

Complication-attributable admission episodes after shunt surgery for idiopathic normal pressure hydrocephalus in Japan: a scenario-based micro-costing analysis of hospital margins under DPC/PDPS and fee-for-service

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Received: 23 April 2026 / Accepted: 1 October 2026

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Abstract

Background Shunt-related complications after surgery for idiopathic normal pressure hydrocephalus (iNPH) generate repeat admissions, procedures, and bed use, but their provider-side financial consequences depend on the reimbursement rule. Evidence on hospital accounting margins under Japan's mixed Diagnosis Procedure Combination/Per-Diem Payment System (DPC/PDPS) remains limited. This study compared modeled hospital margins under DPC/PDPS and a fee-for-service (FFS) comparator and, as a secondary analysis, estimated infection-specific prevention thresholds.

Methods A deterministic scenario-based micro-costing model was constructed from the hospital perspective. The primary analysis comprised 10 mutually exclusive complete complication pathways: suspected infection without immediate shunt removal (A1), a two-admission deep-infection pathway consisting of shunt removal followed by staged reconstruction (A23), two subdural-lesion pathways, four mechanical-revision pathways, one abdominal-complication pathway, and one seizure pathway. A2 and A3 were analyzed as component admissions of A23 but were not counted as additional independent pathways. Revenue and cost were calculated separately for each admission and then summed for A23. One-way, two-way, joint-scenario, and length-of-stay (LOS) sensitivity analyses were performed.

Results Under DPC/PDPS, all 10 complete pathways had positive base-case margins, ranging from Japanese yen (JPY) 35,230 to JPY 231,428. Under FFS, 9 of 10 pathways had negative margins, ranging from JPY -284,283 to JPY -29,951; total shunt revision (C4) was the only positive pathway, at JPY 7,859. Within A23, the A2 component margin was JPY -8,145 under DPC/PDPS and JPY -295,282 under FFS, whereas A3 was JPY 239,573 and JPY 10,999, respectively. The A23 FFS margin was JPY -284,283, calculated by summing the two admission-level ledgers, including admission-specific inpatient and other FFS revenue items. At the base ward cost, the A23 DPC/PDPS margin fell from JPY 420,088 at a relative per-diem coefficient of 1.2 to JPY 42,768 at 0.8; it became JPY -447,142 when ward cost was JPY 55,000/day. Extending A23 from 35 to 49 bed-days changed its DPC/

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PDPS margin from JPY 231,428 to JPY −29,582. For A1 plus A23, the DPC/PDPS accounting margin of JPY 275,359 was offset at an opportunity cost of JPY 6,556 per occupied bed-day.

Conclusions Reimbursement design substantially changed modeled provider margins. Positive accounting margins under DPC/PDPS did not establish that complication admissions were financially desirable or that the payment system was policy-optimal, because local ward cost, LOS, and capacity constraints could reverse the result. The estimates should be recalibrated with institution-specific cost and claims data.

Keywords Idiopathic normal pressure hydrocephalus · Shunt · Reimbursement · Micro-costing · Hospital margin · Bed capacity

Background

Idiopathic normal pressure hydrocephalus (iNPH) is characterized by gait disturbance, cognitive impairment, and urinary incontinence in older adults and can improve after shunt surgery; however, complications and reoperations occur with a certain frequency [1–6]. From a provider perspective, these events are encountered not only as adverse outcomes but also as repeat admissions, repeat procedures, prolonged bed occupancy, and delayed access for other patients. Japan widely uses the Diagnosis Procedure Combination/Per-Diem Payment System (DPC/PDPS) for acute inpatient care, and its combination of diagnosis-based per-diem payment and separately billable services can make the hospital-side financial effect of a complication difficult to infer from clinical severity alone [7, 8].

DPC/PDPS differs from a simple per-discharge diagnosis-related group payment. The inclusive per-diem amount decreases across length-of-stay (LOS) periods, while surgery, specified special medical materials, and selected services remain reimbursed separately. Consequently, two clinically similar complication admissions can generate different provider margins depending on LOS, the mix of separately reimbursed items, and the hospital-specific payment coefficient. This distinction matters for hospital management because nominal reimbursement, accounting margin, and the value of preserving scarce bed capacity are not equivalent.

Most iNPH studies of subsequent hospitalization report event rates, risk factors, or downstream expenditure [9, 10]. They do not show how a mixed per-diem/fee-for-service (FFS) payment rule interacts with scenario-specific hospital resource use. The present study therefore addresses a provider-side evidence gap: it estimates the accounting margin generated after a complication pathway has occurred and identifies which assumptions can change the sign of that margin. The modeled FFS comparator is not intended to represent another country's health system or reproduce every possible Japanese claim item; it provides a transparent counterfactual for examining how the inpatient per-diem component changes provider incentives.

The primary objective was to compare hospital margins for complete complication-attributable pathways after iNPH shunt surgery under DPC/PDPS and the base-case FFS comparator. The secondary objective was restricted to infection-related pathways and estimated when prevention of A1 and A23 could become financially favorable after bed-capacity opportunity cost was considered. The analysis was designed as a threshold framework rather than a cost-effectiveness evaluation of a specific intervention.

Methods

Study design, perspective, and analysis units

This deterministic scenario-based micro-costing study estimated incremental hospital revenue, cost, and accounting margin attributable to additional admissions after iNPH shunt surgery. The hospital perspective was used. Inputs came from public fee schedules, official price lists, national statistics, cited literature, and institution-specific

operational reference values. No patient-level or aggregate clinical record data were used in the model; all clinical pathways were prespecified scenarios. Accordingly, institutional review board approval and informed consent were not applicable.

The primary unit of analysis was a mutually exclusive complete complication pathway. Ten complete pathways were evaluated: A1, A23, B1, B2, C1, C2, C3, C4, E1, and F1. The deep-infection pathway A23 consisted of two separate component admissions: A2, for shunt removal and antimicrobial treatment, and A3, for planned staged reconstruction after infection control. A2 and A3 were reported to show where revenue and cost arose, but they were not counted as two additional independent pathways. For A23, each admission was calculated separately, including a separate FFS inpatient basic fee and early-hospitalization add-on, and the two admission ledgers were then added. This structure avoids counting A2, A3, and A23 as three independent outcomes.

Clinical pathways and scenario assumptions

Table 1 summarizes the pathway role, modeled clinical course, DPC code, LOS, surgery points, material list price, and drug list price. The scenarios were specified by consensus among the participating neurosurgeons on the basis of usual pathways at the modeled hospital, with guideline or literature support where available. They were constructed to span the dominant resource-use patterns after shunt surgery: diagnostic evaluation with medical treatment, prolonged antimicrobial therapy, conservative observation, reoperation with or without special medical materials, and nonshunt medical management. The values are explicit reference scenarios rather than observed national averages or estimated mean pathways.

A1 represented inpatient evaluation and empiric treatment for suspected infection without immediate shunt removal. A2 represented a deep-infection component admission requiring shunt removal and a 21-day broad-spectrum antimicrobial course; A3 represented a separate 14-day planned reconstruction admission. A23 was the additive two-admission pathway A2 plus A3. The infection regimens were deliberately conservative upper-bound base cases guided by healthcare-associated ventriculitis and meningitis recommendations and antimicrobial stewardship principles [11, 12]; the 21-day A2 course was not presented as a pathogen-specific universal standard. A3, B2, and C1-C4 included the modeled hospital's three-day cefazolin prophylaxis reference. These durations were not presented as universal standards.

Table 1 Scenario definitions, analysis role, and major inputs

Unit	Role	Modeled pathway	DPC code	LOS	Surgery points	Materials (JPY)	Drug list (JPY)
A1	Complete	Suspected infection; evaluation and empiric treatment without immediate removal	010080xx97×00x	7	0	0	41,804
A2	Component	Deep infection; shunt removal and antimicrobial treatment	010080xx97×00x	21	1,680	0	125,412
A3	Component	Planned staged VP shunt reconstruction after infection control	010200xx01×00x	14	24,310	323,930	4,152
A23	Complete, 2 admissions	A2 followed by A3; calculated separately and added	Two codes	35	25,990	323,930	129,564
B1	Complete	Subdural collection/hematoma; observation and valve adjustment	010050xx99×0xx	7	0	0	0
B2	Complete	Subdural hematoma; burr-hole drainage	010050xx02×00x	14	10,900	0	4,152
C1	Complete	Mechanical trouble; proximal catheter revision	010200xx01×00x	14	15,850	30,030	4,152
C2	Complete	Mechanical trouble; distal catheter revision	010200xx01×00x	14	6,600	38,430	4,152
C3	Complete	Mechanical trouble; valve revision	010200xx01×00x	14	15,850	249,930	4,152
C4	Complete	Mechanical trouble; total shunt revision	010200xx01×00x	14	19,150	323,930	4,152
E1	Complete	Abdominal infectious complication; antimicrobial treatment	060370xx9700xx	14	0	0	24,024
F1	Complete	Seizure; intravenous-to-oral levetiracetam	010230xx99×00x	7	0	0	4,005

A2 and A3 are component admissions of A23 and are not counted as separate complete pathways

LOS length of stay, VP ventriculoperitoneal, DPC Diagnosis Procedure Combination

B1 represented a seven-day conservative admission for a subdural collection or hematoma with at least two head computed tomography (CT) examinations. B2 represented a 14-day admission with burr-hole drainage. C1–C4 represented 14-day admissions for proximal catheter, distal catheter, valve, or total shunt revision, with head and abdominal CT at evaluation and postoperative head CT. E1 represented a 14-day abdominal infectious complication treated with seven days of piperacillin and tazobactam [13]. F1 represented a seven-day seizure admission with intravenous-to-oral levetiracetam [14]. The 14-day A3 LOS and 70-minute operating-room duration were prespecified by consensus among the participating neurosurgeons as representative values for planned shunt reconstruction at the modeled hospital; they were not derived from patient records. Their influence was examined through A23 LOS sensitivity and operating-room cost sensitivity. Imaging frequency, laboratory testing, antimicrobial duration, and LOS can differ by institution; their influence was addressed by LOS scenarios, an other-revenue multiplier, and explicit limitations.

Revenue model

Incremental accounting margin for unit j was defined as revenue minus modeled cost: $\Delta \Pi_j = R_j - C_j$.

Under DPC/PDPS, total revenue was the sum of the official DPC per-diem component, scenario-specific fixed revenue for tests, imaging, procedures, and other modeled items, surgery revenue, and special-material reimbursement. The model applies the relative DPC coefficient only to the official per-diem component: $R_j^{\text{DPC}} = \kappa R_j^{\text{per-diem}} + R_j^{\text{fixed}}{}^{\text{DPC}} + R_j^{\text{surg}} + R_j^{\text{mat}}$.

The reference value of the relative coefficient was 1.00. Values of 0.80–1.20 were used as a stress-test around this normalized reference; they were not treated as a national empirical distribution. Official DPC per-diem schedules and coding sources are listed in Additional file 1 [15–17]. For the FFS comparator, inpatient basic-fee revenue for LOS L was calculated from Acute Care General Inpatient Fee 1, with 1,688 points/day, an additional 450 points/day on days 1–14, and 192 points/day on days 15–30 [18]: $R^{\text{inpatient}}{}^{\text{fss}}(L) = 10[1,688L + 450 \min(L, 14) + 192 \min(\max(L - 14, 0), 16)]$.

One reimbursement point was converted to 10 Japanese yen (JPY). Surgery, materials, imaging, tests, cultures, and injection-related procedure fees included in the scenario-specific revenue ledger were added separately. Because this base-case model did not reproduce every possible claim item, the break-even unmodeled FFS points/day was reported as a net modeled threshold. It is not an estimate of actual omitted reimbursement and should be interpreted after recognizing that additional unmodeled services can also generate additional cost.

Cost model

Modeled cost comprised ward stay, operating-room (OR) time, specified special medical materials, and selected drugs: $C_j = c^{\text{ward}}L_j + c^{\text{OR}}t_j + \alpha^{\text{mat}}M_j + \alpha^{\text{drug}}D_j$.

The base ward cost of JPY 35,612/day was derived from the 25th Survey of Economic Conditions in Health Care and the 2024 Hospital Report [19, 20]. For hospitals claiming Acute Care General Inpatient Fee 1, medical and nursing operating expense was reduced by drug and medical-material expense, allocated to inpatient care in proportion to inpatient service revenue, and divided by average bed count, general-bed occupancy, and 365 days. The operating-room reference of JPY 892/minute was obtained with a time-driven activity-based costing structure using publicly available occupation-specific salary inputs and practical capacity [21]; it was a modeled unit cost rather than an observed hospital cost-center average. Special medical material cost used the modeled hospital's tax-exclusive reference purchase ratio of 0.85 relative to the official reimbursement ceiling. Applying the 10% consumption-tax factor produced a cost coefficient of 0.935. Drug cost used the hospital's reference purchase ratio of 0.88 relative to the official drug price [22–24]. These procurement ratios were institution-specific operational reference values, not Japanese national standards or transaction-weighted averages.

Imaging and laboratory reimbursement was included in the scenario-specific revenue ledger. Direct acquisition costs for CT, magnetic resonance imaging (MRI), and laboratory testing were not separately micro-costed because the available sources did not provide institution-specific unit costs. The top-down ward cost may contain part of the shared diagnostic overhead, but this cannot be verified from the available data. Accordingly, the base-case margin may be overstated if those direct costs are not captured by the ward allocation. For example, B1 had no surgery, material, or selected drug cost, but it still incurred JPY 249,286 in ward cost; it did not have zero total cost.

Sensitivity and threshold analyses

To separate locally interpretable calibration from deliberately wide stress testing, ward and operating-room costs were first varied within a prespecified plus or minus 20% band around the reference values: JPY 28,490–42,735/day for ward cost and JPY 713–1,070/minute for operating-room cost. The main two-way analysis combined the ward-cost calibration band with a relative DPC coefficient of 0.80–1.20. Broader one-way stress tests used ranges of JPY 15,000–55,000/day for ward cost and JPY 500–1,500/minute for operating-room cost. Additional broad stress tests varied the tax-exclusive material purchase ratio from 0.80 to 0.95 with the tax factor fixed at 1.10, the drug purchase ratio from 0.80 to 1.00, other modeled revenue from 0.75 to 1.25 times the base ledger, and opportunity cost from JPY 0 to 20,000/bed-day. The plus or minus 20% band was a prespecified institutional calibration range, and the broader bounds were deliberately wide stress tests; neither was interpreted as a confidence interval or national empirical distribution.

Simultaneous uncertainty was examined in two ways. First, a two-way grid varied the relative DPC coefficient from 0.80 to 1.20 and ward cost across the primary JPY 28,490–42,735/day calibration band for A23. Second, a broad $3 \times 3 \times 3$ stress analysis combined coefficient values of 0.80, 1.00, and 1.20; ward costs of JPY 15,000, 35,612, and 55,000/day; and opportunity costs of JPY 0, 10,000, and 20,000/bed-day. LOS sensitivity used clinically interpretable week-based scenarios: A1, 5/7/10 days; A23, 14 + 7, 21 + 14, and 28 + 21 days for A2 + A3; B1, 5/7/10 days; and C4 and E1, 7/14/21 days. Revenue and cost were calculated at each LOS, including DPC period changes and the FFS early-hospitalization add-ons. The antimicrobial list amounts for A1 and A2 were scaled with LOS, whereas the fixed three-day perioperative cefazolin course was held constant. The other-revenue multiplier varied the ledgered reimbursement for imaging, tests, procedures, and other fixed items; direct diagnostic acquisition costs remained outside the model.

A formal probabilistic sensitivity analysis was not performed. The available data did not provide empirical probability distributions or correlation structures for LOS, antibiotic duration, imaging, local unit costs, or reimbursement components. Assigning arbitrary distributions would have implied unsupported precision. The deterministic simultaneous analyses were therefore used to show sign changes under combinations of explicit assumptions, and the absence of a probabilistic analysis was treated as a limitation.

Capacity-adjusted margin was defined by subtracting the opportunity cost per occupied bed-day from the accounting margin: $\Delta \Pi_j^{\text{cap}} = \Delta \Pi_j - C^{\text{opp}} L_j$.

The prevention analysis was restricted to infection pathways A1 and A23. If absolute risk reduction was ARR and prevention cost per index procedure was B, the break-even condition was: $B^* = -\text{ARR}(\Delta \Pi_j^{\text{cap}}_{\text{A1}} + \Delta \Pi_j^{\text{cap}}_{\text{A23}})$.

Negative break-even values indicate that avoiding the event would reduce positive hospital accounting margin under that assumption; positive values indicate the maximum prevention cost compatible with financial break-even. No observed complication incidence or empirically estimated preventive effectiveness was incorporated.

Analysis and reproducibility

All calculations were deterministic. Monetary values were rounded to the nearest JPY for reporting. The Python script calculates component-admission revenues and costs, forms A23 by exact addition of A2 and A3, validates

the base-case values, records the institution-specific procurement inputs and non-patient scenario scope, separates primary calibration from broad stress-test outputs, and regenerates all figures and sensitivity tables. The script and input/output tables are provided as Additional file 2 and in the supplementary appendix.

Results

Analysis units and base-case margins

The primary analysis contained 10 mutually exclusive complete pathways. Under DPC/PDPS, all 10 had positive base-case accounting margins, ranging from JPY 35,230 for B1 to JPY 231,428 for A23. Under FFS, 9 of 10 had negative base-case margins, ranging from JPY -284,283 for A23 to JPY -29,951 for C3. C4 was the only positive complete pathway, at JPY 7,859. Among the nine negative complete pathways, the break-even unmodeled FFS threshold ranged from 213.9 points/day for C3 to 1,044.6 points/day for E1 (Table 2; Fig. 1).

The component-admission analysis clarified the staged infection pathway. A2 generated a DPC/PDPS margin of JPY -8,145 and an FFS margin of JPY -295,282. A3 generated margins of JPY 239,573 and JPY 10,999, respectively. Separate calculations for the two admissions yielded an A23 FFS inpatient revenue of JPY 730,240, total FFS revenue of JPY 1,503,883, total cost of JPY 1,788,166, and FFS margin of JPY -284,283. The A23 DPC/PDPS margin was JPY 231,428. A23 equaled A2 plus A3 under both payment approaches; only A23, not its component admissions, was counted among the 10 complete pathways.

Full revenue and cost components for all complete pathways and component admissions are shown in Tables 3 and 4. B1 did not incur surgery, special-material, or selected drug cost, but its seven-day ward allocation was JPY 249,286. Thus, the zero entries in individual cost categories did not mean that the admission had zero incurred cost.

Deterministic uncertainty analyses

The two-way analysis showed that the A23 DPC/PDPS margin depended jointly on the relative per-diem coefficient and ward cost within the primary ward-cost calibration band (Fig. 2). At the lower ward-cost value of JPY 28,490/day, the margin ranged from JPY 292,054 at a coefficient of 0.80 to JPY 669,374 at 1.20. At the base ward cost of JPY 35,612/day, the corresponding margins were JPY 42,768, JPY 231,428, and JPY 420,088 at coefficients of 0.80, 1.00, and 1.20. At the upper calibration value of JPY 42,735/day, the margin was JPY -206,518 at 0.80, JPY -17,858 at 1.00, and JPY 170,802 at 1.20.

Table 2 Base-case margins and break-even thresholds for mutually exclusive complete pathways

Pathway	LOS	DPC/PDPS margin (JPY)	FFS margin (JPY)	Break-even unmodeled FFS points/day	Break-even ward cost under DPC/PDPS (JPY/day)	Break-even opportunity cost under DPC/PDPS (JPY/day)
A1	7	43,931	-44,680	638.3	41,888	6,276
A23	35	231,428	-284,283	812.2	42,225	6,612
B1	7	35,230	-55,186	788.4	40,645	5,033
B2	14	80,587	-69,036	493.1	41,368	5,756
C1	14	178,216	-44,244	316.0	48,342	12,730
C2	14	86,262	-136,198	972.8	41,774	6,162
C3	14	192,509	-29,951	213.9	49,363	13,751
C4	14	230,319	7,859	0.0	52,064	16,451
E1	14	138,211	-146,239	1,044.6	45,484	9,872
F1	7	96,420	-69,015	985.9	49,387	13,774

Break-even unmodeled FFS points/day is a net modeled threshold, not an estimate of actual omitted reimbursement

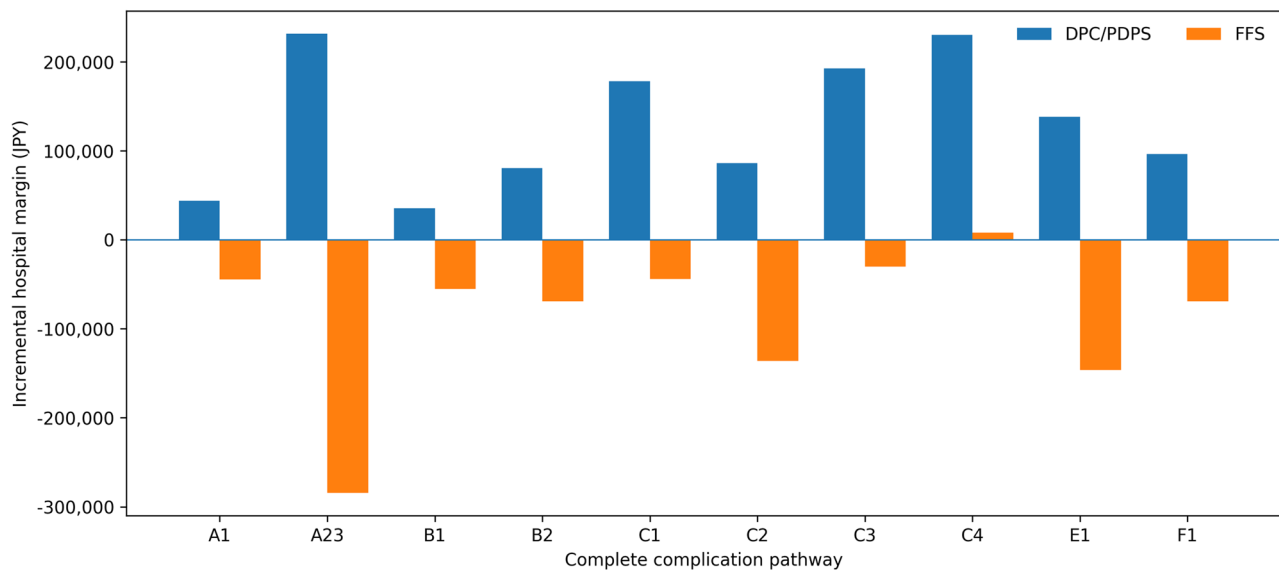


Fig. 1 Incremental hospital margins across complete complication pathways. Bars compare the Diagnosis Procedure Combination/Per-Diem Payment System (DPC/PDPS) and fee-for-service (FFS) base-case margins. A23 is the two-admission infection pathway A2 plus A3; A2 and A3 are not displayed as additional independent pathways

Table 3 Revenue components for all complete pathways and component admissions

Unit	Role	DPC per-diem	Other DPC revenue	Surgery	Materials	Total DPC revenue	Total FFS revenue
A1	Complete	221,480	108,524	0	0	330,004	241,393
A2	Component	601,140	294,558	16,800	0	912,498	625,361
A3	Component	342,160	197,906	243,100	323,930	1,107,096	878,522
A23	Complete, 2 admissions	943,300	492,464	259,900	323,930	2,019,594	1,503,883
B1	Complete	190,950	93,566	0	0	284,516	194,100
B2	Complete	339,540	166,375	109,000	0	614,915	465,292
C1	Complete	342,160	240,252	158,500	30,030	770,942	548,482
C2	Complete	342,160	240,252	66,000	38,430	686,842	464,382
C3	Complete	342,160	240,252	158,500	249,930	990,842	768,382
C4	Complete	342,160	240,252	191,500	323,930	1,097,842	875,382
E1	Complete	393,210	264,714	0	0	657,924	373,474
F1	Complete	182,270	166,960	0	0	349,230	183,795

The relative DPC coefficient applies only to the official DPC per-diem component. Other DPC revenue comprises modeled tests, imaging, procedures, and other fixed items in the scenario-specific revenue ledger

Within the primary plus or minus 20% one-way calibration, changing ward cost moved the A23 margin from JPY 480,714 to JPY -17,858, whereas changing operating-room cost moved it from JPY 256,398 to JPY 206,458. The broader stress tests showed larger sign changes: ward cost produced a range from JPY -447,142 to JPY 952,858, and opportunity cost produced a capacity-adjusted range from JPY -468,572 to JPY 231,428. Varying the tax-exclusive material purchase ratio from 0.80 to 0.95 changed the margin from JPY 249,245 to JPY 195,796; varying the drug purchase ratio from 0.80 to 1.00 changed it from JPY 241,791 to JPY 215,879 (Supplementary Figure S1 and Supplementary Tables S4, S6, and S7).

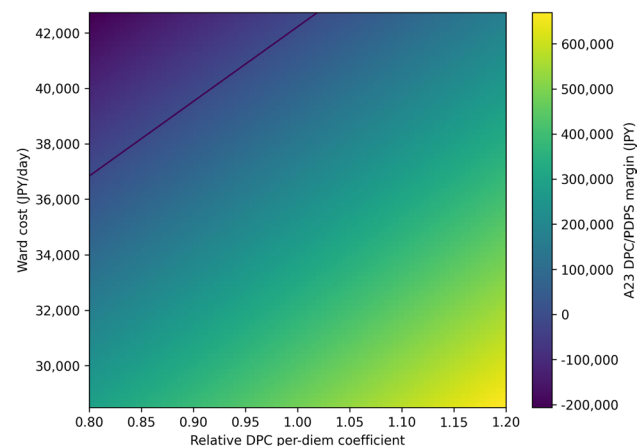
LOS sensitivity also changed the sign of several results. For A23, the DPC/PDPS margin decreased from JPY 461,887 at 21 total bed-days to JPY 231,428 at 35 days and JPY -29,582 at 49 days; the corresponding FFS margins were JPY -30,184, JPY -284,283, and JPY -556,443. The B1 DPC/PDPS margin changed from JPY 64,935 at five days to JPY -9,327 at 10 days. The C4 FFS margin changed from JPY 107,485 at seven days to JPY 7,859 at 14 days and JPY -109,827 at 21 days (Supplementary Figure S2 and Supplementary Table S5).

Table 4 Cost components for all complete pathways and component admissions

Unit	Role	Ward cost	Operating-room cost	Material cost	Selected drug cost	Total cost
A1	Complete	249,286	0	0	36,787	286,073
A2	Component	747,858	62,423	0	110,362	920,643
A3	Component	498,572	62,423	302,875	3,653	867,523
A23	Complete, 2 admissions	1,246,430	124,846	302,875	114,015	1,788,166
B1	Complete	249,286	0	0	0	249,286
B2	Complete	498,572	32,103	0	3,653	534,328
C1	Complete	498,572	62,423	28,078	3,653	592,726
C2	Complete	498,572	62,423	35,932	3,653	600,580
C3	Complete	498,572	62,423	233,685	3,653	798,333
C4	Complete	498,572	62,423	302,875	3,653	867,523
E1	Complete	498,572	0	0	21,141	519,713
F1	Complete	249,286	0	0	3,524	252,810

All monetary values are JPY. Direct imaging and laboratory acquisition costs were not separately disaggregated

Fig. 2 Two-way sensitivity of the A23 DPC/PDPS margin to the relative DPC per-diem coefficient and ward cost. Ward cost is shown across the prespecified plus or minus 20% institutional calibration band around JPY 35,612/day; the coefficient range of 0.80–1.20 is a normalized stress test. The contour denotes zero accounting margin

**Table 5** Infection-specific break-even prevention cost for A1 and A23

Payment profile	Targets	Bed-days	Composite margin (JPY)	ARR 1% (JPY)	ARR 5% (JPY)	ARR 10% (JPY)
FFS base case	A1 + A23	42	-328,963	3,290	16,448	32,896
DPC/PDPS, opportunity cost JPY 0/day	A1 + A23	42	275,359	-2,754	-13,768	-27,536
DPC/PDPS, opportunity cost JPY 10,000/day	A1 + A23	42	-144,641	1,446	7,232	14,464
DPC/PDPS, opportunity cost JPY 20,000/day	A1 + A23	42	-564,641	5,646	28,232	56,464

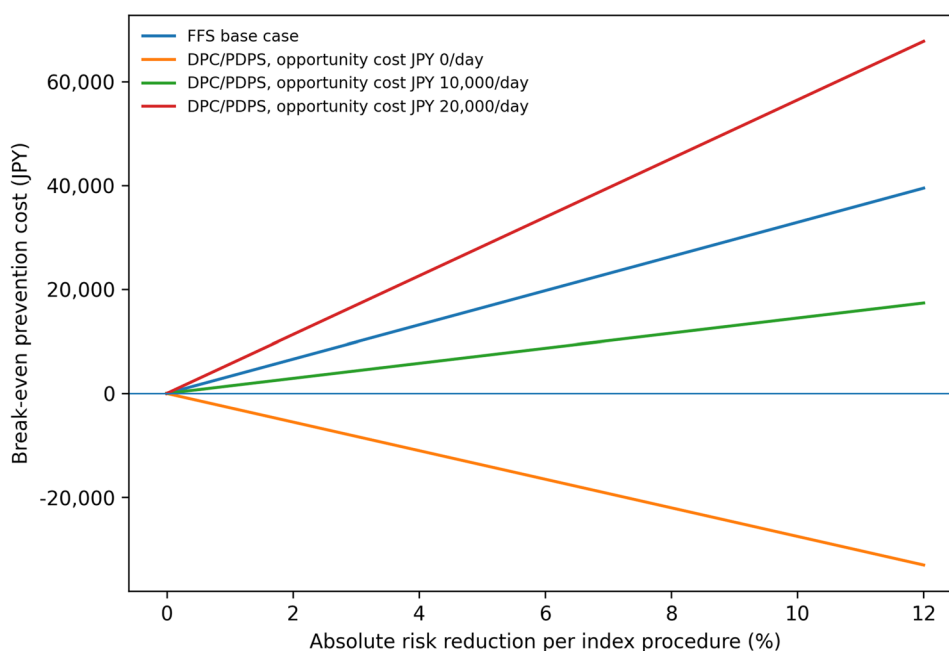
Negative break-even values indicate that prevention would reduce positive hospital accounting margin under the stated assumption

ARR absolute risk reduction

Infection-specific prevention thresholds

The combined base-case DPC/PDPS accounting margin for A1 plus A23 was JPY 275,359 across 42 bed-days. Dividing JPY 275,359 by 42 yielded a break-even opportunity cost of JPY 6,556 per occupied bed-day. At zero opportunity cost, preventing the two infection pathways would reduce positive accounting margin, producing negative break-even prevention costs. At opportunity costs of JPY 10,000 and JPY 20,000/day, the capacity-adjusted composite margins were JPY -144,641 and JPY -564,641, respectively. Under FFS, the composite margin was JPY -328,963; the corresponding maximum break-even prevention costs were JPY 3,290, JPY 16,448, and JPY 32,896 per index procedure at ARR values of 1%, 5%, and 10% (Table 5; Fig. 3).

Fig. 3 Infection-specific break-even prevention cost under alternative capacity assumptions. Curves show the maximum prevention cost per index procedure compatible with hospital financial break-even for preventing A1 and A23 at different absolute risk reductions and opportunity costs



Discussion

The analysis distinguished 10 mutually exclusive complete complication pathways from their component admissions. Under the reference assumptions, DPC/PDPS produced positive accounting margins for all 10 complete pathways, whereas the FFS comparator was negative for nine. The result reflects payment architecture: DPC per-diem revenue and separately reimbursed surgery or materials can cover the modeled ward, operating-room, material, and selected drug costs even when an FFS inpatient basic fee does not.

The staged infection pathway illustrates why the analysis unit matters. A2 itself was near break-even under DPC/PDPS and substantially negative under FFS, while A3 was positive under both payment approaches. A23 must therefore be interpreted as the total financial consequence of two admissions caused by one deep-infection pathway, not as a third independent event. Calculating A2 and A3 separately, including admission-specific inpatient basic fees, early-hospitalization add-ons, and other FFS revenue items, yielded an A23 FFS margin of JPY −284,283. This combined margin was used in the infection-specific prevention threshold analysis.

Hospital heterogeneity was a major determinant. The reference coefficient, ward cost, operating-room cost, purchase ratios, opportunity cost, and clinical pathway assumptions are not transferable constants. The sensitivity analysis therefore separates a prespecified plus or minus 20% calibration band for ward and operating-room cost from broader stress tests intended to identify sign changes under substantially different hospital conditions. The material ratio of 0.85 and drug ratio of 0.88 are reference values used at the modeled hospital rather than national purchasing benchmarks. Readers should replace the reference inputs with their own facility coefficient, procurement ratios, staffing and operating-room cost, occupancy, and foregone contribution margin. The reported thresholds are calibration points, not national benchmarks.

The LOS analysis adds a practical management interpretation. Shortening LOS improved the accounting margin under both payment approaches, but the magnitude depended on the per-diem schedule and early-hospitalization add-ons. A23 became negative under DPC/PDPS when the two component admissions totaled 49 days, B1 became negative at 10 days, and C4 moved from a small positive FFS margin at 14 days to a negative margin at 21 days. These findings are scenario results rather than causal evidence that LOS reduction alone improves outcomes or total system efficiency; clinically inappropriate shortening could create other costs or readmissions.

The study does not establish that DPC/PDPS is financially appropriate for shunt complications in a normative or system-wide sense. It shows that, at the modeled hospital inputs, the payment rule generated a positive hospital accounting margin for the 10 complete pathways. That finding does not demonstrate appropriate payment, efficient resource allocation, or lower payer expenditure. Once bed-capacity opportunity cost was included, infection-related margins could become negative. A payment system may therefore yield non-negative provider margin while the complication still increases payer spending, consumes scarce capacity, and worsens patient outcomes.

The infection analysis should likewise be read as a threshold framework, not a conventional cost-effectiveness analysis. No observed infection incidence, intervention effect, implementation cost, quality-adjusted life-year, or patient outcome was modeled. The estimated break-even prevention costs answer a narrower question: given an assumed ARR, what per-index-procedure cost would offset the hospital margin of A1 and A23 under specified capacity assumptions? Payer expenditure, hospital accounting margin, and broader health-system cost remain distinct quantities.

The scenario structure complements existing iNPH literature. A nationwide study reported that mechanical device complications, extracranial postoperative infection, and subdural hemorrhage were common causes of 30- and 90-day readmission after ventriculoperitoneal shunt placement [9]. Frailty has also been associated with adverse events, readmission, longer LOS, and higher admission cost after shunt surgery [25]. At the system level, shunt revision and replacement add substantial downstream expenditure [10], while readmission has broader reimbursement implications in neurosurgery [26]. The present model addresses a different level of analysis: the provider margin once a specified pathway occurs.

Prior economic reports also show why an intervention cannot be judged from reimbursement alone. Antibiotic-impregnated shunt catheters have been associated with lower infection-related cost in adults [27], whereas laparoscopic assistance increased direct cost without reducing distal revision in another analysis [28]. In the current framework, a preventive or technical intervention becomes financially favorable only when the expected avoided capacity-adjusted margin exceeds implementation cost. Clinical effectiveness and patient safety remain the primary requirements.

Several limitations should be emphasized. First, this was a deterministic scenario model, not an empirical costing study. The clinical pathways, LOS, imaging, antimicrobial duration, operating-room time, and other revenue items were assumptions and may differ across hospitals. The 14-day A3 LOS and 70-minute operating-room duration were consensus scenario values rather than estimates from patient records. Second, a probabilistic sensitivity analysis was not performed because empirical distributions and correlations were unavailable; the simultaneous deterministic analyses show selected combinations but do not provide probability statements. Third, the FFS comparator was not a complete claims reproduction, so the break-even unmodeled points/day is a net threshold rather than predicted actual reimbursement. Fourth, direct CT, MRI, and laboratory acquisition costs were not separately micro-costed; the extent to which they are represented in the top-down ward allocation is unknown. Fifth, the ward and operating-room unit costs were modeled references derived from aggregate public inputs rather than transaction-level hospital cost accounting. The material and drug purchase ratios were institution-specific reference values rather than national standards or item-weighted transaction averages. Sixth, DPC coding, coefficients, local procurement, staffing, occupancy, and opportunity cost are institution-specific. Finally, observed complication incidence, preventive effectiveness, patient outcomes, and system-wide expenditure were outside the model. Future research should calibrate the framework with claims, patient-level resource use, and hospital cost-accounting data and should estimate empirical parameter distributions for probabilistic analysis.

Conclusions

Reimbursement structure and bed-capacity constraints can substantially change the apparent provider-side financial consequences of complication-attributable admissions after iNPH shunt surgery. In the reference scenario, DPC/PDPS produced positive accounting margins for all complete pathways, but those margins were not evidence that complications were financially desirable or that the payment system was policy-optimal. LOS, ward cost, and opportunity cost could reverse the result. Institution-specific calibration is therefore necessary before using these thresholds for service planning or prevention decisions.

Abbreviations

ARR	Absolute risk reduction
CSF	Cerebrospinal fluid
CT	Computed tomography
DPC/PDPS	Diagnosis Procedure Combination/Per-Diem Payment System
FFS	Fee-for-service
Inph	Idiopathic normal pressure hydrocephalus
IV	Intravenous
LOS	Length of stay
MRI	Magnetic resonance imaging
OR	Operating room
TDABC	Time-driven activity-based costing
VP	Ventriculoperitoneal

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1186/s13561-026-00871-4>.

Acknowledgements During the preparation of this work, the authors used ChatGPT (OpenAI) to assist with English-language editing and manuscript revision. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

Authors' contributions KG conceived the study, developed the methodology, performed the formal analysis, and drafted the manuscript. NK conceived the study, developed the methodology, supervised the work, and critically revised the manuscript. TN, TO, and KM contributed to investigation and validation. KM also critically revised the manuscript. All authors read and approved the final manuscript.

Funding This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data availability The data supporting this study are available within the article and its supplementary files. All modeled inputs were derived from publicly available fee schedules, official price lists, national statistics, and cited literature; no individual patient-level dataset was used. The reproducible Python script used to generate the figures is provided as a supplementary file.

Declarations

Ethics approval and consent to participate Not applicable. This deterministic scenario model used no patient-level or aggregate clinical record data.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

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