidectomy share mechanically shrinks the eligible pool, and rising thyroid-cancer detection in China (incidence and the overdiagnosis-attributable proportion both increased between 1998 and 2012 [19]) would, other things equal, raise rather than lower demand; yet none of these mechanisms predicts a step confined to the wave month. They are therefore better regarded as background conditions that shaped the pre-pandemic trajectory than as the demonstrated cause of the post-reopening shift. Second, the wave-month anchoring means that short-run operational factors—ward closure during the infection peak, staff absence, bed competition with respiratory admissions, and diversion of thyroid-cancer surgical referrals to other centres—cannot be separated from a genuine de-escalation of therapy. We therefore report a persistent but quantitatively uncertain reduction and treat the mechanism as unresolved; the surgical-guideline pathway is a plausible background trend, not a demonstrated cause. This center-specific trajectory, in a ward that opened after the pandemic began, diverges from any assumption of uniform global recovery [4,5–8] and should not be generalized without multi-center replication.

4.4 Operational and policy implications

- **Monitor slopes, not only levels.** Annual dashboards classify the department as recovered and growing (2,506 in 2024, +12.1%), whereas segmented analysis shows the underlying growth rate never returned to its pre-pandemic path until capacity was reached; monthly segmented monitoring is especially informative for recently opened services.
- **Plan category-specific recall.** High-priority inpatient oncologic imaging normalized after restrictions ended, but elective therapy did not; explicit post-disruption recall registries and prioritization for deferred radionuclide therapy are warranted.

- **Build bed and supply contingencies.** An eight-bed, multi-day-admission service dependent on non-local ^{131}I supply is exposed to small disruptions; multi-hospital bed scheduling and alternative suppliers mitigated them here.
- **Model recurring calendar effects.** The Lunar New Year trough (−74/month, comparable to a major intervention) should be planned for so seasonal losses are not mistaken for intervention effects. In this series a March/Two Sessions indicator was positive rather than negative (+26.50; P=0.005), so any annual supply interruption during that period was not detectable at monthly resolution.

These recommendations arise from a single center and should be evaluated multi-center.

4.5 Strengths and limitations

Strengths include 74 consecutive months spanning all pandemic phases; intervention points defined independently from policy documents; HAC robust standard errors with explicit adjustment for the Lunar New Year, which overlapped the first intervention; count models appropriate to the sparse ^{131}I series; a bounded, capacity-aware counterfactual; and stratified analyses that isolated clinically meaningful heterogeneity.

Limitations remain. (1) The pre-pandemic baseline was only ten months of a start-up ramp, so the baseline slope estimates scaling-up rather than steady state; excluding the first three months lowers the slope from 18.75 to 14.70/month, and a significant negative quadratic term indicates pre-existing deceleration, so an arrest of growth cannot be fully distinguished from natural saturation (M5). (2) The single-center design lacks a concurrent control series and a hospital-wide rate denominator, so causal attribution rests on temporal association and policy timing, while concurrent capacity expansion (the ^{131}I ward, PET/CT, second SPECT/CT, workforce growth from 6 to 15) is a time-varying confound. (3) The counterfactual assumes a logistic form and a capacity asymptote that is a scenario parameter

rather than an estimate; the K=264 anchor was observed only after capacity expansion and the K=230 anchor is contradicted by later counts, so the deficit range is a scenario, not an interval, and no causal claim is made from it. (4) Aggregate records lack diagnosis, urgency, indication, and outcomes, so downstream harm cannot be assessed, lost demand cannot be separated from diverted care, and the ^{131}I category cannot separate administration from therapy-associated imaging. (5) Nineteen valid encounters lacked category codes and 29 lacked recorded sex; they are retained in totals and are unlikely to bias monthly trends. (6) The ^{131}I estimate is anchored on the January 2023 infection wave and is specification-dependent (IRR 0.40–0.68; non-significant when the post period starts in April 2023). (7) The exact number of records removed at quality control could not be re-derived from the archived monthly ledger, so the exclusion step is reported without a line-level audit trail. (8) Findings may not generalize beyond one tertiary hospital in Ningxia.

5. Conclusions

In this 74-month single-center study, COVID-19 arrested the utilization growth of a young nuclear medicine department rather than producing the persistent absolute-volume decline reported from mature departments, although a pre-existing deceleration means that arrest and natural saturation cannot be fully distinguished. The February 2020 intervention was followed by a one-month collapse and a flattened growth slope, the autumn-2022 outbreak caused a deep but transient inpatient-concentrated disruption, and the December 2022 reopening produced neither an immediate rebound nor a return to the earlier growth rate; the Lunar New Year exerted a recurring reduction of comparable magnitude. Recovery was heterogeneous: bone and inpatient oncologic services stabilized near capacity, pulmonary-perfusion and PET/CT services expanded, while ^{131}I therapy activity fell by roughly one-third to one-half after reopening—an estimate whose magnitude depends on how the January 2023 infection wave is modelled—and did not recover. A capacity-bounded

scenario indicates approximately 2,800–4,700 forgone encounters over February 2020–May 2025, with the monthly gap closed by early 2025. Young, capacity-constrained specialty services need slope-based monitoring, therapy recall and bed-contingency plans, and resilient supply arrangements; multi-center, diagnosis-level studies with rate denominators are needed to confirm these findings.

Declarations

List of abbreviations: ^{131}I, iodine-131; ATA, American Thyroid Association; BNMS, British Nuclear Medicine Society; CI, confidence interval; CNY, Chinese Lunar New Year; COVID-19, coronavirus disease 2019; CT, computed tomography; HAC, heteroskedasticity- and autocorrelation-consistent; HIS, hospital information system; IAEA, International Atomic Energy Agency; IRR, incidence-rate ratio; ITS, interrupted time series; NB2, negative binomial (type 2); PET, positron emission tomography; SPECT, single-photon emission computed tomography; STROBE, Strengthening the Reporting of Observational Studies in Epidemiology.

Ethics approval and consent to participate: The study was approved by the Ethics Committee of People's Hospital of Ningxia Hui Autonomous Region (approval no. 2025-NZR-191). The requirement for informed consent was waived because the analysis used retrospective, fully de-identified administrative records, with no identifiable human material and no participant contact.

Consent for publication: Not applicable (no individual-level data, images, or identifiable details).

Availability of data and materials: The aggregated monthly series underlying all models (74 months, by service category) is provided as Additional file 2, and the analysis script as Additional file 3. Record-level hospital data are not publicly available because they contain protected health information and remain subject to institutional data-governance

approval; de-identified extracts are available from the corresponding author on reasonable request.

Competing interests: The authors declare that they have no competing interests.

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Authors' contributions: Yong Yang: Conceptualization, Methodology, Formal analysis, Writing – original draft, Supervision, Funding acquisition. Wei Cui: Data curation, Investigation, Writing – review & editing. Xia Ma: Data curation, Validation, Writing – review & editing. Jingxia Wang: Investigation, Resources, Writing – review & editing. Wenjing Ha: Data curation, Investigation, Writing – review & editing. Rui Liang: Methodology, Validation, Writing – review & editing. All authors read and approved the final manuscript.

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Table 1. Nuclear medicine services and patient characteristics, April 2019–May 2025 (n=11,831).

Characteristic	n	%
Service category		
Bone scintigraphy	7,649	64.7
Renal imaging	1,000	8.5
Thyroid imaging	905	7.6
Other nuclear medicine services	622	5.3
Myocardial perfusion imaging	408	3.4
Parathyroid imaging	297	2.5
^{131}I therapy-related encounters†	283	2.4
Salivary-gland imaging	282	2.4
Pulmonary perfusion/ventilation imaging	199	1.7
PET/CT	167	1.4
Unclassified (no category code)‡	19	0.2
Encounter type		
Inpatient	8,897	75.2
Outpatient	2,624	22.2
Unclassified	310	2.6
Sex		
Female	6,381	53.9
Male	5,421	45.8
Unrecorded (24 missing; 5 coded unknown)	29	0.2
Mean age, years (mean ± SD)	57.5 ± 15.2	—

†Aggregate ^{131}I-related category (therapy administration plus therapy-associated imaging); see §2.2. One additional February 2025 post-therapy scan (n=284 in the monthly series) lacked a category code and is included among the 19 unclassified encounters.

‡The 19 unclassified encounters (1 in 2024; 18 in January–May 2025) were valid encounters that the category pivot dropped because of a missing service identifier; they are retained in total and monthly counts. Percentages may not sum to 100 because of rounding.

Note: The 19 encounters dated April–June 2019 (13, 5, and 1 in April, May, and June) pre-date the documented July 2019 clinical opening and were installation/commissioning and quality-control scans; they are retained in the primary analysis and excluded in sensitivity model M5. Patient characteristics are summarized at encounter level.

577 **Table 2.** COVID-19 timeline and hospital/department operational measures, 2020–2025.

Date	Policy / event	Hospital or department operational measure
Jan 2020	COVID-19 declared; nationwide Level-1 response; Lunar New Year (25 Jan)	Infection-control training; access screening; elective procedures reviewed
Feb 2020	National first-wave controls; traffic restrictions	Outpatient volume reduced; urgent inpatient therapies maintained; radiopharmaceutical delivery affected
Mar 2020	Gradual local resumption	Routine clinics resumed; ^{131}I treatment ward (8 beds) opened
2020–2021	Dynamic-zero policy; local sporadic cases	Pre-appointment triage; closed management during alerts; multi-site ^{131}I bed scheduling; annual Two Sessions-period supply interruptions
Oct 2021	Yinchuan 46-day imported-case controls	No full ward closure; outpatient appointments reduced intermittently (not modeled as an intervention point)
20 Sep 2022	Ningxia Level-IV response	Entry controls; closed-loop management began
20 Sep–4 Oct 2022	Yinchuan outbreak; designated-hospital conversion	Outpatient clinic suspended 22 Sep–8 Oct; ward closed; urgent cases transferred
10 Oct 2022	Closed-loop lifted; graded district reopening	Green/yellow/red zoning; outpatient and emergency resumed
26 Oct–8 Nov 2022	Phased reopening of closed wards	Elective procedures resumed in batches
7 Dec 2022	"New Ten Measures"; national reopening	Cessation of routine mass testing; cross-regional mobility restored
Dec 2022–Jan 2023	National infection wave	Staff illness and patient deferral; low January volume
Mar 2023 onward	Post-wave recovery	Recovery of outpatient and inpatient volume; infection control maintained in treatment ward
Dec 2024	PET/CT launched	Service-line expansion
Apr 2025	Second SPECT/CT in use	Imaging capacity expansion

Table 3. Primary segmented ITS model for total monthly volume (M1; n=74).

Parameter	Coefficient	95% CI	*P*
Intercept	−33.85	−52.98 to −14.73	<0.001
Baseline slope (per month)	**+18.75**	**15.33 to 22.16**	**<0.0001**
Level change at Feb 2020	−25.76	−59.49 to 7.97	0.134
Slope change after Feb 2020	**−16.69**	**−20.67 to −12.70**	**<0.0001**
2022 outbreak pulse (Sep–Nov)	**−95.09**	**−122.28 to −67.89**	**<0.0001**
Level change at reopening (Jan 2023)	−20.08	−50.65 to 10.49	0.198
Slope change after reopening	−0.10	−1.65 to 1.45	0.898
Lunar New Year month	**−73.90**	**−104.32 to −43.47**	**<0.0001**
Annual sine term	7.01	−4.73 to 18.75	0.242
Annual cosine term	−12.89	−22.89 to −2.88	0.012
R^2 / Durbin–Watson	0.778 / 1.90	—	—

Coefficients are absolute monthly count changes. CIs are HAC 95% confidence intervals from the final fitted model.
Composite slopes: early-pandemic ($\beta_1+\beta_3$) ≈ +2.1/month (*P*=0.28); post-reopening ($\beta_1+\beta_3+\beta_6$) ≈ +2.0/month.

Table 4. Stratified segmented ITS models with the CNY term (selected coefficients; n=74).

Outcome (R^2)	Baseline slope	Slope change after Feb 2020	2022 pulse	Reopening level	Reopening slope change
Total (0.778)	+18.75***	−16.69***	−95.09***	−20.08	−0.10
Outpatient (0.721)	+3.28***	−2.48***	−21.63***	−5.17	−0.38
Inpatient (0.774)	+15.63***	−14.31***	−72.25***	−15.57	+0.21
Bone scintigraphy (0.775)	+12.54***	−11.25***	−48.00***	+8.12	−1.00*
Non-bone services (0.694)	+6.21***	−5.44***	−47.09***	−28.21**	+0.90*
Total excluding PET/CT (0.760)	+18.59***	−16.55***	−97.30***	−9.83	−1.15

Significance: *P<0.05, **P<0.01, ***P<0.001. Coefficients are absolute monthly count changes; all models include the CNY indicator and annual sine/cosine terms. Bone reopening level P=0.378; non-bone reopening level 95% CI −44.56 to −11.85 and slope-change 95% CI 0.04–1.76; all other non-starred reopening coefficients P>0.07.

Table 5. Segmented count models for monthly ^{131}I encounters, March 2020–May 2025 (n=63).

Term	Poisson IRR (95% CI)	*P*	NB2 IRR (95% CI)	*P*
Pre-reopening trend (per month)	1.024 (1.002–1.046)	0.029	1.021 (0.999–1.043)	0.056
Post-reopening level (Jan 2023)	0.473 (0.285–0.786)	0.004	0.448 (0.243–0.828)	0.010
Post-reopening trend (per month)	0.973 (0.945–1.002)	0.066	0.972 (0.939–1.006)	0.104
2022 pulse	0.158 (0.065–0.383)	<0.0001	0.171 (0.069–0.424)	0.0002
Lunar New Year month	0.248 (0.119–0.516)	0.0002	0.251 (0.120–0.523)	0.0003

IRR, incidence-rate ratio; CI, confidence interval; NB2, negative-binomial (overdispersion sensitivity; dispersion test $P \approx 0.09$). Mean monthly encounters were 5.24 (March 2020–December 2022) and 3.66 (January 2023–May 2025).

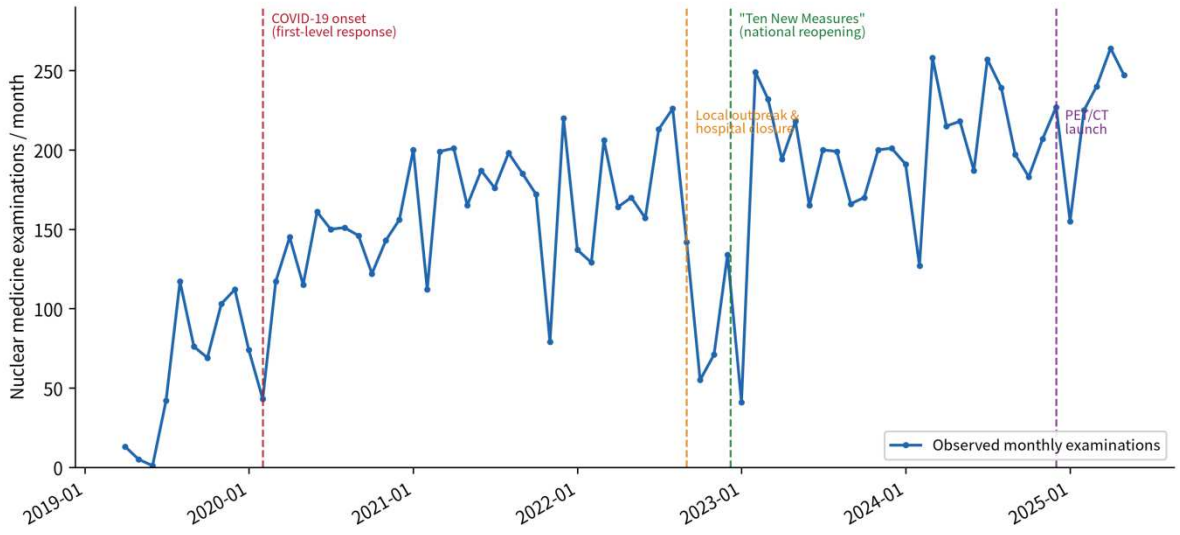
Sensitivity of the post-reopening level (Poisson IRR, 95% CI): primary 0.473 (0.285–0.786), $P=0.004$; with a January–March 2023 wave indicator 0.556 (0.324–0.956), $P=0.034$ (wave IRR 0.555); excluding January–March 2023 0.540 (0.332–0.877), $P=0.013$; post period from April 2023 0.675 (0.415–1.097), $P=0.112$; post period from December 2022 0.399 (0.243–0.654), $P<0.001$. Ljung–Box $Q=3.37$ ($P=0.339$, lag 3) and 4.06 ($P=0.668$, lag 6) for Pearson residuals; HAC(3) standard errors leave the primary estimate significant ($P<0.001$).

Table 6. Sensitivity analyses for total monthly volume (M1–M8).

Model	Baseline slope	Feb-2020 level	Feb-2020 slope change	Pulse term(s)	Reopening level	Reopening slope change	R^2
M1 Primary (CNY; Sep–Nov pulse)	18.75***	−25.76	−16.69***	−95.09***	−20.08	−0.10	0.778
M2 Pulse split monthly	18.58***	−25.56	−16.49***	Sep −44.77***; Oct −128.96***; *Nov −113.48***	−20.52	−0.13	0.791
M3 Oct–Nov pulse	18.66***	−24.14	−16.78***	−115.74***	−15.65	+0.07	0.785
M4 Reopening lagged 1 month	18.70***	−19.84	−17.11***	−85.72***	−0.04	−0.10	0.773
M5 Excluding commissioning scans†	14.70***	−18.75	−12.63***	−94.18***	−20.32	−0.10	0.714
M6 Explicit Feb-2020 pulse	18.58***	−13.51	−17.06***	−88.70***	−13.14	+0.42	0.807
M7 March/Two Sessions indicator	18.21***	−24.80	−16.12***	−96.55***	−21.02	−0.11	0.788
M8 Break moved to Jan 2020	18.48***	−4.98	−16.55***	−93.69***	−18.59	+0.04	0.776

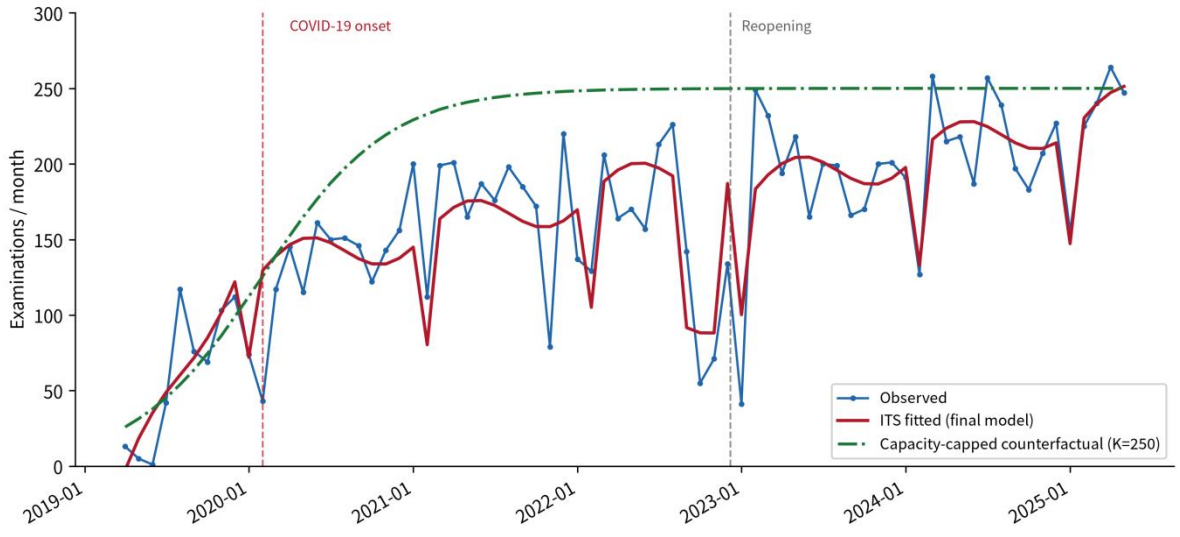
***$P<0.001$ for the starred structural terms; in every model the post-reopening level and slope-change terms were non-significant ($P\geq0.13$ and $P\geq0.86$; M4 level $P=0.999$), and the CNY term remained significant (−72.75 to −75.32; all $P<0.0001$). M6 adds an explicit February-2020 single-month pulse (−101.80; $P<0.0001$), which reduces the February-2020 level term to −13.51 and the slope change to −17.06; M7 adds a March/Two Sessions indicator (+26.50; $P=0.005$); M8 moves the interruption break to January 2020, giving a near-zero level term (−4.98; $P=0.703$). †Excludes 19 April–June 2019 commissioning/quality-control encounters, equivalent at monthly resolution to restricting the baseline to July 2019 onward. All coefficients are absolute monthly count changes.

Figure legends



602

603 **Figure 1.** Monthly nuclear medicine examinations and therapy-related encounters,
604 April 2019–May 2025, with COVID-19 intervention points. The vertical dashed line marks
605 February 2020; the shaded band marks the September–November 2022 local outbreak; the
606 vertical dotted line marks the December 2022 reopening. The solid line is the observed
607 monthly count; markers indicate the October 2022 local trough (55), the January 2023
608 minimum (41), and the April 2025 peak (264).



609

610 **Figure 2.** Observed monthly volume (blue), segmented ITS fitted values from the
611 final CNY-adjusted model (red), and the capacity-capped counterfactual (green dashed,
612 K=250), April 2019–May 2025. The red dashed line marks COVID-19 onset (February

2020); the grey dashed line marks the policy reopening (December 2022) and the dotted grey line the start of the modelled post-reopening period (January 2023). The counterfactual is a logistic saturation curve fitted to the pre-pandemic months and is bounded at a finite monthly capacity; it is used only for bounded gap estimation (cumulative deficit 2,833–4,682 encounters for K=230–264; monthly gap closed by early 2025), not for causal inference or unconstrained extrapolation.

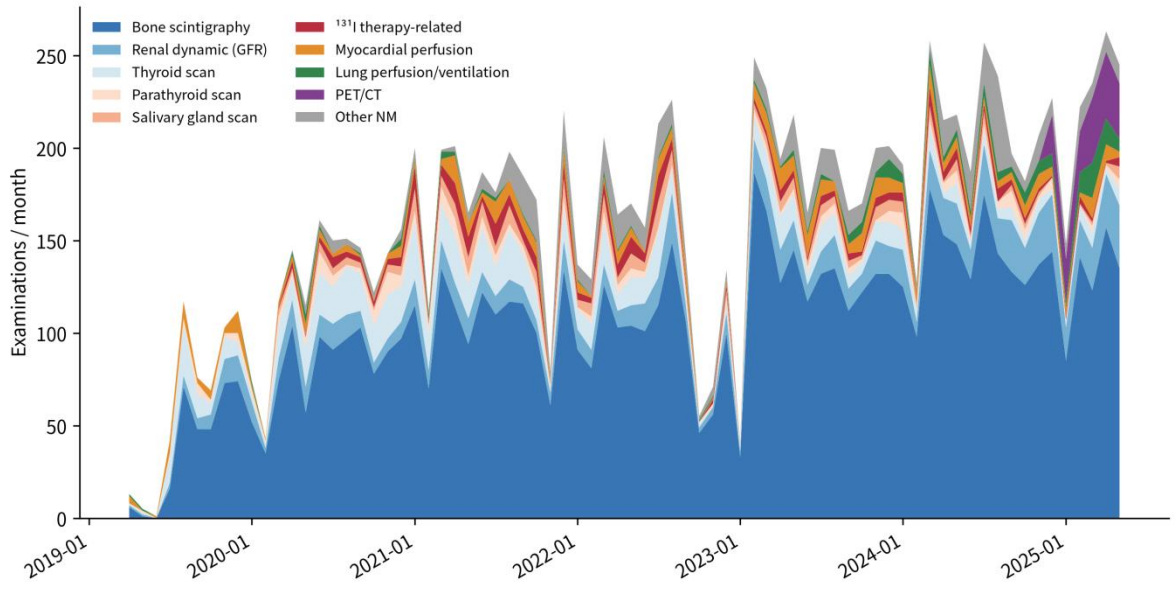


Figure 3. Annual service volumes by category, 2019–2025. Panel A: major diagnostic categories; Panel B: ^{131}I therapy-related encounters and PET/CT. Note that 2019 (April onward) and 2025 (January–May) are partial years.