Cardiovascular surgery risk prediction from the patient's perspective

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Objective: Previous studies have developed cardiovascular surgery outcome prediction models using only patient risk factors, but surgery outcomes from the patient's perspective seem to differ between hospitals. We have developed outcome prediction models that incorporate preoperative patient risks, as well as hospital processes and structure.

Methods: Data were collected from the Japan Cardiovascular Database for patients scheduled for cardiovascular surgery between January 2005 and December 2007. We analyzed 33,821 procedures in 102 hospitals. Logistic regression was used to generate risk models, which were then validated through split-sample validation.

Results: Odds ratios, 95% confidence intervals, and *P* values for structures and processes in the mortality prediction model were as follows: "hospital annual adult cardiac surgery volume (continuous; every 1 procedure increase per year)" (odds ratio, 0.998; confidence interval, 0.997–0.999; *P* < .001); "recommended staffing and equipment" (odds ratio, 0.75; confidence interval, 0.64–0.87; *P* < .001); "daily conferences with cardiologists" (odds ratio, 0.79; confidence interval, 0.60–1.02; *P* = .073); "intensivists involved in postsurgical management" (odds ratio, 0.89; confidence interval, 0.77–1.02; *P* = .90); "public hospitals" (odds ratio, 0.80; confidence interval, 0.70–0.93; *P* = .003); "surgeons lacking miscellaneous duties" (odds ratio, 0.80; confidence interval, 0.70–0.93; *P* = .003); and "surgeons who work no more than 32 hours per week" (odds ratio, 0.55; confidence interval, 0.32–0.95; *P* = .032). The mortality prediction model had a C-index of 0.85 and a Hosmer–Lemeshow *P* value of .79.

Conclusions: Our models yielded good discrimination and calibration, so they may prove useful for hospital selection based on individual patient risks and circumstances. Improved surgeon work environments were also shown to be important for both surgeons and patients. (*J Thorac Cardiovasc Surg* 2011;142:e71-6)

Patient outcome evaluation is gaining acceptance as a first step in the assessment and improvement of healthcare quality. Prior studies identified predictors of mortality and morbidity,¹⁻⁶ but many of these models were developed using only patient risk factors. Given that most of these models were created for healthcare quality benchmarking, their predicted outcomes should not rely on the particular hospital in which the procedure was performed. However, from the patient's perspective, predicted outcomes of cardiovascular surgery seem to differ between hospitals, a perception that has been proven accurate.

Many studies have suggested that patients undergoing cardiovascular surgery at high-volume hospitals have lower risks of operative mortality compared with patients at lower-volume centers.⁷⁻¹¹ Hospital volume is used as a surrogate measure for numerous processes of care that directly influence patient outcomes because individual processes have not been well characterized and are

difficult to measure. For some procedures, higher volume, particularly at the surgeon level, may translate directly to better clinical judgment and technical proficiency in the operating room. Such processes may be hard to transfer to lower-volume providers. On the other hand, high-volume and low-volume centers may also differ with regard to other processes of preoperative and postoperative care, which could be adopted by lower-volume centers.¹²

To better understand the volume–outcome relationship in cardiovascular surgery, we focused on practices that involve cardiovascular procedures, including hospital processes and structure, which embody potential risks of perioperative mortality. These models may be useful not only for cardiologists considering treatment indication and referral but also for patients, because they may assist patients in site selection.

MATERIALS AND METHODS

Study Population

The Japan Adult Cardiovascular Surgery Database (JACVSD) was initiated in 2000 to estimate surgical outcomes after cardiovascular procedures in many centers throughout Japan. The JACVSD adult cardiovascular division currently captures clinical information from approximately half of all Japanese hospitals performing cardiovascular surgery. The data collection form has 255 variables (definitions are available online at <http://www.jacvds.umin.jp>), and these are almost identical to those in the Society of Thoracic Surgeons National Database (definitions are available online at

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Abbreviations and Acronyms

CI	= confidence interval
JACVSD	= Japan Adult Cardiovascular Surgery Database
OR	= odds ratio

<http://sts.org>). The JACVSD has developed software for the web-based data collection system through which the data manager of each participating hospital submits their data electronically to the central office. Although participation in the JACVSD is voluntary, data completeness is a high priority. Accuracy of submitted data was maintained by a data audit that was achieved by monthly visits by administrative office members to the participating hospital to check data against clinical records. Validity of data was further confirmed by an independent comparison of the volume of cardiac surgery at a particular hospital entered in the JACVSD with that reported in the annual survey by the Japanese Association for Thoracic Surgery.¹³

We examined all cardiovascular surgery procedures between January 1, 2005, and December 31, 2007. JACVSD records that had been obtained without patients' informed consent were excluded from this analysis. Records with missing age (or out of range), sex, or 30-day status (see "End Points") were also excluded. With the exception of body surface area, sex-specific median values were entered for all missing or out-of-range values. Although participation in the JACVSD is voluntary, data completeness is high, and less than 3% entries lack overall preoperative risk factors used in this study. After this data cleaning, the population for this risk model analysis consisted of 33,821 cardiovascular procedures from 102 participating sites throughout Japan. On the basis of interviews with cardiovascular surgeons and former studies (references), we developed items regarding structures (resources and administration) and processes (culture and professional cooperation) that may affect cardiovascular surgery outcomes.

End Points

The primary outcome measure of the JACVSD was 30-day operative mortality, which was defined exactly the same as the 30-day operative mortality in the Society of Thoracic Surgeons National Database. This includes any patient who died during the index hospitalization, regardless of the length of hospital stay, and any patient who died within 30 days of the operation after being discharged from the hospital. By using the definition from a previous study,^{14,15} major morbidity was defined as any of the following 5 postoperative in-hospital complications: stroke, reoperation for any reason, need for mechanical ventilation for more than 24 hours after surgery, renal failure, or deep sternal wound infection.

Statistical Analysis

Data ($n = 33,821$) were randomly divided into 2 subsets for model development (27,191 records, 80%) and validation tests (6630 records, 20%). The statistical model was multiple logistic regression; variables entered in the model were selected from all variables shown in Tables 1 and 2 using bivariate tests. Chi-square tests analyzed categorical covariates, and unpaired t tests or Wilcoxon rank-sum tests were used for continuous covariates. All variables significant at the $P < .2$ level were entered into the model. This model considered volume a continuous variable. A multivariate stepwise logistic regression analysis was then performed for each outcome. Stability of the model was checked every time a variable was eliminated. When all statistically nonsignificant variables had been eliminated from the model, "goodness-of-fit" was evaluated and the area under the receiver operating characteristic curve was used to assess how well the model could discriminate between patients who lived and patients who had died.¹⁶ Model calibration (the degree to which observed outcomes were

similar to the predicted outcomes across patient groups) was evaluated by comparing the observed with the predicted mean values within each of 10 equal-sized subgroups arranged in order of increasing patient risk. To evaluate model calibration, the Hosmer–Lemeshow test was applied.

RESULTS**Patient Characteristics**

Patient characteristics and outcomes of each procedure are shown in Table 1. The 33,821 procedures consisted of the following: isolated CABG surgery ($n = 10,972$), valve surgery ($n = 10,935$), thoracic aortic surgery ($n = 7559$), and other procedures ($n = 4355$). Patient median age was 68.9 years (range 60.0–75.2 years), and the percentage of male patients per procedure was as follows: CABG surgery (77.2%), valve surgery (55.1%), thoracic aortic surgery (64.5%), and other procedures (57.3%). As shown in Table 3, 30-day operative mortality rates were 2.2% for isolated CABG surgery, 3.7% for valve surgery, 8.4% for thoracic aortic surgery, and 7.1% for other procedures. Composite rates for mortality or major morbidity were 14.2% for isolated CABG surgery, 15.5% for valve surgery, 31.7% for thoracic aortic surgery, and 7.1% for other procedures.

Participant Hospital Characteristics

The characteristics of participant hospitals are shown in Table 2. Of the 102 hospitals, 53.9% were public hospitals (managed by a local public organization), 45.1% were university hospitals (affiliated with a university), and 89.2% were general hospitals (had various diagnosis and treatment departments, including at least an internal medicine department and a surgery department). Sixty-one (63.7%) of the participating hospitals met staffing and equipment criteria recommended by previous research in Japan of having more than 4 cardiovascular surgeons, more than 2 expert cardiovascular surgeons, more than 4 cardiologists, more than 2 anesthesiologists, more than 2 clinical engineers, an intensive-care unit facility, a hemodialysis unit, and more than 2 heart-lung machines. Most participant hospitals (97.1%) held more than 1 conference per week with cardiovascular surgeons.

Model Results and Performance

Two models were developed, and the final logistic model is presented in Table 4. Odds ratios (ORs), confidence intervals (CIs), and P values for structures and processes in the mortality prediction model were as follows: "hospital annual adult cardiac surgery volume (continuous: every 1 procedure increase per year)" (OR, 0.998; CI, 0.997–0.999; $P < .001$); "recommended staffing and equipment" (OR, 0.75; CI, 0.64–0.87; $P < .001$); "daily conferences with cardiologists" (OR, 0.79; CI, 0.60–1.02; $P = .073$); "intensivists involved in postsurgical management" (OR, 0.89; CI, 0.77–1.02; $P = .90$); "public hospitals" (OR, 0.80; CI,

TABLE 1. Characteristics of patients (N = 33,821)

	All patients (n = 33,821)		Test data set (N = 27,191)		Validation data set (N = 6630)	
Age (y), median (25–75)	68.9 (60.0–75.2)		68.9 (60.0–75.2)		69.0 (59.8–75.3)	
BSA (kg/m ²) median (25–75)	1.60 (1.47–1.73)		1.60 (1.47–1.73)		1.60 (1.46–1.73)	
	n	%	n	%	n	%
Gender (male)	21,909	64.8	17,575	64.6	4334	65.4
BMI 31–35 kg/m ²	923	2.7	759	2.7	163	2.7
BMI > 35 kg/m ²	142	0.4	125	0.5	17	0.3
Smoking	13,886	41.1	11,134	40.9	2752	41.5
Diabetes	8778	26.0	7060	26.0	1718	25.9
Renal failure	3807	11.3	3080	11.3	727	11.0
Renal failure requiring dialysis	1682	5.0	1370	5.0	312	4.7
Cerebrovascular disease (recent)	340	1.0	268	1.0	72	1.1
Infectious endocarditis	705	2.1	549	2.0	156	2.4
COPD (moderate, severe)	671	2.0	551	2.0	120	1.8
Extracardiac arteriopathy (peripheral)	3398	10.0	2750	10.1	648	9.8
Extracardiac arteriopathy (thoracic)	5992	17.7	4842	17.8	1150	17.3
Neurologic disorder	1302	3.8	1055	3.9	247	3.7
Congestive heart failure	8193	24.2	6589	24.2	1604	24.2
Cardiogenic shock	1579	4.7	1269	4.7	310	4.7
NYHA IV	2951	8.7	2362	8.7	589	8.9
Preoperative inotropic agents	1676	5.0	1342	4.9	334	5.0
Triple vessel disease	9120	27.0	7343	27.0	1777	26.8
Poor LV function	1745	5.2	1397	5.1	348	5.2
Tricuspid stenosis	85	0.3	70	0.3	15	0.2
Reoperation	2126	6.3	1705	6.3	421	6.3
Status (urgent)	2772	8.2	2213	8.1	559	8.4
Status (emergency)	3480	10.3	2762	10.2	718	10.8
Surgery type “isolated CABG” (reference)	10,972	32.4	8804	32.4	2168	32.7
CABG combined surgery	3427	10.1	2783	10.0	699	10.5
Surgery type “valve”	10,935	32.3	8839	32.5	2096	31.6
Aortic valve plus mitral valve	1432	4.2	1138	4.2	294	4.4
Surgery type “thoracic aorta”	7559	22.4	6089	22.4	1470	22.2
Thoracic aortic surgery indication (rupture)	662	2.0	524	1.9	138	2.1
Range of replacement (root)	922	2.7	729	2.7	193	2.9
Range of replacement (arch)	3061	9.1	2470	9.1	591	8.9
Range of replacement (distal)	1288	3.8	1042	3.8	246	3.7
Range of replacement (descending)	1361	4.0	1114	4.1	247	3.7
Range of replacement (thoracoabdominal)	553	1.6	451	1.7	102	1.5
Surgery type “other procedures”	4355	12.9	3459	12.7	896	13.5
Resection/myoplasty	157	0.5	119	0.4	38	0.6
Septal perforation/rupture	314	0.9	255	0.9	59	0.9

BSA, Body surface area; BMI, body mass index; COPD, chronic obstructive pulmonary disease; NYHA, New York Heart Association; LV, left ventricle; CABG, coronary artery bypass grafting.

0.70–0.93; $P = .003$); “surgeons who lack miscellaneous duties” (OR, 0.80; CI, 0.70–0.93; $P = .003$); and “surgeons who do not perform more than 32 hours of continuous labor” (OR, 0.55; CI, 0.32–0.95; $P = .032$).

Model performance was evaluated using the C-index (area under the receiver operating characteristic curve) as a measure of model discrimination and the Hosmer–Lemeshow test as a measure of “goodness-of-fit.” The C-index was 0.85 for the mortality model and 0.74 for the composite mortality or morbidity model; the Hosmer–Lemeshow test P value was .79 for the mortality model

and 0.49 for the composite mortality or morbidity model. Details of model performance metrics are shown in Table 5.

DISCUSSION

In this study, we developed a cardiovascular surgery risk prediction model from the patient perspective. Results of the C-index and Hosmer–Lemeshow test indicate good discrimination and calibration of the models. Patients may use these models to select a hospital according to their individual risks and circumstances. Choosing the optimal hospital also may be based on factors such as patient travel times and

TABLE 2. Characteristics of hospital (N = 102)

Hospital annual adult cardiac surgery volume, median (25–75)	115.3 (70.8–168.1)	
	n	%
Public hospital	55	53.9
University hospital	46	45.1
General hospital	91	89.2
Recommended staffing and equipment*	65	63.7
Autologous blood transfusion system	88	86.3
Have an infection control team	90	88.2
Conference with cardiovascular surgeons (every day)	49	48.0
Conference with cardiovascular surgeons (≥1/wk)	99	97.1
Conference with cardiologists (every day)	7	6.9
Conference with cardiologists (≥1/wk)	74	72.5
Conference with nurse (≥1/wk)	47	46.1
Conference with anesthesiologist (≥1/wk)	40	39.2
Intensivists involved in postsurgical management	54	52.9
Have some protocols regarding drug selection	37	36.3
Have some protocols regarding drug dilution method	70	68.6
Have some protocols regarding patients' rehabilitation	49	48.0
Routinely check head and aortic wall CT scan	78	76.5
Preoperative beta-blocker use for CABG surgery (first choice)	5	4.9
Discharge beta-blocker use for CABG surgery (first choice)	12	11.8
Discharge antiplatelet use for CABG surgery (first choice)	92	90.2
Discharge anti-lipid use for CABG surgery (first choice)	15	14.7
ITA use for CABG surgery (first choice)	99	97.1
Off-pump procedure for CABG surgery (first choice)	49	48.0
Surgeons do not have miscellaneous duties	59	57.8
Surgeons do not have >32-h labor	4	3.9

CT, Computed tomography; ITA, internal thoracic artery; CABG, coronary artery bypass grafting. *Recommended staffing and equipment were “>4 CV surgeons,” “>2 expert CV surgeons,” “>4 cardiologists,” “>2 anesthesiologists,” “>2 clinical engineers,” “have an intensive-care unit facility,” “have a hemodialysis unit,” and “>2 heart-lung machines.”

inpatient service, as well as expected outcomes for each hospital. In addition, cardiologists could use these models to determine cardiovascular surgery indications, hospital referral, and informed consent.

Effects of healthcare structures and processes in these models have further implications. Previous studies revealed the importance of teamwork in surgery as an important predictor of patient outcomes.¹⁷ Similarly, results of this study suggest that interdisciplinary professional communication may improve the outcome of cardiovascular surgery, although the best style of communication may vary by country. Because more than 2 cardiovascular surgeons routinely work together in cardiovascular surgery in Japan,⁷ 97.1% of participant hospitals have conferences with cardiovascular surgeons more than once per week. These region-specific characteristics might yield differences in the relative impact of process and structure metrics between Japan and other countries.

Although the effect of procedural volume reported by previous studies^{7,8,18} implied a critical role for adequate staffing and equipment, increased experience in high-volume hospitals may also be important (“practice makes perfect” hypothesis). Meeting the recommended staffing and equipment guidelines had significant effects on cardiovascular surgery outcomes (OR 0.75 in mortality model and 0.88 in composite model) independently of the hospital’s annual adult cardiac surgery volume. The results of this study also suggest that improving the work environment of cardiovascular surgeons is important not only for surgeons but also for patients. Long, continuous labor is common in Japan. Although continuous labor more than 32 hours is banned by Japanese labor standards law, more than 90% of hospitals routinely impose this on surgeons. The lack of physician assistants in Japan means that surgeons have a wide range of work-related responsibilities. Thus, most surgeons in this study report having miscellaneous duties. The increased workload of doctors in Japanese hospital means that many doctors experience work burnout. A previous study indicated that hospitals operating at or over capacity may experience heightened rates of adverse events,¹⁹ and the present study also found that work

TABLE 3. Outcomes of each procedure (N = 33,821)

	Isolated CABG surgery (N = 10,972)	Valve surgery (N = 10,935)	Thoracic aortic surgery (N = 7559)	Other procedures (N = 4355)	All procedures
30-d operative mortality	2.2%	3.7%	8.4%	7.1%	4.7%
Composite mortality or major morbidity	14.2%	15.5%	31.7%	19.5%	19.2%
Reoperation for any reason	5.8%	6.8%	9.3%	7.0%	7.1%
Stroke	1.5%	1.8%	6.6%	2.5%	2.9%
Renal failure newly dialysis required	3.1%	3.6%	6.1%	5.1%	4.2%
Deep sternal infection	2.1%	1.5%	2.4%	1.7%	1.9%
Prolonged ventilation	5.8%	6.3%	19.2%	9.8%	9.5%

CABG, Coronary artery bypass grafting.

TABLE 4. Description of each prediction model (N = 27,191)

	30-d operative mortality				Composite mortality or major morbidity			
	P	OR	95% CI		P	OR	95% CI	
			Lower	Upper			Lower	Upper
Preoperative risks								
Age, y (16–60, 61–65, 66–70, 71–75, 76–80, 81–100)	.000	1.22	1.17	1.27	.000	1.11	1.09	1.13
BMI 31–35 kg/m ²	.057	1.42	0.99	2.04	.000	1.76	1.49	2.08
BMI > 35 kg/m ²	.054	2.05	0.99	4.26	—	—	—	—
Smoking	—	—	—	—	.003	1.11	1.04	1.19
Diabetes	—	—	—	—	.001	1.15	1.06	1.25
Renal failure	.000	1.92	1.59	2.32	.000	2.19	1.95	2.45
Renal failure requiring dialysis	.000	4.15	3.23	5.34	.080	2.53	2.15	2.98
Cerebrovascular disease (recent)	—	—	—	—	.010	1.47	1.10	1.97
Infectious endocarditis	.004	1.64	1.17	2.30	.006	1.36	1.09	1.69
COPD (moderate, severe)	.000	2.49	1.87	3.30	.000	1.80	1.47	2.19
Extracardiac arteriopathy (peripheral)	.000	1.61	1.35	1.92	.000	1.43	1.29	1.58
Extracardiac arteriopathy (thoracic)	—	—	—	—	.000	1.28	1.14	1.43
Neurologic disorder	.022	1.33	1.04	1.69	.002	1.29	1.10	1.51
Congestive heart failure	.000	1.59	1.35	1.87	.000	1.27	1.17	1.39
Cardiogenic shock	.000	1.68	1.35	2.10	.000	1.60	1.37	1.88
NYHA IV	.000	1.51	1.24	1.84	.000	1.74	1.54	1.96
Preoperative inotropic agents	.000	1.50	1.22	1.85	.000	1.34	1.16	1.55
Triple vessel disease	—	—	—	—	.003	1.18	1.06	1.32
Poor LV function	.000	2.34	1.90	2.87	.000	1.66	1.44	1.90
Tricuspid stenosis	.030	2.63	1.10	6.31	.000	2.87	2.55	3.22
Reoperation	.000	2.73	2.26	3.30	—	—	—	—
Status (urgent)	.000	1.72	1.39	2.13	.000	1.41	1.25	1.59
Status (emergency)	.000	2.98	2.46	3.62	.000	2.06	1.81	2.33
Surgery type “isolated CABG” (reference)	.000				.000			
CABG combined surgery	.000	1.65	1.38	1.98	.000	1.57	1.40	1.76
Surgery type “valve”	.000	1.60	1.29	1.99	.001	1.26	1.10	1.43
Aortic valve + mitral valve	.001	2.61	1.96	3.48	.000	1.85	1.58	2.18
Surgery type “thoracic aorta”	.000	2.60	2.05	3.30	.000	1.61	1.35	1.92
Thoracic aortic surgery indication (rupture)	.000	4.23	3.23	5.54	.000	2.58	2.08	3.19
Range of replacement (root)	—	—	—	—	.082	1.93	1.57	2.36
Range of replacement (arch)	.004	3.61	2.89	4.51	.000	2.52	2.22	2.87
Range of replacement (distal)	.001	4.02	3.07	5.25	.004	2.04	1.74	2.40
Range of replacement (descending)	.000	4.47	3.44	5.80	—	—	—	—
Range of replacement (thoracoabdominal)	.000	6.66	4.69	9.45	.000	3.34	2.66	4.20
Surgery type “other procedures”	.000	2.16	1.71	2.72	.029	1.18	1.02	1.37
Resection/myoplasty	.046	4.32	2.18	8.56	.025	1.99	1.26	3.13
Septal perforation/rupture	—	—	—	—	.000	2.94	2.16	4.01
Structure and process of care								
Hospital annual adult cardiac surgery volume (continuous)	.000	0.998	0.997	0.999	0.000	0.999	0.998	0.999
Recommended staffing and equipment*	.000	0.75	0.64	0.87	.003	0.88	0.80	0.95
Conference with cardiologists (every day)	.073	0.79	0.60	1.02	—	—	—	—
Conference with nurse (≥1/wk)	—	—	—	—	.003	0.89	0.82	0.96
Intensivists concerned postsurgical management	.090	0.89	0.77	1.02	.007	0.91	0.84	0.97
Have some protocols regarding drug dilution method	—	—	—	—	.000	0.83	0.77	0.90
Public hospitals	.003	0.80	0.70	0.93	—	—	—	—
Surgeons do not have miscellaneous duties	.003	0.80	0.70	0.93	.095	0.94	0.87	1.01
Surgeons do not have >32-h labor	.032	0.55	0.32	0.95	—	—	—	—

OR, Odds ratio; CI, confidence interval; BMI, body mass index; LV, left ventricle; NYHA, New York Heart Association; COPD, chronic obstructive pulmonary disease. *Recommended staffing and equipment were “>4 CV surgeons,” “>2 expert CV surgeons,” “>4 cardiologists,” “>2 anesthesiologists,” “>2 clinical engineers,” “have an intensive-care unit facility,” “have a hemodialysis unit,” and “>2 heart-lung machines.”

TABLE 5. Performance of each prediction model (N = 6630)

	30-d operative mortality	Composite mortality or major morbidity
C-statistics	0.847	0.744
Hosmer–Lemeshow test (P value)	.790	.485

environment improvements might result in benefits for surgery outcomes and surgeons' quality of life.

Study Limitations

This study has several limitations. Although we chose healthcare structures and processes of care based on interviews and previous studies, specific items we chose to represent the structures and processes may not cover all relevant factors. For that reason, the validity of process and structure metrics should be reevaluated. In addition, process indicators were collected at the hospital level in this study. To obtain a better understanding of process metrics relative to standardized clinical characteristics, future studies should confirm process metrics at the patient level. Because participation in the JACVSD is voluntary, the database does not cover all cardiovascular programs in Japan.¹³ As such, the generalizability of our findings is limited. In addition, although predicted patient outcomes based on hospital process compliance rates may be useful for choosing a hospital, patients do not always have sufficient granularity information, such as whether the appropriate processes are in place or whether the surgical skill for a particular procedure they require is available. Patients should be cautious in their search, recognizing that individual circumstances may dictate different requirements.

CONCLUSIONS

To better understand the volume–outcome relationship in cardiovascular surgery, we focused on practices that involve cardiovascular procedures, including hospital processes and structure, which embody potential risks of perioperative mortality. Our models yielded good discrimination and calibration, so they may prove useful for hospital selection based on individual patient risks and circumstances. As for structure of care in Japan, improved surgeon work environments were also shown to be important for both surgeons and patients.

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