Effects of Appointing a Full-Time Neurointensivist to Run a Closed-Type Neurological Intensive Care Unit

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Background and Purpose To investigate whether appointing a full-time neurointensivist to manage a closed-type neurological intensive care unit (NRICU) improves the quality of critical care and patient outcomes.

Methods This study included patients admitted to the NRICU at a university hospital in Seoul, Korea. Two time periods were defined according to the presence of a neurointensivist in the preexisting open-type NRICU: the before and after periods. Hospital medical records were queried and compared between these two time periods, as were the biannual satisfaction survey results for the families of patients.

Results Of the 15,210 patients in the neurology department, 2,199 were admitted to the NRICU (n=995 and 1,204 during the before and after periods, respectively; p<0.001). The length of stay was shorter during the after than during the before period in both the NRICU (3 vs. 4 days; p<0.001) and the hospital overall (12.5 vs. 14.0 days; p<0.001). Neurological consultations (2,070 vs. 3,097; p<0.001) and intrahospital transfers from general intensive care units to the NRICU (21 vs. 40; p=0.111) increased from the before to after the period. The mean satisfaction scores of the families of the patients also increased, from 78.3 to 89.7. In a Cox proportional hazards model, appointing a neurointensivist did not result in a statistically significant change in 6-month mortality (hazard ratio, 0.82; 95% confidence interval, 0.652–1.031; p=0.089).

Conclusions Appointing a full-time neurointensivist to manage a closed-type NRICU had beneficial effects on quality indicators and patient outcomes.

Key Words critical care, intensive care unit, neurology, critical care outcomes

INTRODUCTION

Neurocritical care has been classified as a subspecialty of neurology that primarily focuses on critical care for neurologically ill patients and neurological care for critically ill patients. Previous studies have found that providing neurocritical care services may improve clinical outcomes in critically ill patients with neurological diseases, including traumatic brain injury, intracerebral hemorrhage, and subarachnoid hemorrhage. Social awareness about patient safety has also increased the awareness about high-quality neurocritical care among patients and neurologists. Having a neurointensivist staff member and organizing the intensive care unit (ICU) infrastructure are crucially important for providing adequate care to neurocritically ill patients. However, there is currently a lack of full-time neurointensivists in Korean hospitals despite the presence of neurological, neurosurgical, or general ICUs in most general hospitals. To our knowledge, the effects of full-time neurointensivist staffing in a dedicated neurological intensive care unit (NRICU)—which may comprise a different patient population than a neurosurgical ICU, a combined neurological and neuro-
surgical ICU, or a general ICU—on the quality of care and outcomes of neurocritically ill patients have not been described previously.

The ICU can be organized in two ways in terms of the role played by an intensivist, and this may influence the quality of critical care and patient outcomes. In an open-type ICU, patients are admitted to the ICU under the care of a nonintensivist physician, and an intensivist is available to provide their expertise via elective or mandatory consultations. In a closed-type ICU, patient care is transferred to an intensivist who is responsible for the clinical management and family meetings. For general critical care, the closed-type ICU is thought to be a more favorable setting than the open type in terms of patient safety and efficiency in the use of ICU resources. However, studies of the effects of the two ICU types on quality of care and patient outcomes in the field of neurocritical care are lacking.

Here we report the effects of full-time neurointensivist staffing in a closed-type NRICU on the quality of critical care and patient outcomes.

**METHODS**

**Study design and population**

A quasi-experimental uncontrolled before-and-after study design was utilized. Patients were included in the current study if they were admitted to the NRICU of the Department of Neurology at Asan Medical Center, Seoul, Korea between March 1, 2010 and February 28, 2016. Patients were excluded if they were younger than 18 years, did not have medical records available for analysis in this study, or if brain death was declared before admission to the NRICU. Two time periods were defined according to the appointment of a neurointensivist: the before period (from March 1, 2010 to February 28, 2013) and the after period (from March 1, 2013 to February 28, 2016). This study was approved by the Institutional Review Boards, and the need for written informed consent was waived because of the retrospective design of the study (IRB No. 2016-0379).

**Infrastructure and staffing of the NRICU**

The NRICU of Asan Medical Center includes 13 beds, 7.5 of which are formally assigned to patients admitted to the Department of Neurology. When critically ill patients are admitted to the Department of Neurology, they are admitted routinely to the NRICU. During the before period, these patients were managed by neurology residents, neurology fellows, and attending neurologists, and elective consultations with general intensivists were performed as necessary (open-type ICU). A full-time neurointensivist (S.-B.J.) was appointed on March 1, 2013, after which neurology patients in the NRICU were managed by neurology residents and this neurointensivist. Patient care in the NRICU was transferred to the neurointensivist (closed-type ICU). For 92 patients with seizures or status epilepticus, the neurointensivist provided mandatory comanagement with attending neurologists; such management was transferred completely to the neurointensivist after January 2016. The neurointensivist was also responsible for every consultation to the Department of Neurology for patients with a neurological problem during admission to general ICUs. In addition, the neurointensivist covered one session per week of the outpatient neurology clinic, where he followed up patients discharged from the NRICU and patients previously consulted at general ICUs. There were no other changes to the nurse staffing and infrastructure of the NRICU during the 6-year period of the current study. The characteristics of the NRICU infrastructure are compared between the two time periods in Table 1.

The neurointensivist introduced protocols for use in the NRICU, including barbiturate coma therapy, targeted temperature management, measurement and management of intracranial pressure, osmotherapy, management of malignant infarctions, evaluation of brain death, evaluation and management of meningoencephalitis, and evaluation and management of comatose restoration of spontaneous circulation after cardiopulmonary resuscitation. The neurointensivist held regular sessions to educate neurology residents and NRICU nurses regarding these protocols and general issues related to neurocritical care.

**Data collection**

Electronic medical record and medical cost data were queried by the Information Technology Service Management of Asan Medical Center for all patients admitted to the NRICU during the study period. Data were obtained on demographics, comorbidities, vital signs, laboratory tests, medications, procedure records, complications, and clinical status (severity of illness) on admission, including scores on the Glasgow Coma Scale and Acute Physiology and Chronic Health Evaluation II (APACHE II). Additional patient information and formal reports on imaging investigations were retrieved from the electronic medical records and the picture archiving and communication system, respectively. Information on the survival status up to 6 months after admission to the NRICU was obtained from the electronic medical records. Hospital-acquired pneumonia and catheter-associated urinary tract infection were defined in accordance with international guidelines. Venous thromboembolism was diagnosed when computed tomography and/or ultrasonography revealed a thrombus in the venous struc-
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Gastrointestinal bleeding was diagnosed in an endoscopy examination. The predicted in-hospital mortality rate was calculated based on the APACHE II score.16

Neurology consultations, inter-ICU transfers, family satisfaction, and medical costs

The number of neurology consultations was assessed from general ICUs and the number of intrahospital inter-ICU transfers. Transfers were categorized into transfers from general ICUs (nonneurology departments) to the NRICU (neurology department) and transfers from the NRICU to general ICUs. The current study regarded the numbers of neurology consultations and inter-ICU transfers from general ICUs to the NRICU as proxies for the satisfaction of general intensivists (nonneurologists) with the neurological service provided by neurologists during the before period or by a neurointensivist during the after period.

A hospital customer-satisfaction team conducted a patient-family satisfaction survey regularly (twice yearly) throughout the 6-year study period. This survey consisted of a face-to-face interview with 30 families of patients admitted to the NRICU who were chosen randomly by the team. The questionnaire comprised one item assessing the general satisfaction with medical services in the NRICU and four items assessing opinions about physicians (neurologists or a neurointensivist), including their kindness, trust, explanations, and availability for family meetings. Each item of the questionnaire was rated on a 5-point scale, with the lowest score representing dissatisfaction and the highest score representing satisfaction.

Total medical costs incurred during the hospital stays were calculated for the two study periods. They were organized into cost per year and cost per patient, with the latter further categorized into deductible and nondeductible costs.

Statistical analysis

Data are presented as median and interquartile range (IQR) values for continuous variables and as number and percentage values for categorical variables. Baseline characteristics (demographics, comorbidities, diagnosis, and severity of illness), clinical management, quality indicators, clinical outcomes, the number of neurology consultations, the number of inter-ICU transfers, and the family satisfaction scores were compared between before and after appointing a full-time neurointensivist. Pearson’s χ² test and Fisher’s exact test were used for categorical variables, and the t test or the Mann-Whitney U test was used for continuous variables, as appropriate. The Kaplan-Meier method was used to generate survival curves, and the curves were compared using a Cox proportional hazards analysis with adjustments for demographics, comorbidities, and severity of illness (total acute physiology scores on the APACHE II score). Statistical significance was defined as a two-tailed p value of <0.05. All data were analyzed using SPSS (version 21, IBM Corporation, Armonk, NY, USA).

Table 1. ICU infrastructure and practices during the two study periods

|                      | Before period               | After period               |
|----------------------|-----------------------------|----------------------------|
| Study period         | 03/01/2010–02/28/2013       | 03/01/2013–02/28/2016      |
| Total beds in the NRICU, n | 13                          | 13                         |
| Beds dedicated to the Department of Neurology, n | 7.5                         | 7.5                        |
| Nurses, n            | 23                          | 23                         |
| Total number of attending physicians | 11 neurologists (11 nonintensivist neurologists) | 1 neurointensivist (1 neurologist intensivist) |
| Treating physicians per patient, n | 3 (R2, R4/F, attending neurologist) | 2 (R2, attending neurointensivist) |
| Communication for decision making between residents and attending physicians | R2 ≠ R4/F ≠ attending neurologist | R2 ≠ attending neurointensivist |
| Organizational system | Open type                   | Closed type                |
| Performance of procedure | R2 with/without R4           | R2 with attending neurointensivist |
| Weekday rounds of attending physicians | Irregularly, once or more | Regularly, twice or more |
| Weekend rounds of attending physicians | Irregularly, none or once | Regularly, once or more |
| Family meeting, scheduled | Irregularly, once           | Regularly, once or twice  |
| Education about critical care provided to residents and nurses | No                          | Yes                        |
| NRICU protocols       | Absent                      | Present                    |
| Neurology consultations at general ICUs | To 11 neurologists | To 1 neurointensivist |

attending physician: faculty neurologists (the before period) or a faculty neurointensivist (the after period), F: neurology fellow supervising R2, ICU: intensive care unit, NRICU: neurological intensive care unit, R2: year-2 neurology resident, R4: year-4 neurology resident supervising R2.
RESULTS

There were 15,210 admissions to the Department of Neurology during the study period: 7,550 during the before period and 7,660 during the after period. Of these, 1,057 and 1,229 patients were admitted to the NRICU during the before and after periods, respectively. Sixty-two patients who were admitted to the NRICU during the before period were excluded for the following reasons: younger than 18 years (9 patients), medical records unavailable due to transfer to the Department of Psychiatry (3 patients), and hospital readmission to the NRICU (50 patients). Likewise, 25 patients who were admitted to the NRICU during the after period were excluded for the following reasons: younger than 18 years (3 patients), medical records unavailable (2 patients), hospital readmission to the NRICU (18 patients), and brain death declared prior to admission to the NRICU (2 patients). The remaining 2,199 patients were included in the final analysis, comprising 995 (13.2%) during the before period and 1,204 (15.7%) during the after period. Accordingly, the number of patients who were admitted to the NRICU increased by 21% after appointing a neurointensivist ($p < 0.001$). The 2,199 patients included 1,354 (61.6%) men. The patients were aged $63.4 \pm 14.6$ years (mean ± SD; median, 66.0 years; IQR, 55.0–74.0 years), and their APACHE II score was $11.1 \pm 6.3$ (median, 10.0; IQR, 7.0–15.0; Table 2).

Clinical practices, quality indicators, and outcomes

The clinical practices and complications during admission to the NRICU are listed in Table 3. Prophylaxis for deep-vein thrombosis with subcutaneous unfractionated or low-molecular-weight heparin was performed more frequently during the after period than during the before period ($p < 0.010$). There were nonsignificantly fewer patients with kidney injury requiring continuous renal replacement therapy during the after period than during the before period ($p = 0.070$). The specialized neurocritical care treatments of continuous electroencephalographic monitoring ($p < 0.001$), intracranial pressure monitoring ($p = 0.078$), therapeutic hypothermia ($p < 0.001$), and barbiturate coma therapy ($p = 0.013$) were performed more frequently during the after period than during the before period. The complication rates in the NRICU did not differ significantly between the two periods.

Patient outcomes and quality indicators regarding clinical management are presented in Table 4. Among the patients on mechanical ventilation, there were nonsignificantly more mechanical ventilator-free days during the after period than during the before period [median, 12 days (IQR, 4–20 days) vs. median, 10 days (IQR, 2–7 days), $p = 0.085$]. The ICU stay was significantly shorter during the after period than during the before period [median, 12.5 days (IQR, 7–31 days) vs. median, 14 days (IQR, 8–36 days), $p < 0.001$]. The predicted in-hospi-

Table 2. Baseline characteristics

| Demographics          | Before period (n=995) | After period (n=1,204) | SD (%) |
|-----------------------|----------------------|------------------------|--------|
| Age, years            | 66 (53–73)           | 66 (55–74)             | -4.12  |
| Sex, male             | 606 (60.9)           | 748 (62.1)             | 4.17   |
| Comorbidities         |                      |                        |        |
| Hypertension          | 519 (52.2)           | 601 (49.9)             | 5.21   |
| Diabetes mellitus     | 273 (27.4)           | 286 (23.8)             | 5.11   |
| Hypercholesterolemia  | 471 (47.3)           | 540 (44.9)             | 5.09   |
| Alcohol consumption   | 50 (5.0)             | 70 (5.8)               | 0.30   |
| Smoking               | 176 (17.7)           | 241 (20.0)             | 0.91   |
| Neurological diagnosis|                      |                        |        |
| Cerebrovascular disease| 392 (39.4)         | 486 (40.4)             | -1.98  |
| Scheduled procedure or operation | 396 (39.8) | 403 (33.5) | 6.83   |
| Meningoencephalitis   | 54 (5.4)             | 98 (8.1)               | -10.50 |
| Seizure or status epilepticus | 30 (3.0)   | 82 (6.8)               | -4.01  |
| Demyelinating diseases| 32 (3.2)             | 36 (3.0)               | 1.30   |
| Others                | 91 (9.1)             | 100 (8.3)              | 2.98   |
| Clinical status on admission |                |                        |        |
| GCS score             | 14.0 (10.0–15.0)     | 14.0 (10.0–15.0)       | 0      |
| APACHE II score       | 10.0 (7.0–15.0)      | 10.0 (6.0–15.0)        | 2.72   |

Data are n (%) or median (IQR) values.

APACHE II: Acute Physiology and Chronic Health Evaluation II, GCS: Glasgow Coma Scale, IQR: interquartile range.
tal mortality rate was 9.8% during the before period and 9.7% during the after period according to APACHE II scores; the corresponding observed rates were 5.6% (56/995) and 4.6% (55/1,204), respectively. The 6-month mortality rate did not differ significantly between the after and before periods \(n=149 (12.4\%) \text{ vs. } n=146 (14.7\%), p=0.131\]. Applying a Cox proportional hazards model revealed that appointing a neurointensivist did not result in statistically significant differences in 6-month mortality after adjustments for demographics (age and sex), comorbidities (hypertension, diabetes mellitus, hypercholesterolemia, alcohol, and smoking), and acute physiology scores on the APACHE II score (hazard ratio, 0.82; 95% confidence interval, 0.652–1.031; \(p=0.089\)) (Fig. 1).

Neurology consultations, inter-ICU transfers, and family satisfaction
The number of neurology consultations increased after appointing a full-time neurointensivist, from 2,070 (9.7%) to 3,097 (14.7%) \((p<0.001\)). Inter-ICU transfers from general ICUs to the NRICU \([21 (2.1\%) \text{ vs. } 40 (3.3\%), p=0.111\] increased nonsignificantly, and inter-ICU transfers from the NRICU to general ICUs \([29 (2.9\%) \text{ vs. } 8 (0.7\%), p<0.001\] decreased significantly (Table 5). The mean scores for the general satisfaction of patient families with medical services during admission to the NRICU increased from 78.3 to 89.7; that is, the degree of general satisfaction increased by 14.6%. The mean scores for questions about physicians in terms of their kindness (from 81.3 to 91.7), decision-making (from 81.0 to 91.3), explanations (from 79.7 to 91.0), and availability for family meetings (from 72.3 to 85.0) also all increased.

### Medical costs
The total medical cost incurred during the hospital stays was 15,325,767,625 won for 995 patients during the before period and 16,880,071,965 won for 1,204 patients during

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**Table 3. Clinical practice and complications**

| Clinical management procedures                                      | Before period (n=995) | After period (n=1,204) | \(p\)  |
|---------------------------------------------------------------------|-----------------------|------------------------|--------|
| Deep vein thrombosis prophylaxis                                    | 242 (24.3)            | 353 (29.3)             | 0.010  |
| Gastrointestinal prophylaxis                                        | 892 (89.6)            | 1074 (89.2)            | 0.788  |
| Endotracheal intubation                                             | 194 (19.5)            | 247 (20.5)             | 0.589  |
| Tracheotomy                                                        | 112 (11.3)            | 125 (10.4)             | 0.556  |
| Mechanical ventilation                                              | 161 (16.2)            | 225 (18.7)             | 0.138  |
| Continuous renal replacement therapy                                | 33 (3.3)              | 24 (2.0)               | 0.070  |
| Continuous electroencephalography monitoring                       | 29 (2.9)              | 101 (8.4)              | <0.001 |
| Intracranial pressure monitoring                                    | 16 (1.6)              | 34 (2.8)               | 0.078  |
| Therapeutic hypothermia                                             | 0 (0)                 | 18 (1.5)               | <0.001 |
| Barbiturate coma therapy                                            | 7 (0.7)               | 25 (2.1)               | 0.013  |

**Table 4. Clinical outcomes and quality indicators**

| Outcome                                                                 | Before period (n=995) | After period (n=1,204) | \(p\)  |
|------------------------------------------------------------------------|-----------------------|------------------------|--------|
| Mechanical ventilatior-free days                                      | 10 (2–7)              | 12 (4–20)              | 0.085  |
| NRICU readmission                                                     | 44 (4.4)              | 46 (3.8)               | 0.548  |
| Length of NRICU stay, days                                           | 4.0 (2.0–8.0)         | 3.0 (2.0–6.0)          | <0.001 |
| Length of hospital stay, days                                         | 14.0 (8.0–36.0)       | 12.5 (7.0–31.0)        | <0.001 |
| GCS score at NRICU discharge                                          | 14 (11–15)            | 14 (11–15)             | 0.394  |
| In-hospital mortality                                                 | 56 (5.6)              | 55 (4.6)               | 0.302  |
| Six-month mortality                                                   | 146 (14.7)            | 149 (12.4)             | 0.131  |

Data are \(n\)\% or median (IQR) values.

GCS: Glasgow Coma Scale, IQR: interquartile range, NRICU: neurological intensive care unit.
the after period. The annual medical cost increased from 5,108,589,208 won during the before period to 5,626,690,655 won during the after period. Thus, the annual hospital income increased by 518,101,447 won after appointing a single neurointensivist. The total median medical cost per patient was 10,993,897 won during the before period and 9,914,534 won during the after period ($p=0.001$). The medical cost paid by patients decreased from 3,925,302 won to 3,288,087 won ($p<0.001$), and that paid by the National Health Insurance Corporation decreased from 6,811,628 won to 6,214,627 won ($p=0.026$) after appointing a neurointensivist. Thus, both the medical cost per patient paid by the patients themselves and that paid by the National Health Insurance Corporation decreased significantly after appointing a neurointensivist (Table 6).

DISCUSSION

We investigated the effect of appointing a full-time neurointensivist to manage a closed-type NRICU. After appointing a neurointensivist, the length of NRICU stays decreased by 1 day (from 4 to 3 days); this decrease was maintained in our analysis of the length of hospital stays (from 14.0 to 12.5 days). The decreases in the lengths of ICU and hospital stays did not occur at the expense of patient safety, including the ICU readmission rate. Rather, the decrease in length of stay allowed significantly more admissions to the NRICU (which increased by 21%), which demonstrates the more efficient utilization of NRICU beds. Furthermore, the in-hospital and 6-month mortality rates showed decreasing tendencies, from 5.6% to 4.6% and from 14.7% to 12.4%, respectively, but these changes were not statistically significant. Neurology consulta-

Table 5. Neurological consultations and inter-ICU transfers among patients admitted to the NRICU and general ICUs

|                          | Before period (ICUs: n=21,336) | After period (ICUs: n=21,009) | p     |
|--------------------------|---------------------------------|-------------------------------|-------|
|                          | (NRICU: n=995)                  | (NRICU: n=1,204)              |       |
| Neurology consultations  | 2,070 (9.7)                     | 3,097 (14.7)                  | <0.001|
| For stroke               | 600                             | 817                           |       |
| For metabolic encephalopathy | 416                          | 659                           |       |
| For seizure              | 412                             | 738                           |       |
| For evaluation of coma and brain death | 278                  | 380                           |       |
| For neuromuscular diseases | 163                          | 194                           |       |
| For neurodegenerative diseases | 75                           | 124                           |       |
| For abnormal movements   | 70                              | 80                            |       |
| For infection or inflammation of the CNS | 56                        | 105                           |       |
| Intrahospital, inter-ICU transfers |                           |                               |       |
| From general ICUs to the NRICU | 21 (2.1) | 40 (3.3)                      | 0.111 |
| For stroke management    | 16                              | 26                            |       |
| For neurological deterioration | 5                           | 14                            |       |
| From the NRICU to general ICUs | 29 (2.9) | 8 (0.7)                      | <0.001|
| For mechanical ventilation | 11                          | 0                             |       |
| For cardiac management   | 7                               | 0                             |       |
| For chemotherapy         | 3                               | 3                             |       |
| For other types of medical management | 2                        | 0                             |       |
| For operations           | 6                               | 5                             |       |

Data are n or n (%) values.
CNS: central nervous system, ICU: intensive care unit, NRICU: neurological intensive care unit.

Fig. 1. Presence of a neurointensivist and 6-month survival outcomes. Kaplan-Meier curves showing the proportion of surviving patients stratified by whether a neurointensivist was appointed.
Appointing a Full-Time Neurointensivist

The in-hospital mortality rate in the current study decreased by 1% after implementing a full-time neurointensivist; that is, 1 more of every 100 neurocritically ill patients survived after this change. However, this finding did not reach statistical significance, which is probably due to the sample size being insufficient and the already low mortality rate of the preexisting NRICU infrastructure of the study hospital. Alternatively, the lower mortality in the current study compared with previous studies may have been due to differences in the study populations: patients with traumatic brain injury, intracerebral hemorrhage, and subarachnoid hemorrhage who are admitted to a neurosurgical ICU or a combined neurological and neurosurgical ICU generally have a higher mortality rate than patients with ischemic stroke and other neurological diseases.17,18 The observed in-hospital mortality rate was below that expected based on APACHE II score during both the before period (5.6% vs. 9.8%) and the after period (4.6% vs. 9.7%), respectively. The decrease in the 6-month mortality rate may be related to the beneficial effects provided by having a neurointensivist in the NRICU because appropriate care during the critical phase of illness may improve the long-term outcomes of patients.19 Our findings suggest that appointing a neurointensivist and changing the organization of an NRICU from an open type to a closed type can reduce patient mortality. However, this interpretation requires confirmation since this was a single-center study and our findings did not reach statistical significance.

Studies assessing the satisfaction of general intensivists and the families of patients in the NRICU are lacking. We considered the number of neurology consultations and inter-ICU transfers as proxies for the satisfaction of general intensivists who were working in nonneurology ICUs with the performance of neurologists or the neurointensivist. These proxies were used because no data from prospective surveys of coworkers were available, and a survey initiated during the after period could be affected by recall bias. The number of neurology consultations from general ICUs and inter-ICU transfers from general ICUs to the NRICU increased after appointing a neurointensivist. This could be interpreted as indicating that the satisfaction of general intensivists with the neurology service provided by the neurointensivist increased compared to the service provided by neurologists. Alternatively, the decrease in the number of inter-ICU transfers from the NRICU to general ICUs might be related to the competence of a closed-type NRICU run by a neurointensivist. To assess the satisfaction of the families of patients, the results of the prospective survey performed during the before period and the after period were available for the current study. These results showed that the general satisfaction of patient families with critical care in the NRICU and with how the physicians performed increased after appointing a neurointensivist. Thus, having a neurointensivist staff member might also satisfy the general intensivists by managing neurological problems occurring in general ICUs and satisfy the patient families by providing improved critical care in the NRICU.

Our study was subject to some limitations. First, a single-

### Table 6. Medical costs incurred during hospital stay

|                      | Before period (n=995)          | After period (n=1,204)          | p      |
|----------------------|-------------------------------|--------------------------------|--------|
| **Cost per year, won** |                               |                                |        |
| Total cost           | 5,108,589,208                 | 5,626,690,655                  | NA     |
| Paid by patients     | 1,922,103,697                 | 2,125,910,448                  | NA     |
| Paid by the NHIC     | 3,186,485,511                 | 3,500,780,207                  | NA     |
| **Cost per patient, won** |                           |                                |        |
| Total cost           | 10,993,897 (7,135,764–17,392,009) | 9,914,534 (6,081,234–16,454,063) | 0.001  |
| Paid by patients     | 3,925,302 (2,475,226–7,275,650) | 3,288,087 (2,008,943–6,625,974) | <0.001 |
| Deductible cost      | 935,381 (489,964–2,095,110)   | 867,789 (478,575–1,904,109)    | 0.176  |
| Nondeductible cost   | 2,809,588 (1,654,818–5,113,634) | 2,292,364 (1,304,439–4,658,748) | <0.001 |
| Paid by the NHIC     | 6,811,628 (4,309,383–10,545,011) | 6,214,627 (3,760,034–10,019,246) | 0.026  |

Data for the cost per patient are median (IQR) values. IQR: interquartile range, NA: not available, NHIC: National Health Insurance Corporation.
The shortage of neurointensivists in Korea, hospital neurointensivist is sufficient to run a closed-type NRICU. However, the present results should not be interpreted as evidence that appointing a single neurointensivist was associated with improved outcomes because the latter data were not available for the current retrospective study. The mortality rate may be an inadequate parameter for evaluating the clinical outcomes of neurocritically ill patients. Fourth, the satisfaction of neurology residents and nurses regarding the education they received about neurocritical care and management in the NRICU was not investigated, because none of the residents and only a small proportion of the nurses were employed in the NRICU throughout the 6-year study period. Fifth, the professional burnout of the neurointensivist was not assessed. Although the current study showed that appointing a neurointensivist was associated with improvements in quality indicators and patient outcomes, running a closed-type NRICU for a prolonged period with a single neurointensivist may eventually lead to negative impacts on patient care and safety due to neurointensivist burnout.\(^\text{20}\)

In conclusion, appointing a full-time neurointensivist and implementing organizational changes for running a closed-type NRICU have beneficial effects on quality indicators of care, patient outcomes, and satisfaction of general intensivists and patient families. However, the present results should not be interpreted as evidence that appointing a single neurointensivist is sufficient to run a closed-type NRICU. Given the shortage of neurointensivists in Korea, hospital administrative efforts should also be made to prevent professional burnout and enable shift work for neurointensivists.

### Conflicts of Interest

The authors have no potential conflicts of interest to disclose.

### Acknowledgements

This research was supported by grants from the Korean Neurocritical Care Society (2016); and the Korea Health Technology R&D Project through the Korea Health Industry Development Institute (KHIDI), funded by the Ministry of Health & Welfare, Republic of Korea (grant number: HI18C1487).

### REFERENCES

1. Wijdicks EF. The scope of neurology of critical illness. Handb Clin Neurol 2017;141:443–447.
2. Diringer MN, Edwards DF. Admission to a neurologic/neurosurgical intensive care unit is associated with reduced mortality rate after intracerebral hemorrhage. Crit Care Med 2001;29:635–640.
3. Josephson SA, Douglas VC, Lawton MT, English JD, Smith WS, Ko NU. Improvement in intensive care unit outcomes in patients with subarachnoid hemorrhage after initiation of neurointensivist co-management. J Neurosurg 2010;112:626–630.
4. Samuels O, Webb A, Culler S, Martin K, Barrow D. Impact of a dedicated neurocritical care team in treating patients with aneurysmal subarachnoid hemorrhage. Neurocrit Care 2011;14:334–340.
5. Suarez JI, Zaidat OO, Suri MF, Feen ES, Lynch G, Hickman J, et al. Length of stay and mortality in neurocritically ill patients: impact of a specialized neurocritical care team. Crit Care Med 2004;32:2311–2317.
6. Varelas PN, Eastwood D, Yun HY, Spanaki MV, Haeckin B, Kessaris C, et al. Impact of a neurointensivist on outcomes in patients with head trauma treated in a neurosciences intensive care unit. J Neurosurg 2006;104:713–719.
7. Lim CM, Kwak SH, Suh GY, Koh Y. Critical care in Korea: present and future. J Korean Med Sci 2015;30:1540–1544.
8. Marcolini EG, Seder DB, Bonombo J, Bleck TP, Hemphill JC 3rd, Shutter L, et al. The present state of neurointensivist training in the United States: a comparison to other critical care training programs. Crit Care Med 2018;46:307–315.
9. Song HK, Lee BI, Lee JH, Lee KS, Whang SH. Status of neurocritical care in Korea: a nationwide questionnaire survey. J Neurocrit Care 2013;6:82–86.
10. Varelas PN, Conti MM, Spanaki MV, Potts E, Bradford D, Sunstrom C, et al. The impact of a neurointensivist-led team on a semiclosed neurosciences intensive care unit. Crit Care Med 2004;32:2191–2198.
11. Chowdhury D, Duggal AK. Intensive care unit models: do you want them to be open or closed? A critical review. Neurol India 2017;65:39–45.
12. Watson GA, Alarcon LH. Intensivists: don’t quit your day job...yet! Crit Care 2010;14:305.
13. Pronovost PJ, Angus DC, Dormand T, Robinson KA, Dremislov TT, Young TL. Physician staffing patterns and clinical outcomes in critically ill patients: a systematic review. JAMA 2002;288:2151–2162.
14. Van der Sluis FJ, Slagt C, Liebman B, Beute J, Mulder JW, Engel AF. The impact of open versus closed format ICU admission practices on the outcome of high risk surgical patients: a cohort analysis. BMC Surg 2011;11:18.
15. American Thoracic Society; Infectious Diseases Society of America. Guidelines for the management of adults with hospital-acquired, ventilator-associated, and healthcare-associated pneumonia. Am J Respir Crit Care Med 2005;171:388–416.
16. Knaus WA, Draper EA, Wagner DP, Zimmerman JE. APACHE II: a severity of disease classification system. Crit Care Med 1985;13:818–829.
17. Jeong JH, Bang J, Jeong W, Yum K, Chang J, Hong JH, et al. A dedicated neurological intensive care unit offers improved outcomes for pa-
tients with brain and spine injuries. *J Intensive Care Med* 2019;34:104-108.

18. Ryu JA, Yang JH, Chung CR, Suh GY, Hong SC. Impact of neurointensivist co-management on the clinical outcomes of patients admitted to a neurosurgical intensive care unit. *J Korean Med Sci* 2017;32:1024-1030.

19. Jeon SB, Koh Y, Choi HA, Lee K. Critical care for patients with massive ischemic stroke. *J Stroke* 2014;16:146-160.

20. See KC, Zhao MY, Nakataki E, Chittawatanarat K, Fang WF, Faruq MO, et al. Professional burnout among physicians and nurses in Asian intensive care units: a multinational survey. *Intensive Care Med* 2018;44:2079-2090.