Development and Evaluation of an Integrated Outpatient Infusion Care Model for the Treatment of Pediatric Headache

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**Complete Title:** Development and Evaluation of an Integrated Outpatient Infusion Care Model for the Treatment of Pediatric Headache

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Abstract

BACKGROUND: Care for pediatric patients with headache often occurs in high-cost settings such as emergency departments (ED) and inpatient settings. Outpatient infusion centers have the potential to reduce care costs for pediatric headache management.

METHODS: In this quality improvement study, we describe our experience creating the capacity to support an integrated outpatient pediatric headache infusion care model through an infusion center. We compare costs of receiving headache treatment in this model compared to the emergency and inpatient settings. Since dihydroergotamine (DHE) is a costly infusion, encounters at which DHE was administered were analyzed separately. We track the number of ED visits and inpatient admissions for headache using run charts. As a balancing measure, we compare treatment efficacy between the infusion care model and the inpatient setting.

RESULTS: The mean percentage increase in cost of receiving headache treatment in the inpatient setting with DHE was 61% (CI: 30-99%) and without DHE was 582% (CI: 299-1068%) compared to receiving equivalent treatments in the infusion center. The mean percentage increase in cost of receiving headache treatment in the ED was 30% (CI: -15-100%) compared to equivalent treatment in the infusion center. After the intervention, ED visits and inpatient admissions for headache decreased. The mean change in head pain was similar across care settings.

CONCLUSIONS: Our findings demonstrate that developing an integrated ambulatory care model with infusion capacity for refractory pediatric headache is feasible and our early outcomes suggest this may have a favorable impact on the overall value of care for this population.
Keywords: Pediatric, headache, dihydroergotamine, infusion capacity, care integration, cost, value
Background

Headache is a common cause of pain and disability in children and adolescents and is a major contributor to frequently missed school days and activities [1,2]. Optimal management of refractory pediatric headache requires care coordination and care integration. Without this framework, care fragmentation occurs, which can lead to overutilization of care and inefficiency across health systems [3]. In pediatric headache, this can manifest as patients’ escalating their care to high-cost settings. For example, when outpatient rescue medications fail to improve headache, patients often visit the emergency department (ED) or require inpatient admission for additional treatments.

Headache accounts for 1% of all visits to pediatric EDs [4]. Treatment of headache in the ED is variable but usually consists of ketorolac, triptans, antiemetics, and intravenous fluids, alone or in combination [5]. While many patients respond well to these treatments, approximately 6-7% of patients fail treatment in the ED and require inpatient admission for further management of headache [6]. In the inpatient setting, management of headache typically involves continuation of ketorolac, antiemetics, and the addition of dihydroergotamine (DHE). Treatment with DHE is effective for pediatric migraine, but the inpatient burden and cost of headache admissions are increasing [7–10]. In a prior retrospective study, the average cost of an inpatient admission for DHE among pediatric patients admitted to a single center was $7,569 [8]. Because health care costs have increased over time, it can be extrapolated that the cost for an inpatient headache admission in 2021 is likely higher than this.

Given the high cost of ED visits and inpatient hospitalizations for pediatric headache, intensive outpatient treatment of headache at infusion centers has been proposed as a potential alternative. In addition to being less costly, use of infusion centers offers additional potential
advantages, including an opportunity to develop headache services that are more integrated with multidisciplinary teams, individualized treatment plans formulated by a neurologist, and streamlined care with less disruption to the patient/family’s schedule. Accordingly, integrated outpatient infusion care models have the potential to reduce care fragmentation and subsequently lower health care costs and improve the patient/family’s experience of care. In fact, comprehensive, multidisciplinary care at outpatient infusion centers for headache treatment has shown to subsequently decrease healthcare utilization as measured by a reduction in headache-related phone calls, ED/urgent care visits, and neurology clinic visits [11]. In spite of these potential benefits, there is a paucity of literature regarding the process of developing such integrated headache infusion care models and the relative costs of outpatient infusion centers compared with ED visits or inpatient admissions for pediatric headache have not been described.

This pilot study was designed as a quality improvement project with the primary aim of assessing the feasibility of developing an integrated care model supporting infusions for headache treatment including the use of DHE in an ambulatory setting. Our secondary aims were to compare the relative costs of receiving headache treatment in this model compared to the emergency and inpatient settings, to examine the impact of this intervention on the number of inpatient neurology admissions and ED visits for primary headache management, and to evaluate the patient experience with treatment in the infusion center. Comparison of the treatment efficacy between the outpatient infusion care model and the inpatient setting was used as a balancing measure.

Methods

Design of Intervention

*Integrated infusion care model planning*
At Boston Children’s Hospital (BCH), developing an integrated headache infusion care model required adding functionality to the existing structure at an outpatient infusion center. The development of this care model was made possible by close collaboration between neurology physicians, neurology nurse practitioners (NPs), infusion center nurse managers, infusion center NPs, and infusion center registered nurses. Collaboration among neurology physicians and NPs allowed for careful examination of the current work-flow and treatment options for this patient population, which led to identification of areas for optimization. By partnering with the infusion center clinicians, we were able to identify ways to utilize their expertise to ensure care integration in the pilot study. This multidisciplinary team created well-defined patient referral criteria, a comprehensive referral algorithm to be used by clinicians, and a standardized, but customizable, infusion center treatment protocol.

**Work-flow intervention**

The model for acute management of refractory headache prior to offering treatment through an integrated infusion care model is demonstrated in Figure 1a. The work-flow model after development of this care model is demonstrated in Figure 1b.

![Figure 1a. Model of work-flow for refractory headache management prior to intervention](image-url)
Figure 1b. Model of work-flow for refractory headache management after intervention

**Integrated infusion care model treatment criteria**

Criteria for receiving treatment through the integrated infusion care model were created to ensure patient safety, account for patient preferences, and minimize patient inconvenience. The criteria include:

- Established Neurology patient
- Age: ≥10 years
- Failed individualized headache action plan
- No significant co-morbid medical or psychiatric diagnosis
- Does not need expedited imaging or work-up
- Patient/family has transportation to and from the infusion center
- Time is within infusion center operating hours OR patient is able to wait until following day to schedule

If the patient meets these criteria, the clinician and patient/family engage in shared decision making regarding the best care setting for treatment.

**Integrated infusion care model referral process**
For included patients, the referring clinician sends an email or calls the infusion center to initiate the appointment. Appointments are offered for the same day or the following day depending on availability. The infusion center is open weekdays from 7:30am to 10:00pm and on weekends from 7:30am to 7:00pm. The infusion center schedules the appointment, confirms the time with the patient and/or family, and ensures that the visit will be covered by insurance through patient financial services. This approach clearly delineates the responsibilities of each team member across different settings.

**Integrated infusion care model treatment protocol**

Specific treatments administered at the infusion center are determined by the referring clinician and include intravenous targeted combination headache medications including, but not limited to, normal saline, anti-inflammatory agents, anti-emetics, triptans, corticosteroids, valproic acid, magnesium, and DHE. The referring clinician clearly outlines the treatment plan in the patient’s medical chart using a standardized template. This template allows for careful handoffs between care settings. The infusion center clinician then activates the treatment plan when the patient arrives. For patients who do not receive DHE, treatment in the infusion center is one day in duration and the patient can receive up to two rounds of intravenous medications. For patients receiving DHE, treatment in the infusion center is typically scheduled for three consecutive eight-hour days with two DHE doses per day. This is similar to the inpatient DHE protocol. The primary difference between the outpatient and inpatient protocols is that DHE is given every six hours in the outpatient setting compared to every eight hours in the inpatient setting. This was chosen to decrease the length of time spent in the infusion center as the patient
goes home at the end of each treatment day. Both the outpatient infusion center and inpatient DHE treatment protocols are based on the Raskin protocol [12].

At the conclusion of treatment in the infusion center, the care team completes a discharge checklist. This includes the registered nurse in the infusion center reviewing headache-specific education sheets and helping to facilitate a follow up appointment with the patient’s primary neurologist after discharge. In addition, the infusion center NP reviews the home medication plan with the patient/family and provides any prescriptions that were previously discussed with the patient’s primary neurologist. The NP also provides an update to the patient’s primary neurologist on the patient’s response to treatment. This bidirectional communication between the infusion center and the neurology department is essential to reduce care fragmentation across settings.

*Notable differences in care coordination between the treatment sites*

In the infusion center care model, the treatment plan is determined by the patient’s primary neurology clinician, who knows the patient well and has expertise in managing headache. Because the primary neurology clinician is intimately involved in treatment decisions in the integrated infusion care model, they can easily make adjustments to the patient’s outpatient treatment plan as well (e.g., change to the patient’s acute and preventative medications after discharge). This aspect of the model supports continuity and longitudinality of care by the neurology provider. In the ED, most patients who are treated for headache receive standardized headache treatment that is determined by an emergency medicine clinician. In the inpatient setting, the patient’s treatment plan is created by a neurologist but not the patient’s primary neurology clinician.
Data source and participants

For ED and inpatient visits, we included encounters by established neurology patients <26 years of age who presented to the emergency department with a chief complaint of headache or required admission to the inpatient neurology service for headache management at BCH between January 2018 and December 2018, before the ambulatory headache infusion care model was developed. Age <26 years was chosen to capture the typical patient population we treat within the neurology department at our institution. Encounters were identified using BCH360, the hospital’s business intelligence system through the MicroStrategy platform that pulls information from the hospital’s data warehouse. Encounters in the ED were included if they involved established neurology patients who received ketorolac for an ICD-10 code diagnosis of primary headache disorder (ICD-10 codes used outlined in supplementary file 1). Inpatient encounters were included for established neurology patients admitted to the inpatient neurology service at BCH with an ICD-10 code diagnosis of primary headache disorder who received ketorolac or dihydroergotamine. Established neurology patients were defined as patients seen in the neurology clinic within the prior two years from the date of their ED visit or inpatient admission. Only established neurology patients were included in this pilot study, as the outpatient infusion care model is currently only available to established neurology patients, thus making the patient populations more comparable across settings. For admissions, a retrospective chart review was conducted to ensure patients were treated for a primary headache disorder and to obtain head pain scores at admission and discharge. For patients who received treatment in the ED and were subsequently admitted to the inpatient neurology service, these were considered one inpatient encounter. Outpatient infusion center encounters were included for patients who
received headache management through the integrated infusion care model between May 2019 and January 2021. Head pain scores were obtained through retrospective chart review.

For the relevant encounters, information about the cost per encounter was pulled from the hospital’s Strata database. Strata is the hospital’s cost accounting/decision support system. This includes the loading of all Epic HB patient data and Peoplesoft general ledger data into the system and the calculation of direct and indirect patient level cost data. The total cost was the sum of indirect and direct hospital costs. In order to make visits to the infusion center more comparable to inpatient admissions, consecutive days of visits to the infusion center were considered as one “encounter” to better reflect the total cost associated with the episode of headache. Co-payment information was pulled using Clarity, one of Epic’s reporting databases.

Outcomes

Primary outcome

In order to assess the feasibility of the intervention, we tracked the number of patients who completed treatment in the infusion center over time.

Secondary outcomes

To understand the financial impact of our intervention, we compared the relative costs of receiving headache treatment in the infusion care model compared to the emergency and inpatient settings. To assess the impact on health care utilization, we monitored the number of inpatient neurology admissions and ED visits for primary headache management before and after implementation of our intervention using run charts. To evaluate the patient experience with treatment in the infusion center, we collected post-treatment patient satisfaction data through surveys.
Balancing measure

We compared the treatment efficacy between the outpatient infusion care model and the inpatient setting using mean change in head pain score.

Survey development

A post-treatment survey was developed with consultation from the neurology quality improvement team at BCH to assess patient satisfaction with the intervention. The patient received a paper survey after completing treatment for their headache as part of their discharge paperwork. On this survey, patients were asked to rate their overall experience in the infusion center on a 5-point Likert scale (1 = “very poor,” 2 = “poor,” 3 = “neutral,” 4 = “good,” 5 = “very good”). Patients were also asked where they would prefer to receive treatment if their headache returned (“infusion center,” “ED,” “inpatient,” or “I don’t know”). Survey distribution began in May 2019.

Statistical Analysis

Means were compared using t-test, and 3-way comparisons were performed using ANOVA. Proportions were compared using Chi-square or (for small sample sizes) the Fisher’s exact test. Given that cost was not normally distributed, we compared settings using a generalized linear model with the gamma family and log link, with total cost as the dependent variable and practice setting as the independent variable. This model estimated the mean percentage difference between settings, with the infusion center setting as the referent. A p-value <0.05 was considered statistically significant. All analyses were performed using Stata 14 (College Station, TX).
Since DHE is a costly infusion that is usually reserved for patients with headache that is particularly refractory to standard therapies, infusion center and inpatient encounters at which DHE was administered were analyzed separately from encounters at which DHE was not administered. We do not give DHE treatment in the emergency department at our institution, thus these data are not included.

Ethical Statement:

The Boston Children’s Hospital Institutional Review Board (IRB) determined that this study was exempt from human subjects review as it was designed as a quality improvement initiative.

Results

Primary Outcome

The number of patients who completed treatment in the infusion care model increased over time (Figure 2).

Figure 2: Number of Patients who Completed Treatment in the Infusion Care Model over Time
Secondary Outcomes

Patient characteristics and cost comparison

The patients’ demographic features were similar between the three care sites (Table 1). The majority of patients were white female adolescents. The mean percentage increase in cost of receiving headache treatment in the inpatient setting with DHE was 61% (CI: 30 to 99%) and without DHE was 582% (CI: 299 to 1068%) compared to receiving equivalent treatments in the infusion center. The mean percentage increase in cost of receiving headache treatment in the emergency department without DHE for headache was 30% (CI: -15 to 100%) compared to equivalent treatment in the infusion center. The proportion of patients who required a co-payment for their visit in the infusion center was significantly smaller than in the ED (14% in the infusion center, 38% in the ED, p=0.024). However, there was not a statistically significant difference in the proportion who required a co-payment between the infusion center and the inpatient setting (38% vs. 23%, p=0.33).

Table 1. Patient Demographic and Headache Information Across Care Sites

<table>
<thead>
<tr>
<th></th>
<th>Infusion Center</th>
<th>ED</th>
<th>Inpatient</th>
<th>p values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Encounters</td>
<td>21</td>
<td>168</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Encounters for DHE</td>
<td>11</td>
<td>0</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Mean Age (range)</td>
<td>16 (11-21)</td>
<td>16 (7-25)</td>
<td>15 (6-23)</td>
<td>0.61</td>
</tr>
<tr>
<td># patients &gt;18 years old (%)</td>
<td>4 (19%)</td>
<td>37 (22%)</td>
<td>5 (17%)</td>
<td>0.88</td>
</tr>
<tr>
<td>Female Sex, n (%)</td>
<td>19 (90%)</td>
<td>137 (82%)</td>
<td>26 (87%)</td>
<td>0.70</td>
</tr>
<tr>
<td>Race, n (%)</td>
<td></td>
<td></td>
<td></td>
<td>0.20</td>
</tr>
<tr>
<td>Race/Cause</td>
<td>Migraine, n (%)</td>
<td>NDPH, n (%)</td>
<td>Tension, n (%)</td>
<td>Post-traumatic, n (%)</td>
</tr>
<tr>
<td>-----------</td>
<td>----------------</td>
<td>-------------</td>
<td>---------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>White</td>
<td>17 (81%)</td>
<td>110 (66%)</td>
<td>24 (80%)</td>
<td>1 (5%)</td>
</tr>
<tr>
<td>Black</td>
<td>1 (5%)</td>
<td>23 (14%)</td>
<td>1 (3%)</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>1 (5%)</td>
<td>29 (17%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asian</td>
<td>1 (5%)</td>
<td>2 (1%)</td>
<td>1 (3%)</td>
<td></td>
</tr>
<tr>
<td>Did not answer</td>
<td>1 (5%)</td>
<td>4 (2%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hispanic, n (%)</td>
<td>1 (5%)</td>
<td>23 (14%)</td>
<td>3 (10%)</td>
<td>0.16</td>
</tr>
</tbody>
</table>

Type of Insurance, n (%)

<table>
<thead>
<tr>
<th>Type of Insurance</th>
<th>Migraine</th>
<th>NDPH</th>
<th>Tension</th>
<th>Post-traumatic</th>
<th>Unspecified</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public Insurance</td>
<td>4 (19%)</td>
<td>64 (38%)</td>
<td>2 (1%)</td>
<td></td>
<td>56 (33%)</td>
</tr>
<tr>
<td>Private Insurance</td>
<td>17 (81%)</td>
<td>97 (58%)</td>
<td></td>
<td>2 (1%)</td>
<td>7 (4%)</td>
</tr>
<tr>
<td>International Insurance</td>
<td>0</td>
<td>7 (4%)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

^1 Comparison of migraine vs. other diagnosis
*DHE: dihydroergotamine; NDPH: new daily persistent headache

Length of Stay

The mean time spent receiving treatment with DHE in the infusion center was 0.73 days (CI: 0.5-0.95) compared to 2.84 days (CI: 2.41-3.26) in the inpatient setting (p<0.001). The mean time spent receiving treatment without DHE in the infusion center, ED, and inpatient setting
were 0.20 days (CI: 0.12-0.28), 0.26 days (CI: 0.24-0.28), and 2.15 days (CI: 1.58-2.72), respectively (p<0.001).

*Effect on inpatient admissions and ED visits*

Overall, there was a decrease in the number of inpatient admissions for primary headache management for established neurology patients after the infusion care model was established (Figure 3). The median number of admissions per quarter was 11 prior to the intervention and 6 after the intervention. There was also an overall decrease in the number of ED visits for primary headache management by established neurology patients (Figure 4). The median number of ED visits per quarter by established neurology patients was 46 prior to the intervention and 35.5 after the intervention.

Figure 3: Run Chart for Inpatient Admissions for Headache by Established Neurology Patients Over Time
Patient Satisfaction

A total of 23 surveys were given to patients who underwent treatment in the outpatient infusion care model. Of those, 14 surveys were completed for a response rate of 61%. The mean patient experience score in the outpatient infusion care model on a 1-5 scale was 4.5. Of those who completed the survey, 79% (11/14) said they preferred to receive treatment in the infusion center for future headache care, while 3 patients responded with “I don’t know.”

Balancing Measure: treatment efficacy

The mean change in head pain scores from admission to discharge were similar across care sites (table 2 and 3).
Table 2: Treatment Efficacy for DHE Across Care Sites

<table>
<thead>
<tr>
<th></th>
<th>DHE</th>
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<tbody>
<tr>
<td></td>
<td>Infusion Center</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean head pain score</td>
<td>7.00 (CI: 5.54-8.46)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>at admission</td>
<td>7.97 (CI: 7.14-8.79)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>p value</td>
<td>0.23</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean head pain score</td>
<td>4.73 (CI: 2.91-6.55)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>at discharge</td>
<td>5.73 (CI: 4.55-6.92)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean change in head</td>
<td>-2.27 (CI: 0.78-3.76)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pain</td>
<td>-2.23 (CI: 1.12-3.26)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>p value</td>
<td>0.96</td>
<td></td>
<td></td>
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</tbody>
</table>

Table 3: Treatment Efficacy without DHE Across Care Sites

<table>
<thead>
<tr>
<th></th>
<th>Non-DHE</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Infusion Center</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>8 (2 missing)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean head pain score</td>
<td>6.19 (CI: 4.25-8.13)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>at admission</td>
<td>7.64 (CI: 6.44-8.85)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>p value</td>
<td>0.19</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean head pain score</td>
<td>1.88 (CI: 0.16-3.59)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>at discharge</td>
<td>3.57 (CI: 1.90-5.24)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean change in head</td>
<td>-4.31 (CI: 2.22-6.40)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pain</td>
<td>-4.07 (CI: 2.34-5.80)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>p value</td>
<td>0.86</td>
<td></td>
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</tbody>
</table>

**Discussion**

Our pilot study found that development of an ambulatory integrated infusion care model through an infusion center was feasible for treatment of refractory pediatric headache. The cost of headache treatment in the inpatient setting was significantly increased compared to the infusion center, but there was no significant difference between the costs of headache treatment in the ED and the infusion center. The proportion of patients who required a co-payment for their treatment in the infusion center was significantly smaller than those treated in the ED, but no
different compared to those treated in the inpatient setting. After the intervention, ED visits and inpatient admissions for headache decreased. The majority of patients surveyed who underwent treatment in the infusion care model were satisfied with the intervention, and there were no differences in treatment efficacy between the inpatient setting and the outpatient infusion care model.

This pilot intervention demonstrates the feasibility of successful care integration and resultant reduction in care costs for pediatric patients with refractory headache, a population known to have high medical care utilization and total health care costs [13–15]. Initially, very few patients were referred for treatment in the infusion care model. However, this number increased substantially as we provided education to clinicians regarding this new option for treatment. The foundation of this pilot was built on core principles of integrated team-based care with clearly defined team member roles and efficient communication between team members across settings [16]. Several factors may explain the decreased healthcare costs associated with an ambulatory integrated infusion care model compared to the inpatient setting. Most notable being less time spent receiving treatment leading to an overall decrease in the length of stay. However, decreased overhead costs and less nonactionable laboratory testing and/or neuroimaging may also contribute, though our pilot study did not assess these directly. This model has the added advantage of scalability given that it was developed by embedding integrated capacity in an existing structure. This model can therefore be readily adapted by infusion centers at other institutions as well as used for other disease processes requiring infusion treatments.

Unique to our study was comparing cost data across settings and highlighting the direct economic impact associated with an ambulatory integrated infusion care model. However, there
are likely additional economic benefits to this model. In a recent pilot study, outpatient, multidisciplinary treatment for refractory pediatric headache using DHE infusions, decreased subsequent healthcare utilization by these patients as measured by a reduction in headache-related phone calls, ED/urgent care visits, and neurology clinic visits [11]. There may also be indirect cost savings. For example, outpatient appointments allow youth and their caregivers to plan around the scheduled appointment time. Additionally, because successful treatment of acute migraine attacks decreases the risk of headache progression to more chronic headache disorders, integrated infusion care models could help to limit disability in this vulnerable patient population [17].

We believe this integrated care model will help to reduce care fragmentation and prevent patients/families from escalating care to higher-cost settings. We found that after implementation of the intervention, the number of inpatient admissions and ED visits for headache management both decreased. However, this finding should be interpreted with caution as it likely confounded by the COVID-19 pandemic. During the early phases of the pandemic, there was a substantial decrease in the number of pediatric ED visits, including those for headache, as well as pediatric hospital admissions [18,19]. Therefore, additional trend data is needed in order to fully understand the impact of our intervention on ED visits and admissions. However, as capacity for outpatient treatment in the infusion care model continues to increase, we expect headache treatment will continue to shift from the ED and inpatient settings to the outpatient setting.

While the sample size for those who completed surveys was small, early experience data supports overall patient satisfaction with the infusion care model. This care model relies on shared decision making between the primary clinician and the patient/family, helping to empower the patient/family. Additionally, there is a more predictable amount of time spent at the
infusion center and decreased wait time compared to an ED visit. These factors likely contribute to satisfaction with their headache care in the infusion care model. However, these data are biased as all patients who received treatment in the infusion care model chose this care setting when given the option.

Finally, the presence of clinicians trained in creating personalized headache treatment plans for each patient may lead to improved quality of care through this integrated care model. These characteristics may explain why infusion centers have been shown to be effective for treating pediatric headache disorders [11,20]. Our study also found the outpatient infusion care model to be effective for treating headache disorders. There was no difference in the treatment outcomes between the infusion center and the inpatient setting, highlighting that headache management in the infusion care model is similar to the current standard of care. This is of particular interest for those patients who received DHE as the outpatient treatment protocol for DHE varies slightly from the inpatient protocol. DHE is administered every six hours in the infusion care model and every eight hours in the inpatient setting.

The need to implement an ambulatory, integrated, high value model for refractory headache management is time critical given the impact of the COVID-19 pandemic [21]. During the pandemic, there has been worsening mental health, including anxiety and depression, and those with migraine are more likely to suffer severe psychological distress during the pandemic [22,23]. It is well established that psychological stress and anxiety contribute to worsening headaches. However, there has also been a decrease in the number of ED visits and admissions for non-COVID-19 related diseases, likely related to fear of becoming infected with the virus [24,25]. Because of this, outpatient infusion capacity offers a unique opportunity within the
current pandemic to provide alternative options for headache treatment in a “clean” space for asymptomatic patients.

Building capacity for outpatient infusions for headache will also prepare centers for administrating novel therapeutics when they become available. For example, eptinezumab, a calcitonin gene-related peptide monoclonal antibody that is administered via intravenous infusion, has been approved by the FDA for preventative treatment of migraine in adults [26]. Clinical trials assessing the safety and efficacy in children and adolescents are in process.

We acknowledge limitations of the study. First, the small sample size limited our ability to precisely estimate the costs associated with treatment at the infusion center as well as understand the true impact of our intervention on patient satisfaction. Second, since our results are from a single large academic center, they may not be generalizable to all settings. As more integrated headache infusion care models are developed, large multicenter studies are needed to assess how these will impact health care costs on a larger scale.

**Conclusion**

With rising health care costs and utilization, it is imperative to identify areas in which we can mitigate this burden. The development of integrated infusion care models for the treatment of pediatric refractory headache is feasible and may reduce health care costs by offering an alternative to ED visits and inpatient admissions.

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Supplementary file 1: ICD-10 codes

43.001: Migraine without aura, not intractable, with status migrainosus
43.009: Migraine without aura, not intractable, without status migrainosus
43.011: Migraine without aura, intractable, with status migrainosus
43.019: Migraine without aura, intractable, without status migrainosus
43.101: Migraine with aura, not intractable, with status migrainosus
43.109: Migraine with aura, not intractable, without status migrainosus
43.111: Migraine with aura, intractable, with status migrainosus
43.119: Migraine with aura, intractable, without status migrainosus
43.401: Hemiplegic migraine, not intractable, with status migrainosus
43.409: Hemiplegic migraine, not intractable, without status migrainosus
43.411: Hemiplegic migraine, intractable, with status migrainosus
43.419: Hemiplegic migraine, intractable, without status migrainosus
43.501: Persistent migraine aura without cerebral infarction, not intractable, with status migrainosus
43.509: Persistent migraine aura without cerebral infarction, not intractable, without status migrainosus
43.511: Persistent migraine aura without cerebral infarction, intractable, with status migrainosus
43.519: Persistent migraine aura without cerebral infarction, intractable, without status migrainosus
43.601: Persistent migraine aura with cerebral infarction, not intractable, with status migrainosus
43.609: Persistent migraine aura with cerebral infarction, not intractable, without status migrainosus
43.611: Persistent migraine aura with cerebral infarction, intractable, with status migrainosus
43.619: Persistent migraine aura with cerebral infarction, intractable, without status migrainosus
43.701: Chronic migraine without aura, not intractable, with status migrainosus
43.709: Chronic migraine without aura, not intractable, without status migrainosus
43.711: Chronic migraine without aura, intractable, with status migrainosus
43.719: Chronic migraine without aura, intractable, without status migrainosus
43.801: Other migraine, not intractable, with status migrainosus
43.809: Other migraine, not intractable, without status migrainosus
43.811: Other migraine, intractable, with status migrainosus
43.819: Other migraine, intractable, without status migrainosus
43.821: Menstrual migraine, not intractable, with status migrainosus
43.829: Menstrual migraine, not intractable, without status migrainosus
43.831: Menstrual migraine, intractable, with status migrainosus
43.839: Menstrual migraine, intractable, without status migrainosus
43.901: Migraine, unspecified, not intractable, with status migrainosus
43.909: Migraine, unspecified, not intractable, without status migrainosus
43.911: Migraine, unspecified, intractable, with status migrainosus
43.919: Migraine, unspecified, intractable, without status migrainosus
43.D0: Abdominal migraine, not intractable
43.D1: Abdominal migraine, intractable
44.001: Cluster headache syndrome, unspecified, intractable
44.009: Cluster headache syndrome, unspecified, not intractable
44.011: Episodic cluster headache, intractable
44.019: Episodic cluster headache, not intractable
44.021: Chronic cluster headache, intractable
44.029: Chronic cluster headache, not intractable
44.051: Short lasting unilateral neuralgiform headache with conjunctival injection and tearing (SUNCT), intractable
44.059: Short lasting unilateral neuralgiform headache with conjunctival injection and tearing (sunc), not intractable
44.1: Vascular headache, not elsewhere classified
44.201: Tension-type headache, unspecified, intractable
44.209: Tension-type headache, unspecified, not intractable
44.211: Episodic tension-type headache, intractable
44.219: Episodic tension-type headache, not intractable
44.52: New daily persistent headache (ndph)
44.53: Primary thunderclap headache
44.59: Another complicated headache syndrome
44.81: Hypnic headache
44.82: Headache associated with sexual activity
44.83: Primary cough headache
44.84: Primary exertional headache
44.85: Primary stabbing headache
44.89: Other headache syndrome
R51: Headache
Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: