Hydrocephalus is an abnormal accumulation of CSF resulting in the enlargement of ventricles and is an important cause of morbidity and mortality in the pediatric population. The global incidence of hydrocephalus is unknown, but the incidence of congenital hydrocephalus is more common in low- and middle-income countries than that in high-income countries. Social and economic barriers as well as an inadequate neurosurgical workforce in less-developed countries limit access to proper neurosurgical care and worsen the burden of disease. Ventriculoperitoneal (VP) shunting is one of the most common operations performed in the treatment of hydrocephalus since its advent in the 1950s, and it accounts for a large part of the pediatric neurosurgical practice. Despite advancements in surgical techniques and equipment, VP shunting had a high failure rate. Patients with VP shunts may have multiple admissions and shunt revisions over their shunt-dependent lives. Most shunt failures are caused by infection or mechanical complications of the shunt system and occur more frequently within the first 2 years after insertion. However, shunt complications may occur more than 10 years after surgery. Factors related to shunt failure have been extensively studied, and commonly cited risk factors have included patient age and etiology of hydrocephalus. Previous studies of shunt failure, however, were rarely conducted on a national scale. To our knowledge, there was only one study in Thailand that reported a presence of prior VP shunt operation and premature birth as the risk factors for shunt failure.

Every time a child with hydrocephalus returns to the hospital, the risk of shunt failure increases. Close follow-up is crucial once patients have developed the failure, because the risk of subsequent failure was more likely than an earlier one among those with multiple failures.

**OBJECTIVE** Shunt failure is common among patients undergoing ventriculoperitoneal shunting for treatment of hydrocephalus. The present study examined long-term shunt failure and associated risk factors in pediatric patients by using a national hospitalization database of Thailand.

**METHODS** Patients 17 years or younger who had been admitted to 71 public hospitals in 2012–2017 for first-time ventriculoperitoneal shunting for diseases with known etiology and discharged alive were followed through 2019 to ascertain shunt failure. Shunt survivals were calculated using Kaplan-Meier estimates and time to failure was analyzed to identify risk factors for the first failure by using Cox proportional hazards regression. Differences in risks of subsequent failures with respect to place in the order of failures (i.e., first, second, third) were determined using a cumulative hazard function.

**RESULTS** Over a median follow-up of 29.9 months, shunt failure occurred in 33.7% of 2072 patients (median age 8.8 months), with a higher proportion in patients < 1 year than in patients 1–17 years (37.8% vs 28.9%, p < 0.001), and ranged from 26.1% of those having posttraumatic hydrocephalus to 35.9% of those having infectious diseases. The shunt failure rates at 3, 6, and 12 months were 11.5%, 19.0%, and 25.2%, respectively. Patients < 1 year had a higher risk of the first failure than patients 1–17 years (hazard ratio 1.45, 95% CI 1.20–1.76). Among those with shunt failure, 35.8% had multiple failures and 52.9% failed within 180 days after the index shunting. The cumulative hazard of subsequent failure was consistently higher than that of an earlier failure regardless of age and etiology, and the cumulative hazard of the second failure in the patients with 180-day failure was higher than that in the patients in whom shunts failed beyond 180 days.

**CONCLUSIONS** Shunt failure occurred more frequently in younger pediatric patients. Much attention should be placed on the initial shunt operation so as to mitigate the failure risk. Close follow-up was crucial once patients had developed the failure, because the risk of subsequent failure was more likely than an earlier one among those with multiple failures.

**KEYWORDS** ventriculoperitoneal shunt; shunt failure; shunt survival; hydrocephalus
operating room, the patient is at an increased risk of shunt failure and infection, with effects on the individual, family, and society. Each failure has a detrimental effect on the child’s cognitive development and ultimately the quality of life.\textsuperscript{14} Therefore, the present study examined shunt failure in pediatric patients by using the national database of the Universal Coverage Scheme (UCS), the largest public insurance in Thailand. Under the UCS, public hospitals are the main providers of healthcare services to 48 million beneficiaries, and approximately 8000 primary and 800 secondary care facilities located at the district level are the Scheme’s gatekeepers. Most VP shunts are performed in certain tertiary care facilities at the provincial level and in university hospitals, where patients indicated for the procedure require a formal referral. The objective of the present study was to determine patterns of shunt failures and associated risk factors among patients 17 years or younger who had successful initial shunting.

**Methods**

**Data Sources**

Data on nationwide hospitalization for VP shunting and shunt-related revisions and reoperations in 2005–2019 were obtained from the National Health Security Office, the national manager of the UCS. The data elements contained encrypted patient identification, age, sex, admitting hospital identification and type, discharge diagnoses, operating procedures, and discharge status. Regarding the hospital type, the majority of patients were admitted to publicly owned tertiary care facilities, which in this study were classified broadly as general hospitals and university hospitals. Except for the dates of hospital admission and discharge, times and dates of the VP shunt operations were not available. Additional data on dates of death in the Thai population during 2012 to 2019 were based on the civil vital registry. The study was approved by the center for ethics in human research, Khon Kaen University.

**Study Patients and Outcomes**

The study included the UCS beneficiaries 17 years or younger who were hospitalized for VP shunting for the first time in 2012–2017 and followed through 2019 to ascertain shunt failure (Fig. 1). To reduce the possibility that the first appearance of VP shunting in the 2012–2017 data would not be the initial operation, patients who had undergone any prior shunt surgeries including VP shunting and shunt revision or failure in the 2005–2011 data were excluded. Initial VP shunting during 2012–2017 was defined as the index shunting, and those who died during hospitalization after the index shunting were excluded. In addition, a handful of patients admitted to private hospitals were excluded. Patients treated at private hospitals tended to have better socioeconomic status than those admitted to public hospitals. These patients might have had access to antibiotic-soaked catheters or programmable shunt systems conditional on an additional out-of-pocket payment, whereas the UCS covers only fixed-pressure shunt systems.

VP shunting was identified by the *International Classification of Diseases, Ninth Revision, Clinical Modification* (ICD-9-CM) code 02.34 (ventricular shunt to abdominal cavity and organs). The etiology of hydrocephalus based on the *International Classification of Diseases and Related Health Problems, Tenth Revision* (ICD-10) codes was categorized into 5 groups as follows: 1) post-traumatic hydrocephalus (G91.2-G91.3); 2) infectious diseases (A00-B99 and G00-G09); 3) neoplasms (C00-D48); 4) intracranial hemorrhage (I60-I62); and 5) congenital abnormalities (Q00-Q99). Patients with unidentified etiology were excluded from the analysis.

Shunt failure was defined using the ICD-9-CM codes 02.41, 02.42, and 02.43 for shunt irrigation/exploration, replacement, and removal, respectively; 54.95 for incision of peritoneum with shunt exploration or revision; and 02.31, 02.32, 02.33, 02.35, and 02.39 for ventricular shunt to structure in head and neck, circulatory system, thoracic cavity, urinary system, and other operations to establish drainage of ventricle, respectively. In addition, subsequent hospitalization for VP shunting (ICD-9-CM code 02.34) was considered shunt failure. Patients with shunt failure at the hospitalization of the index shunting were excluded from the primary analysis because time to failure could not be determined, given that the dates and times of the procedures performed were not available.

**Data Analysis**

Distribution in patient characteristics, including age, sex, and diagnosed etiologies, was described using appropriate statistics and compared with respect to shunt failure. Time to the first shunt failure was calculated for each patient who was followed up until the end of 2019 as number of days from the discharge date of the index shunting until the earliest discharge date of shunt failure. For those who did not have shunt failure but died before the end of 2019, the number of days were counted until the date of death. For those who did not have shunt failure and were alive until the end of 2019, the number of days were counted until the censor date at the end of 2019. A supplementary analysis was performed to account for patients who had shunt failure at the index shunting. These index shunting failure cases were treated as zero survival because time to failure was counted from the discharge dates.

Shunt survival was determined using Kaplan-Meier estimates. Differences in the shunt survivals across children’s age groups (< 1 year vs 1–17 years) and etiologies were tested for a statistical significance, using the log-rank test for an overall equality of the survivals. The magnitude of an association between time to failure and patient’s age and etiology in terms of hazard ratio (HR) was determined by a multivariable analysis that controlled for sex, hospital types, and years of index shunting, using Cox proportional hazards regression.

The present study also compared time to the second or third shunt failures with time to the first failure. In patients with multiple failures, time from first to second failures or time from second to third failures was calculated. In patients with single shunt failure, time from first failure to date of death or censor date was calculated. Patients with any shunt failure would contribute the data on time to failure twice or thrice, including time to the first failure, time to the second or third failure, or time to death or censor. To account for dependent observations in a patient with multiple shunt
failures who was measured more than once, standard errors of the HRs comparing across places in the order of failures were adjusted for correlated data that clustered within the patient. The difference in shunt failures conditional on the place in the order of failures was illustrated by a cumulative hazard function, which is the negative logarithm of shunt survival at various time points. The cumulative hazard with respect to the place in the order of failures was compared across age groups and etiologies. Additionally, the cumulative hazard of the second failure among patients with first failure was compared between those in whom the shunts failed within 180 days of index surgery and those in whom the shunts failed beyond 180 days.

Results

tive hazard of the second failure among patients with first failure was compared between those in whom the shunts failed within 180 days of index surgery and those in whom the shunts failed beyond 180 days.

FIG. 1. Flowchart showing patient inclusion and exclusion.

A total of 2833 pediatric patients were first hospital-
ized for VP shunting during 2012–2017, and 117 patients died during the index hospitalization. Of the 2716 patients who lived, 257 experienced shunt failure during the index hospitalization. After an exclusion of those admitted to private hospitals (n = 68) or having no ICD-10 codes for etiology (n = 319), 2072 patients remained for the primary analysis (range 301–393 patients each year).

The study patients, whose age range was between 3 days and 17 years (median 8.8 months, interquartile range [IQR] 2.7 months–7.5 years), were admitted to 71 tertiary care hospitals (58 general and 13 university hospitals) during 2012–2017. A little more than half (54.2%) were patients < 1 year old who underwent the initial VP shunting at a median age of 2.9 months (IQR 1.4–5.5 months), and the rest (45.8%) were 1–17 years old and had a median age of 8.5 years (IQR 3.2–13.7 years) (Table 1). There were more boys (57.1%) than girls (42.9%). Half (51.2%) of the patients had congenital abnormalities as the etiology. The second and third most common etiologies were neoplasms (30.1%) and infectious diseases (9.6%). Patients with posttraumatic hydrocephalus and intracranial hemorrhage accounted for 6.8% and 2.3%, respectively. By patient subgroups according to ages, the most common etiology was congenital abnormalities (77.5%) in patients < 1 year and neoplasms (54.3%) in patients 1–17 years. VP shunting was performed more in the general (58.9%) than in the university (41.1%) hospitals.

The median follow-up time was 29.9 months (IQR 5.2–59.2 months). Shunt failure occurred in 699 patients (33.7%, 95% CI 31.7%–35.8%) (Table 1). Shunt failure in patients < 1 year (37.8%) was more frequent than that in patients 1–17 years (28.9%, p < 0.001). The failure rate was similar between male and female patients (32.7% vs 35.1%). The failure proportion was highest in patients undergoing VP shunting due to infectious diseases (35.9%) and congenital abnormalities (35.4%), followed by intracranial hemorrhage (33.3%), neoplasms (31.9%), and posttraumatic hydrocephalus (26.1%). The failure proportion was similar between the general and university hospitals (34.0% vs 33.4%). The difference in the failure rates was not statistically significant across sexes, etiologies, and hospital types.

**Time to First Failure**

Overall shunt survivals until the first failure at 3, 6, 12, 24, 36, and 72 months after the hospitalization of index shunting were 88.5%, 81.0%, 74.8%, 68.8%, 65.6%, and 60.2%, respectively (Fig. 2 upper panel, Supplementary Table S1). The corresponding 3-, 6-, and 12-month failure rates were 11.5%, 19.0%, and 25.2%, respectively. Patients < 1 year had a significantly lower shunt survival than the older counterpart over the same period (p < 0.001): 86.4% versus 91.0%, 77.2% versus 85.6%, 71.6% versus 78.7%, 65.1% versus 73.3%, 62.2% versus 69.8%, and 57.3% versus 63.9%, respectively (Fig. 3 upper panel, Supplementary Table S1). By etiology, shunt survival over the same period in those with posttraumatic hydrocephalus was highest (90.7%, 87.0%, 80.3%, 75.5%, 72.9%, and 71.9%), whereas across the remaining 4 etiologies the difference in shunt survivals was not noticeable (p = 0.214) (Fig. 3 lower panel).

The median survival for patients with neoplasm was 93.0 months, whereas that for patients with other etiologies could not be determined. Among those with shunt failure, the median times to first failure were 7.3, 4.9, 5.1, 6.5, and 6.3 months for infectious diseases, neoplasms, congenital abnormalities, intracranial hemorrhage, and posttraumatic hydrocephalus, respectively.

In the supplementary analysis, an inclusion of 230 patients with shunt failure at the index shunting accrued the total failure to 929 cases or 40.4% of 2302 patients. In Fig.

### TABLE 1. Patient characteristics and presence of shunt failure

<table>
<thead>
<tr>
<th>Variable</th>
<th>No. of VP Shunts (%)</th>
<th>No. w/ Shunt Failures (%)</th>
<th>p Value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>2072 (100)</td>
<td>699 (33.7)</td>
<td>1373 (66.3)</td>
</tr>
<tr>
<td>Age</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;1 yr</td>
<td>1122 (54.2)</td>
<td>424 (37.8)</td>
<td>698 (62.2)</td>
</tr>
<tr>
<td>1–17 yrs</td>
<td>950 (45.8)</td>
<td>275 (28.9)</td>
<td>675 (71.1)</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td>0.243</td>
</tr>
<tr>
<td>Male</td>
<td>1184 (57.1)</td>
<td>387 (32.7)</td>
<td>797 (67.3)</td>
</tr>
<tr>
<td>Female</td>
<td>888 (42.9)</td>
<td>312 (35.1)</td>
<td>576 (64.9)</td>
</tr>
<tr>
<td>Etiology</td>
<td></td>
<td></td>
<td>0.170</td>
</tr>
<tr>
<td>Infectious diseases</td>
<td>198 (9.6)</td>
<td>71 (35.9)</td>
<td>127 (64.1)</td>
</tr>
<tr>
<td>Neoplasms</td>
<td>623 (30.1)</td>
<td>199 (31.9)</td>
<td>424 (68.1)</td>
</tr>
<tr>
<td>Congenital abnormalities</td>
<td>1061 (51.2)</td>
<td>376 (35.4)</td>
<td>685 (64.6)</td>
</tr>
<tr>
<td>Intracranial hemorrhage</td>
<td>48 (2.3)</td>
<td>16 (33.3)</td>
<td>32 (66.7)</td>
</tr>
<tr>
<td>Posttraumatic hydrocephalus</td>
<td>142 (6.8)</td>
<td>37 (26.1)</td>
<td>105 (73.9)</td>
</tr>
<tr>
<td>Admitting hospital</td>
<td></td>
<td></td>
<td>0.770</td>
</tr>
<tr>
<td>General hospital</td>
<td>1221 (58.9)</td>
<td>415 (34.0)</td>
<td>806 (66.0)</td>
</tr>
<tr>
<td>University hospital</td>
<td>851 (41.1)</td>
<td>284 (33.4)</td>
<td>567 (66.6)</td>
</tr>
</tbody>
</table>

* Chi-square test.
FIG. 2. Kaplan-Meier curves showing shunt survival and cumulative hazard from index shunting and from subsequent failures. 

Upper: Shunt survival. Lower: Cumulative hazard. Figure is available in color online only.

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FIG. 3. Kaplan-Meier curves showing shunt survival from index shunting by age group and by etiology. Upper: Age group. Lower: Etiology. ICH = intracranial hemorrhage; PTH = posttraumatic hydrocephalus. Figure is available in color online only.
1, a total of 257 patients had shunt failure during the index hospitalization, and in that group 8 patients were admitted to private hospitals and 19 patients did not have identifiable etiology. Treating the index shunt failures as zero survivals, the survival rates shifted down from that in the primary analysis by 9.8, 8.1, 7.4, 6.9, 6.6, and 6.0 percentage points at months 1, 6, 12, 24, 36, and 72, respectively (Supplementary Table S1). The magnitude of the downward shift in the shunt survivals when failures at the index shunting were included was a little larger in patients 1–17 years than in patients < 1 year.

Controlling for differences in patient sex, hospital type, year of hospitalization, and etiology, patients < 1 year increased the risk of shunt failure significantly as compared with patients 1–17 years (HR 1.45, 95% CI 1.20–1.76) (Table 2). Considering the 5 conditions of etiology as an overall variable, the adjusted association with time to the first failure was not statistically significant (p = 0.053). When compared with patients with neoplasm, those with posttraumatic hydrocephalus and congenital abnormalities had a significantly lower risk of failure (HR 0.68 and 0.76, 95% CI 0.48–0.97 and 0.62–0.94, respectively), whereas a lower risk of failure in those with intracranial hemorrhage (HR 0.80) and infectious diseases (HR 0.84) was not statistically significant (p = 0.384 and 0.237, respectively).

### Multiple Failures

Among 699 patients with shunt failures, 250 patients (35.8%) developed multiple shunt failures: 156 (22.3%) and 94 (13.4%) with shunt failures twice and thrice or more, respectively. Multiple shunt failures occurred more frequently in patients < 1 year (38.4%) than in patients 1–17 years (31.6%, p = 0.067). Multiple shunt failures were similar between boys and girls (34.1% vs 37.8%, p = 0.309) and across patients with infectious diseases, neoplasms, and congenital abnormalities (39.4%, 37.7%, and 36.2%, respectively), which was higher than in those with intracranial hemorrhage (6.2%) and posttraumatic hydrocephalus (27.0%) (p = 0.089). Multiple failures occurred a little more frequently in the general hospitals than in the university hospitals (38.3% vs 32.0%, p = 0.089). Differences in the proportions of the multiple failures across age groups, sexes, etiologies, and hospital types did not reach statistical significance.

For patients experiencing multiple failures, shunt survivals at 3, 6, and 12 months from second to third failures were 79.1%, 69.4%, and 63.9%, respectively (Table 3), which was lower than those from first to second failures (83.2%, 75.0%, and 68.7%) and those from index shunting to first failures (88.5%, 81.0%, and 74.8%) (p < 0.001) (Table 3, Fig. 2 upper panel). A monotonically lower survival from a later failure than that from an earlier one appeared in both patients < 1 year and in those 1–17 years as well as in all subgroups of combined age and etiology (Table 3). The number of patients with posttraumatic hydrocephalus and intracranial hemorrhage who had multiple shunt failures was less than 30 at the beginning, and they were not further analyzed.

Among 699 patients with first shunt failure, 52.9% of devices failed within 180 days after the index shunting. In this subgroup of patients, a cumulative hazard of the second failure was higher than that in patients in whom shunts failed beyond 180 days (HR 1.61, 95% CI 1.25–2.09) (Fig. 4).

An increasing risk of the subsequent failure among patients with multiple failures was shown, with a higher cumulative hazard in the lower panel of Fig. 2. The risk of the third failure was higher than that of the second failure, and that of the second failure was higher than that of the first failure (HR 1.39 and 1.26, 95% CI 1.11–1.74 and 1.09–1.46, respectively).

The cumulative hazard of the third failure in patients < 1 year was highest (Fig. 5). During the first 2 months and after 6 months, the cumulative hazards of third failure in both age groups were similar. In patients < 1 year, during the first 2 months the cumulative hazard of the second was similar to the third failure, and after 2 months the third failure was higher. The cumulative hazard of the first failure in patients < 1 year was comparable to that of the second failure in patients 1–17 years.

### Discussion

Our first finding that approximately one-third (33.7%) of the pediatric patients who underwent VP shunting ex-

<table>
<thead>
<tr>
<th>Variable</th>
<th>HR*</th>
<th>p Value</th>
<th>Lower Limit</th>
<th>Upper Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient's age</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;1 yr</td>
<td>1.45</td>
<td>&lt;0.001</td>
<td>1.20</td>
<td>1.76</td>
</tr>
<tr>
<td>1–17 yrs</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Etiology</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infectious diseases</td>
<td>0.84</td>
<td>0.237</td>
<td>0.63</td>
<td>1.12</td>
</tr>
<tr>
<td>Intracranial hemorrhage</td>
<td>0.80</td>
<td>0.384</td>
<td>0.48</td>
<td>1.33</td>
</tr>
<tr>
<td>Congenital abnormalities</td>
<td>0.76</td>
<td>0.010</td>
<td>0.62</td>
<td>0.94</td>
</tr>
<tr>
<td>Posttraumatic hydrocephalus</td>
<td>0.68</td>
<td>0.034</td>
<td>0.48</td>
<td>0.97</td>
</tr>
<tr>
<td>Neoplasm</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Adjusted for sex, hospital type, and year of hospitalization.
† An overall test with chi-square statistics.
experienced at least 1 episode of shunt failure was within the range reported by recent literature.\textsuperscript{10,12,16–20} The independent risk factor for shunt failure was age < 1 year, and these patients had a 45% higher risk than those age 1–17 years. Even though an association between time to shunt failure and etiology as an overall comparison did not reach statistical significance, posttraumatic hydrocephalus and congenital abnormalities have shown a significantly lower risk (32% and 24%, respectively) than neoplasm.

The shunt failure rates in our study were 11.5%, 19.0%, 25.2%, and 31.3% at 3, 6, 12, and 24 months, respectively. In the United States, a single-center university study (n = 341) by Shannon et al. reported relatively lower rates of 15% and 21% at 6 and 24 months, respectively, and another study in a children’s hospital (n = 466) by Rossi et al. reported relatively higher rates of 24.1% and 29.9% at 3 and 6 months, respectively.\textsuperscript{17,21} In the United Kingdom, a multicenter database study (n = 1615) by Al-Tamimi et al. and a single-center teaching hospital study (n = 321) by Anderson et al. reported relatively higher rates at 12 months of 28.8% and 26.0%, respectively.\textsuperscript{10,12} Our shunt failure trend showing high failure rates within the first year followed by lower rates over time is consistent with published literature.\textsuperscript{12,18,22}

Our primary analysis that did not account for cases of failure at the index shunting was intended to shed light on failure outcomes of a successful shunt operation by avoiding problematic cases that were due to surgical techniques. With the inclusion of index shunt failure in the supplementary analysis, the failure rate accumulated to 40.4% in total and was 32.6% at 1 year, which was greater than that in the reports from the United Kingdom.\textsuperscript{10,12}

Our finding on the higher risk in patients of younger age was consistent with multiple reports that mostly showed that the younger age group had higher shunt failure rates.\textsuperscript{18,23–29} Studies by Tuli et al., Liptak and McDonald, and Liptak et al. showed that shunts inserted in patients younger than 1 year had a greater failure rate.\textsuperscript{29–31} McGirt et al. reported that after adjusting for etiology of hydrocephalus, revision number, and time from placement, a 4% decrease in shunt failure was observed for each additional year.\textsuperscript{18} The higher rate of failure in the < 1-year age group may be due to the inclusion of preterm patients. A review by James et al. attributed the increased risk of shunt failure in very young patients to a worse immune system and weaker skin conditions.\textsuperscript{32} Kulkarni et al. reported that patients with a gestational age < 40 weeks at the time of surgery had the greatest risk of failure.\textsuperscript{23} However, some studies did not find age as a risk factor for shunt failure.\textsuperscript{11,12,21,27} Khan et al. reported no difference in shunt failure between preterm and full-term patients.\textsuperscript{11} Evidence on specific etiology associated with shunt failure was mixed.\textsuperscript{12,21,27,33} Many studies have identified congenital hydrocephalus as a significant risk factor for initial shunt failure.\textsuperscript{11,20,22} In general, patients with hydrocephalus caused by congenital abnormalities are more likely to undergo shunt placement earlier when compared to patients with other etiologies, which may coincide with the notion that younger patients have a higher failure rate. Nonetheless, our study failed to identify congenital abnormalities as an independent risk factor.

### TABLE 3. Shunt survival at 3, 6, and 12 months from index shunting and from first and second failures

<table>
<thead>
<tr>
<th>Age &amp; Etiology</th>
<th>No. of Patients</th>
<th>From Index to 1st Failure</th>
<th>From 1st to 2nd Failures</th>
<th>From 2nd to 3rd Failures</th>
<th>From Index to 1st Failure</th>
<th>From 1st to 2nd Failures</th>
<th>From 2nd to 3rd Failures</th>
</tr>
</thead>
<tbody>
<tr>
<td>All patients</td>
<td>2072</td>
<td>88.5 (95.2)</td>
<td>82.6 (95.2)</td>
<td>79.1 (92.9)</td>
<td>81.0 (95.2)</td>
<td>75.0 (92.9)</td>
<td>69.4 (92.9)</td>
</tr>
<tr>
<td>Patients &lt;1 yr</td>
<td>1122</td>
<td>86.4 (95.2)</td>
<td>81.8 (95.2)</td>
<td>77.1 (92.9)</td>
<td>77.2 (95.2)</td>
<td>73.5 (92.9)</td>
<td>69.6 (92.9)</td>
</tr>
<tr>
<td>Infectious diseases</td>
<td>115</td>
<td>89.9 (95.2)</td>
<td>81.8 (95.2)</td>
<td>77.1 (92.9)</td>
<td>73.5 (92.9)</td>
<td>77.1 (92.9)</td>
<td>73.5 (92.9)</td>
</tr>
<tr>
<td>Neoplasm</td>
<td>107</td>
<td>85.5 (95.2)</td>
<td>82.6 (95.2)</td>
<td>82.6 (95.2)</td>
<td>82.6 (95.2)</td>
<td>79.6 (92.9)</td>
<td>73.9 (92.9)</td>
</tr>
<tr>
<td>Congenital abnormalities</td>
<td>870</td>
<td>86.0 (95.2)</td>
<td>83.3 (95.2)</td>
<td>79.3 (92.9)</td>
<td>79.3 (92.9)</td>
<td>79.3 (92.9)</td>
<td>79.3 (92.9)</td>
</tr>
<tr>
<td>Patients 1–17 yrs</td>
<td>950</td>
<td>91.0 (95.2)</td>
<td>84.2 (95.2)</td>
<td>83.0 (95.2)</td>
<td>83.0 (95.2)</td>
<td>83.0 (95.2)</td>
<td>83.0 (95.2)</td>
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<tr>
<td>Infectious diseases</td>
<td>516</td>
<td>89.0 (95.2)</td>
<td>85.1 (95.2)</td>
<td>81.4 (95.2)</td>
<td>81.4 (95.2)</td>
<td>77.8 (92.9)</td>
<td>77.8 (92.9)</td>
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<tr>
<td>Neoplasm</td>
<td>516</td>
<td>89.0 (95.2)</td>
<td>85.1 (95.2)</td>
<td>81.4 (95.2)</td>
<td>81.4 (95.2)</td>
<td>81.4 (95.2)</td>
<td>81.4 (95.2)</td>
</tr>
<tr>
<td>Congenital abnormalities</td>
<td>191</td>
<td>95.2 (95.2)</td>
<td>84.5 (95.2)</td>
<td>84.5 (95.2)</td>
<td>84.5 (95.2)</td>
<td>84.5 (95.2)</td>
<td>84.5 (95.2)</td>
</tr>
</tbody>
</table>

* Number of patients at risk < 30 persons.
FIG. 4. Kaplan-Meier curves showing cumulative hazard of second failure by time to first failure. Figure is available in color online only.

FIG. 5. Kaplan-Meier curves showing cumulative hazard of subsequent failures by age group. Figure is available in color online only.
Our second finding was that among patients experiencing shunt failure, 35.8% had multiple failures. There was an increasing cumulative hazard for subsequent failure in both age groups and in all etiologies. We found an increase in the risk of second and third failures of 26% and 39% conditional on the first and second failures, respectively. One explanation is that in patients with multiple failures the cases tended to be complicated. A few studies reported risk of subsequent failure among patients with multiple shunt failures. Two United Kingdom studies reported a second failure rate at 1 year of 42.3% and 50.5%, whereas that in our study was relatively lower at 25.2%. A single-center study in the United States with a mean follow-up of 3.2 years reported an increase in the risk of any subsequent failures of 31% for each prior failure. Gonzalez et al. reported a higher 30-day shunt failure rate after shunt revision (14%) than initial shunt failure (8%). Iglesias et al. reported shorter mean survival after every subsequent revision. The true burden and cost of VP shunting lie within these cases of multiple failure. Evidence regarding multiple shunt failures and preventive measures is still lacking.

Our study did not evaluate whether shunt failure was the cause of death because the data could not be verified. Among 117 patients who died at the index shunting, 26 patients (22.2%) had shunt failure. The most common etiology was neoplasms (40.2%), followed by congenital abnormalities (27.3%). An inclusion of these patients was unlikely to have a noticeable effect on shunt survival rates obtained from the primary analysis.

We did not take endoscopic third ventriculostomy into account. That procedure is performed in a few hospitals and is not covered by the UCS. Despite having relative indications for endoscopic third ventriculostomy, most UCS patients would be treated with VP shunts instead due to financial and resource constraints.

In certain circumstances in which multiple failures occurred during a single hospitalization, frequency of the multiple failures would be counted as only a single failure. Causes of shunt malfunction were not determined. Our additional analysis revealed that 14.0% of 699 cases of failure were diagnosed with the ICD-10 codes G00-F03 (meningitis); G04-G05 (encephalitis, myelitis, or encephalomyelitis); G06-F08 (intracranial or intraspinal abscess, granuloma, phlebitis, or thrombophlebitis); and G09 (sequela) during the hospitalization for shunt revision or failure. There were 24.6% of the failure cases diagnosed with the ICD-10 code T85.7 (infection and inflammatory reaction due to other internal prosthetic devices, implants, grafts). The proportion of the above-mentioned diagnoses was similar between single and multiple failure cases.

To our knowledge, this was the first study in Thailand examining VP shunting in pediatric patients that was based on the largest national database, with a maximum follow-up of 8 years. Despite its retrospective nature, a national-scale data set containing a large number of patients and a moderately lengthy follow-up time is a strength of the present study.

Certain limitations remained in the present study. The first issue was about the index shunting, which was defined based on inclusion of the VP shunting in the data-base during 2012–2017, with no prior shunt procedures in 2005–2011. Despite using the 2005–2011 shunt surgeries as the identification method for selecting the index shunting in 2012–2017, surgeries before 2005 might be left out, resulting in an overestimated number of new cases. The second concern was about our exclusion of 319 patients who underwent VP shunting (82.8% in the general hospitals) but in whom the ICD-10 codes on key etiologies of the diagnosis were not found at or prior to the dates of the index hospitalization. Our post hoc analysis found that the failure rate among the excluded patients (13.8%) was much lower than that in the study patients. Another concern was the use of hospital discharge dates instead of operation dates for calculating time to failure; this could either shorten or prolong the reported shunt survival depending on the length of stay windows and preoperative periods. We expected that fluctuation in time to failure would not be beyond the median stay of 13 and 14 days (IQR 7–31 days and 6–33 days) for initial VP shunt insertion and shunt reoperation, respectively. Last, due to unavailable data we did not examine other notable surgical factors associated with shunting, such as shunt position, types of shunt, and surgical techniques. Further studies in Thai pediatric patients, especially in patients < 1 year, should include chart review data on clinical conditions.

Conclusions

Shunt failure among pediatric patients in Thailand occurred mostly within the first year. Younger patients were at a higher risk of failure, and the risk of subsequent failure increased with respect to a prior failure. Great emphasis must be placed on the initial shunt operation to mitigate the risks associated with shunt failure, and close follow-up must be conducted once a patient has experienced shunt failure.

Acknowledgments

We thank the National Health Security Office for providing the data and Jutatip Thungthong for assisting with technical support. We also thank Dr. Walaiporn Patcharanarumol, Senior Research Scholar of Thailand Science Research and Innovation (RTA6280007), for advice on data analysis. This research was partly funded by the International Health Policy Program (IHPP), Thailand (RTA6280007).

References


**Disclosures**

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

**Author Contributions**

Conception and design: both authors. Acquisition of data: Limwattananon. Analysis and interpretation of data: both authors. Drafting the article: Limwattananon. Critical revision of the article: Kitkhuandee. Statistical analysis: Limwattananon. Study supervision: Kitkhuandee.

**Supplemental Information**

Online-Only Content

Supplemental material is available with the online version of the article.

**Supplementary Table S1**


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