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Intrathecal Pain Pump Infusions for Intractable Cancer Pain: An Algorithm for Dosing Without a Neuraxial Trial

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Abstract

BACKGROUND—Patients with pain from advanced cancer often have limited life expectancy. Undergoing an epidural trial for placement of an intrathecal pump in these selected patients can exhaust limited days of life. We sought to analyze historical data at our cancer center to develop an algorithm to predict initial intrathecal pump dosing based on the starting preimplant systemic opioid regimen, thus averting an epidural trial and minimizing hospital stay.

METHODS—We used data pre- and postpump from 46 cancer patients receiving systemic opioids undergoing intrathecal pump placement in the last 6 years, all of whom had undergone an epidural trial before pump placement.

RESULTS—By analyzing intrathecal opioid dosage on discharge (in IV morphine equivalents) to age, type of pain, cancer type, preimplant opioid dose, and preimplant pain score using multiple regression, we created an algorithm that predicts, for cancer patients, an appropriate initial dose for an intrathecal pump based on the prepump systemic opioid dose, thus avoiding an epidural trial. The predicted value does have a broad 95% prediction interval (−122.7% to 147.6%) pointing to the value of a trial when feasible.

CONCLUSIONS—When an epidural trial is not feasible and an intrathecal pump is required in a cancer patient, it is possible to predict an initial dose for the intrathecal pump based on the systemic opioid usage. This minimizes delays in achieving satisfactory analgesia and discharge to home.

Smith et al.^{1,2} have recommended early placement of implantable intrathecal infusion pumps in cancer patients with moderate to severe pain over comprehensive medical management to improve analgesia and side effects. A study in our institution showed for pancreatic cancer,

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oncologists or palliative care doctors can achieve satisfactory pain relief and side effects with medical management alone in two-thirds of patients.³ In those who fail, referral to an interventional pain specialist is often late in the disease: patients are sicker and have significant side effects, poor analgesia, limited life expectancy, no medical alternatives for pain relief, and limited interventional options. These patients are admitted to the hospital to stabilize their pain, many times undergoing a neuraxial analgesic trial (by epidural catheter in our institution) for placement of an intrathecal pump. As there are limited alternatives, the purpose of the epidural trial is not so much to define efficacy but to establish the most effective intrathecal dose and regimen. Given the morbidity and impending mortality of such patients, we sought to discover independent factors that could be used to calculate the initial intrathecal dose from the systemic medications being used without the need for an epidural trial, thus saving time in the hospital and optimizing analgesia on discharge. To our knowledge, only 1 study has tried to describe predictive factors for neuraxial dosing, specifically epidurals, with no study focusing on factors related to intrathecal dosing.⁴ That study focused on a formula to assign relative weights to various pain characteristics rather than a formal statistical analysis. We reviewed our experience in dosing intrathecal pumps in cancer patients to create an equation to estimate the initial optimal intrathecal dosing. We hoped having such an equation would avoid an epidural trial, minimize ongoing intrathecal dose adjustments, and reduce hospital stay. As a secondary goal, we assessed the analgesic benefit provided by the intrathecal pump to our patients.

METHODS

After obtaining IRB approval, billing databases were queried for names of all patients undergoing intrathecal pump placement (Current Procedural Terminology [CPT] 62362-IMPLANTATION/REPLACE, DEVICE, INTRATHECAL/EPIDURAL) from April 2006 until August 2012. This resulted in a list of 78 patients. Eleven patients were excluded as they had either placement or replacement of previously placed intrathecal pumps and no diagnosis of cancer. Another 16 patients had intrathecal pumps without an epidural trial and were excluded because of inadequate prepump data. Reasons for this included short life expectancy and limited ability to remain in the hospital (e.g., insurance or family reasons). Four more patients were excluded because they had sufentanil in their pumps for which we did not have reliable morphine equivalent conversions and therefore could not be compared. One more patient was excluded because relevant data were not accessible. This resulted in a list of 46 patients as the final pool for analysis.

All 46 patients were admitted to the hospital and received systemic medication first and underwent an epidural trial before operative placement of the pump. Because all systemic options had been exhausted, the end point of the trial was demonstration of any improvement of analgesia by epidural administration versus systemic administration, not complete pain relief. Only 2 patients admitted for epidural trials failed; however, both had no diagnosis of cancer and since neither had an implant, they were not part of the 46 patients based on CPT coding.

For the 46 patients in the final pool, age, gender, cancer type, and date of admission for the trial were noted. All were optimized in the hospital receiving oral or IV systemic

medications, usually by patient-controlled analgesia (PCA). The day before epidural placement was assumed to be the best systemic regimen. On that day, the median numerical rating scale (NRS)⁵ score for pain was recorded. The NRS was scored by the patient on questioning by the nurse, with 0 being no reported pain and 10 being the worst pain imaginable. Also noted was presence of neuropathic pain and use of adjuvants (nonsteroidal anti-inflammatory drugs, stimulants, and neuropathic drugs such as anticonvulsants and antidepressants prescribed for pain). On that same day, the average daily use of all systemic opioids was calculated from PCA recordings: the first recorded use and last recorded use for the day were divided by the hours between and multiplied by 24. In addition, the PCA opioid used was noted and total daily use was converted to IV morphine equivalents based on Table 1.⁸ Any extra use of oral opioid medication was also recorded and used to calculate total daily opioid use and was expressed in the variable preoperative opioid dose (in IV morphine equivalents).

Patients later underwent an epidural trial and had intrathecal pumps placed during the same admission. All pumps were from a single manufacturer (Medtronic, Minneapolis, MN). The date of intrathecal pump placement was noted as was the date of discharge. Immediately after pump placement, while still in the hospital, continuing adjustment of pump settings was done to achieve optimal analgesia before discharge. The continuous intrathecal dose the day before hospital discharge was taken to be the optimal dose of the intrathecal pump placement. The postoperative intrathecal dose was noted in IV morphine equivalents (as opposed to direct intrathecal units of dosing) to allow direct comparisons to the preoperative dose and to allow conversion to other intrathecal opioids such as hydromorphone, which may be more straightforward from IV morphine equivalents. Also, the day before hospital discharge, comparative measures were recorded, including median NRS, intrathecal drugs (opioid, local anesthetic, or clonidine), daily rate of infusion, and use of extra systemic opioids and adjuvants. Length of stay (LOS) was defined as date of placement of epidural trial catheter (taken to represent the start of the trial and achievement of best systemic analgesia) until date of discharge postpump implant.

Additional measures analyzed included change in pain score per patient (from pre-epidural trial until discharge after intrathecal pump placement) and time until death (if applicable) from placement of intrathecal pump.

Statistical Analysis

Descriptive statistics for quantitative variables that were normally distributed include mean and SD. Descriptive statistics for quantitative variables that were not normally distributed include median, minimum, maximum, and interquartile range (IQR). For categorical variables (gender, cancer type, opioid type), counts and proportions are provided. Age, preoperative pain scores, and individual change in pain scores showed normal distribution using the Shapiro-Wilk test (with $P > 0.05$ suggesting the variable from which the sample was extracted follows a normal distribution). Postoperative pain scores were skewed from normality by a single value. Both preoperative and postoperative pain scores were 11-point Likert NRS treated as a continuous variable for correlation and regression testing. The variables not normally distributed by the Shapiro-Wilk test included LOS, preoperative

opioid use, postoperative intrathecal opioid dose (intrathecal pump dose in IV morphine equivalents), and pairwise changes in opioid dose.

We chose as the dependent variable postoperative intrathecal dose (in IV morphine equivalents). We tested the hypothesis that there is a relationship between the dependent variable and the clinically relevant independent variables of age (years), preoperative pain score (NRS), and preoperative opioid dose (in IV morphine equivalents) using a multiple linear regression approach. A Spearman correlation coefficient matrix was initially calculated between the dependent and independent variables. Variables correlated with $P < 0.05$ were treated as significant correlates and were chosen for inclusion in multiple regression modeling.

To assess the validity of using a multiple linear regression, scatterplots were generated pairwise for the dependent variable and each included independent variable to confirm linearity between them. Because linearity was not present, the variables were transformed using the natural logarithm (ln) and repeat scatterplots generated and linearity confirmed visually between the transformed dependent variable and each transformed independent variable. After the initial multiple regression modeling with the transformed variables, we assessed the model based on the F test on the analysis of variance with $P < 0.05$ as being significant. Using the t test, each independent variable was assessed as not significant if $P > 0.05$. If not significant, it was removed and the model generated again. An F test was performed to confirm improvement resulting from removal of nonsignificant variables. The distribution of residuals was assessed for normality using Kolmogorov-Smirnov test with $P > 0.05$ suggesting no difference from a normal distribution. Homoscedascity was confirmed visually by plotting the standardized residuals against the regression standardized predicted values.

The next 2 patients scheduled for intrathecal pump placement with an epidural trial were used to compare the actual intrathecal dose ordered and that predicted by the model.

To minimize overfitting, a 48-fold cross-validation regression (leave-one-out cross-validation) was performed using all available patients ($n = 48$) to obtain an estimate of the predictive bias of the model. A Bland-Altman analysis was performed on the percentage differences of the validated predicted postoperative intrathecal doses compared with the actual postoperative intrathecal dose. Percentage differences were analyzed over absolute differences as these were considered more clinically relevant in opioid-tolerant patients (i.e., a 20-mg morphine dose in an opioid-naïve patient has much greater effect than in an opioid-tolerant patient taking, e.g., 500 mg per day).

Microsoft Excel 2010 with the Microsoft Data Analysis module (Microsoft Corporation, Redmond, WA) and the XLStat add-in (Addinsoft SARL, Paris, France) was used for all analyses.

RESULTS

Forty-six patients treated at Memorial Sloan Kettering Cancer Center were included in this study from April 2006 to March 2012 and are summarized in Tables 2 to 5. The mean age of

the patient population was 46 years with equal numbers of males and females (Table 2). All patients were treated for pain from active cancer unrelieved by systemic medications and presented with diverse cancer types, with a slight dominance of lung cancer patients. On the basis of the clinical symptoms reported, every patient had somatic pain, with 47.8% also having coexisting neuropathic pain (Table 2). No patient had only neuropathic pain.

No opioid was used predominately as the IV analgesic for achieving initial pain control, although morphine was the least used (Table 2). Opioid choice in the intrathecal pump heavily favored hydromorphone (84.8%), reflective of our local practice and consistent with expert guidelines.⁶ Intrathecal local anesthetic (89.1%) was favored heavily over intrathecal clonidine (26.1%), again reflective of our local practice, with clonidine added as third line to bupivacaine in almost all cases.

Pairwise, the median opioid use increased by 105.9 mg of IV morphine equivalents (Table 3), and the mean NRS pain scores decreased by 1.2 postpump placement compared with pretrial (Table 4). Some patients had decreased opioid use (lower boundary of IQR = -36.0) which would be expected from inclusion of adjuvants in the pump, such as bupivacaine or clonidine, and from incomplete cross-tolerance. Side effects were not recorded and therefore could not be analyzed.

Median LOS from onset of the epidural trial until discharge was 11.5 days with an IQR of 9 to 17 days and was divided equally among the duration of the epidural trial and postpump adjustments, suggesting that one-half of the LOS was for the epidural trial (Table 5). There were no complications from surgery, with no documentation of infection or meningitis; there were minimal reports of positional headaches.

To identify predictive factors for postimplant opioid dose, a Spearman correlation was performed between the independent and dependent variables noted in the statistical Methods section. Only age and preoperative opioid dose were significantly correlated with the dependent variable, intrathecal pump dose in IV morphine equivalents (Table 6). As described in the statistical Methods section, $\ln(\text{age})$ and $\ln(\text{preoperative opioid dose})$ were noted to be linear with $\ln(\text{postoperative opioid dose})$. A multiple linear regression was performed using the independent variables of $\ln(\text{age})$ and $\ln(\text{preoperative opioid dose})$ with the dependent variable of $\ln(\text{postoperative opioid dose})$. The F test for the analysis of variance was significant ($R^2 = 0.52$, $F = 22.7$, $P < 0.0001$), and the individual independent variables were then analyzed for significance. Based on the initial regression, the $\ln(\text{postoperative daily intrathecal dose})$ was most significantly correlated with the $\ln(\text{preoperative systemic opioid dose})$; $P < 0.0001$ by the t test; $\ln(\text{age})$ was not a significant covariate ($P = 0.082$ by t test). The regression equation was run using $\ln(\text{preoperative systemic opioid dose})$ as the only predictor variable. Results are provided in Table 7. A normal plot of residuals was performed, and the distribution of residuals was noted to follow a normal distribution by the Kolmogorov-Smirnov test ($P = 0.954$).

From this analysis, intrathecal dose was predicted by systemic IV opioid dose through the following equation (Table 7):

$$\ln(\text{PostMS}_{\text{EQ}}) = 2.60 + 0.61 \times \ln(\text{PreMS}_{\text{EQ}}) \quad (1)$$

where PreMS_{EQ} refers to preoperative systemic opioid dose in IV morphine equivalent (mg) per day and $\text{PostMS}_{\text{EQ}}$ refers to intrathecal dose in IV morphine equivalent (mg) per day.

The above equation may be rewritten as follows:

$$\begin{aligned} e^{\ln(\text{PostMSEQ})} &= e^{2.60} \times e^{0.61} \times e^{\ln(\text{PreMSEQ})} \\ \text{PostMS}_{\text{EQ}} &= 13.5 \times (\text{PreMS}_{\text{EQ}})^{0.61} \end{aligned} \quad (2)$$

Equation (2) suggests that for any patient receiving no preoperative systemic opioid dose, the intrathecal dose will also be 0, which is consistent clinically. As the preoperative systemic opioid dose increases, the intrathecal opioid dose will also increase but will attenuate owing to the 0.61 exponent term.

Equation (2) was used to predict dosing in the next 2 patients who presented to our institution, underwent an epidural trial and eventual pump placement (Table 8). In both cases, the equation led to a slight underestimation of the dose actually ordered at discharge.

The additional 2 patients were pooled with the existing 46 patients to compute a 48-fold cross-validated regression. This was done to minimize overfitting of the data in the Bland-Altman analysis when assessing the predictive fit of the model.^b The predicted values were compared with the actual values to assess the percent difference between them (Fig. 1). Overall, it was noted that patients were estimated with a bias of 12.5% (95% confidence interval, -7.6% to 32.5%), and there appeared to be no change in the bias over the range of values, although the variability decreased as the dose increased along the x-axis, possibly a result of fewer datapoints. The 95% prediction interval, i.e., the range in which 95% of the actual values would likely be, was broad and extended from -122.7% to 147.6%.

DISCUSSION

From our data on 46 cancer patients receiving intrathecal pump placements after undergoing epidural trials, we have developed an algorithm to initially dose intrathecal pumps based on the preoperative systemic dose of opioid without the need for an epidural trial. Previous studies have shown cost-effectiveness in intrathecal pumps only when use exceeded 3 months.⁷ Such considerations are not practicable in advanced cancer patients with limited life expectancy and failure of all other attempted analgesic therapies. Those who died during data collection (34 patients as seen in Table 5) had a median life expectancy on discharge of 54.5 days, which is <3 months. One might argue that an intrathecal pump is not indicated, but then what alternatives are there to preserve quality of life for what time is left? In previous years, a permanent epidural catheter was an option, but increasingly it has been difficult to find home care agencies willing to service these devices because of high

^bThe cross-validated regression resulted in Equation (3) ($R^2 = 0.43$): $\text{PostMS}_{\text{EQ}} = 11.9 \times (\text{PreMS}_{\text{EQ}})^{0.66}$

maintenance costs. Therefore, intrathecal pumps may be the only option. The decision sometimes focuses not on whether a pump will be placed but how it will be dosed. Thus, the epidural trial's role is limited to its negative predictive value and to determine a patient's tolerance to adjuvants such as local anesthetic and clonidine. Since 100% of our cancer patients did undergo implantation after an epidural trial, having an algorithm to transition from systemic medications straight to an intrathecal pump without a trial in an advanced cancer patient is useful. This reduces time in the hospital for those with an already limited life expectancy and minimizes medical cost and potential complications.

Our equation for prediction (Equation 2) attenuates predicted intrathecal doses as the preoperative systemic dose increases. This is reasonable as adjuvants, such as bupivacaine and clonidine, are added at these doses to provide added analgesia and reduce the opioid requirement. Alternatively, increasing systemic doses of opioid above a threshold may be unsuccessful in providing additional analgesia, and intrathecal dosing may provide a more effective route or through added analgesia from incomplete cross-tolerance. We suspect the actual dose required by patients would have been larger had bupivacaine and clonidine not been included in almost all intrathecal pumps. Note the 95% prediction interval for the % differences in the Bland-Altman analysis extends from -122.7% to 147.6%. This is a broad range, one that might result in overestimation. Given the dose and duration of opioid use in these patients, there is likely a significant tolerance that would mitigate adverse effects of an overestimation. For those in whom the dose may be underestimated (as in our 2 example patients in Table 8), programming of an intermittent intrathecal bolus and use of adjuvants should minimize inadequate analgesia. Ultimately, the goal of our equation is to provide an *initial* starting point for intrathecal dosing without an epidural trial. Continued adjustments may still be required in the hospital, but the time required for an epidural trial will have been spared. For our group of patients, the median days until death after discharge potentially could increase from 54.5 to 61 days, with associated savings in LOS as well.

A major limitation of our study included the small effective sample size of 46 patients. Although we performed mainly descriptive statistics (median, IQR), we found no 1 cancer type to be overrepresented for intrathecal pump placement or any patient to have purely neuropathic pain (e.g., chemotherapy-induced neuropathy). We surmise this is likely because most of our patients had active cancer and existing treatments for neuropathic pain (medical and interventional) are sufficiently effective to obviate the need to progress to an intrathecal pump. The mean age of our patients was 46 years of age suggesting a possible selection bias for patients who may be better surgical candidates or survive with advanced cancer. In addition, younger patients are more likely to exhaust possible alternatives for analgesia and side effect management than significantly elderly patients.

Postimplant pain scores (NRS) decreased only by a mean of 1.2 for individual patients possibly reflecting that our patients were referred more for intolerable side effects than intolerable pain.^{1,2} Lack of side effect data is the second major limitation of our data. Median postimplant IV equivalents of the intrathecal dose did increase suggesting that either pain was still a significant component postimplant or our intrathecal drug escalation was too generous. Most likely, fewer side effects from intrathecal dosing permitted easier escalation

to better treat pain. It is this continued titration that resulted in an additional median of 5 days in the hospital postimplant.

It is important to emphasize this is a first step to understanding the relationship between systemic opioid dosing and intrathecal dosing. There are likely many factors that govern the relationship between oral and IV doses, subsequent epidural trials and intrathecal pumps. These can include changes in disease status, postoperative pain requirements, and tolerability of medications. Given the broad 95% prediction interval of our equation (-122.7% to 147.6%), it is evident that an epidural trial has inherent value. Therefore, we still recommend an epidural trial when possible to evaluate tolerability to various epidural drugs, better predict dosing, and assess side effects; when this is not possible, our equation allows a starting estimate of dosing, which may be adjusted up or down on the basis of clinical judgment.

CONCLUSION

In a patient presenting with advanced cancer and pain for whom an intrathecal pump is a consideration and a trial is not feasible, an intrathecal pump may potentially be placed with initial opioid dosing predicted solely on prepump daily systemic opioid using the formula in Equation (2). Bupivacaine and clonidine may be optionally included at nominal rates; we typically start with bupivacaine at 8 to 10 mg/d and clonidine 80 to 100 mcg/d with infusion rates of 0.2 to 0.3 mL/d.

To add a measure of safety, we allow for an intermittent bolus dose each equal to 5% to 10% of the calculated dose. We recommend addition of bupivacaine to all pumps with clonidine added for patients with severe preoperative pain.

Considering all these factors, the formula may be stated as:

$$\text{PostMS}_{\text{EQ}} = 13.5 \times (\text{PreMS}_{\text{EQ}})^{0.61} \quad (3)$$

where PreMS_{EQ} refers to preoperative systemic opioid dose in IV morphine equivalent (mg) per day and $\text{PostMS}_{\text{EQ}}$ refers to intrathecal dose in IV morphine equivalent (mg) per day.

The initial drug may be ordered to infuse at 0.25 mL/d with the following concentrations:

Concentration of hydromorphone (mg/mL): $0.030 \times \text{PostMS}_{\text{EQ}}$

Concentration of bupivacaine (mg/mL): 40 mg/mL

Concentration of clonidine (mcg/mL): 400 mcg/mL

Bolus dosing at $0.0004 \times \text{PostMS}_{\text{EQ}}$, (mg) every 4 hours as needed, maximum 6 times/d

Given the broad prediction interval of our equation, we do recommend close clinical follow-up. Potential underdosing may be averted with the use of bolus dosing. Potential overdosing

is mitigated by the opioid tolerance many of these patients exhibit. Despite this, ongoing adjustments may still be required.

Further research is needed, and we have started new questionnaires in our clinic to incorporate side effect and quality of life data to refine our algorithm and better evaluate the benefits of intrathecal therapy for these selected cancer patients.

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DISCLOSURES

Name: Vivek Tim Malhotra, MD.

Contribution: This author helped design and conduct the study, analyze the data, and write the manuscript.

Attestation: Vivek Tim Malhotra has seen the original study data, reviewed the analysis of the data, approved the final manuscript, and is the author responsible for archiving the study files.

Name: James Root, PhD.

Contribution: This author helped analyze the data.

Attestation: James Root approved the final manuscript.

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Figure 1.
Bland and Altman plot of % differences between actual intrathecal dose and predicted intrathecal dose in IV morphine equivalent (mg) per day. CI = confidence interval.

Table 1Table of Morphine Equivalents Used at Memorial Sloan Kettering Cancer Center^a

Drug name/route	Oral	IV	Epidural	Intrathecal
Morphine	30 mg	10 mg	1 mg	0.1 mg
Fentanyl		0.2 mg (200 mcg)		
Hydromorphone	8 mg	2 mg	0.4 mg	0.08 mg
Methadone	2 mg	1 mg		
Oxycodone	20 mg	—		
Oxymorphone	10 mg	1 mg		

^a Adapted from Foley.⁸

Table 2

Demographics and Clinical Data (46 Observations)

Statistic	Mean (SD)	Min, max	Median (IQR)
Age (y)	46.0 (13.3)	24, 81	56.0 (48.3–67.5)
Designation	Category	Frequency per category	Rel. frequency per category (%)
Sex	Female	22	47.8
	Male	24	52.2
Cancer type	Adenocarcinoma	2	4.4
	Bladder	2	4.4
	Breast	2	4.4
	Chordoma	2	4.4
	Colorectal	5	10.9
	Desmoid	1	2.2
	Endometrioid	2	4.4
	Kidney	1	2.2
	Liver	1	2.2
	Lung	10	21.7
	Melanoma	4	8.7
	Pancreas	3	6.5
	Penile	1	2.2
	Prostate	2	4.4
	Sarcoma	5	10.9
	Thyroid	1	2.2
	Uterus	2	4.4
Somatic pain	Yes	46	100.0
Neuropathic pain	Yes	22	47.8
Preoperative adjuvants used	Yes	27	58.7
Preoperative systemic opioid type	Fentanyl	16	34.8
	Hydromorphone	14	30.4
	Methadone	13	28.3
	Morphine	3	6.5
(Postoperative) intrathecal opioid type	Hydromorphone	39	84.8
	Morphine	7	15.2
(Postoperative) intrathecal local used	Yes	41	89.1
(Postoperative) intrathecal clonidine used	Yes	12	26.1

Min = minimum; max = maximum; IQR = interquartile range.

Table 3

Pre- and Postoperative Opioid Usage (46 Observations)

Statistic	Min, max	Median (IQR)
Preoperative systemic IV dose as a group (mg/d, IV morphine equivalents)	34.8, 5748.8	327.1 (171.2–798.3)
Postoperative intrathecal dose as a group (mg/d, IV morphine equivalents)	18.8, 3000.0	624.7 (205.7–1233.6)
Individual change in IV morphine equivalent	–4248.8, 1918.3	105.9 (–36.0 to 252.9)

Min = minimum; max = maximum; IQR = interquartile range.

Table 4

Pre- and Postoperative Pain Scores (46 Observations)

Statistic	Mean (SD)	Min, max	Median (IQR)
Preoperative pain scores (NRS)	4.5 (1.9)	0.8, 8.0	4.0 (3.1–5.9)
Postoperative pain scores (NRS)	3.3 (1.8)	0, 8.0	3.63 (2.1–4.0)
Individual change in NRS	–1.2 (2.1)	–6.0, 3.0	–1.0 (–2.5 to 0)

Min = minimum; max = maximum; IQR = interquartile range; NRS = numerical rating scale.

Table 5

Length of Stay Data

Statistic	Min, max	Median (IQR)	<i>n</i>
Length of stay (d)	6.0, 39.0	11.5 (9.0–17.0)	46
No. of postoperative days until discharge	2.0, 27.0	5.0 (4.0–8.0)	46
No. of days until death after pump placement ^a	3.0, 973.0	54.5 (24.5–150.5)	34 ^a

^aData are not normally distributed.

Min = minimum; max = maximum; IQR = interquartile range.

Table 6

Correlation Matrix (Spearman)

Variables	Age (y)	Preoperative pain score (NRS)	Postoperative pain score (NRS)	Preoperative opioid dose in IV morphine equivalents (mg)	Intrathecal pump dose in IV morphine equivalents (mg)
Age (y)	1	-0.229	-0.127	-0.196	-0.330
Preoperative pain score (NRS)	-0.229	1	0.310	0.181	0.144
Postoperative pain score (NRS)	-0.127	0.310	1	0.081	0.162
Preoperative opioid dose in IV morphine equivalents (mg)	-0.196	0.181	0.081	1	0.667
Intrathecal pump dose in IV morphine equivalents (mg)	-0.330	0.144	0.162	0.667	1

Values in bold are different from 0 with a significance level $\alpha = 0.05$. NRS = numerical rating scale.

Table 7

Regression Results (Equation (1))

	Equation (1)	95% Confidence intervals
Intercept	2.60 [*] (0.58)	1.43–3.77
ln(Preoperative opioid dosage) unstandardized β coefficients	0.61 [*] (0.095)	0.42–0.80
Preoperative opioid dosage standardized coefficients	0.69 [*] (0.11)	0.74–0.91
F	40.58 [*]	
R^2	0.48	
N	46.00	

Standard errors are reported in parentheses.

^{*} $P < 0.0001$

Table 8

Algorithm Applied to Next 2 Patients with Intrathecal Pump

	Patient 1	Patient 2
Sex	Male	Male
Cancer type	Lung	Bladder
Age (y)	59	64
Somatic pain present?	Yes	Yes
Neuropathic pain present?	Yes	No
Preoperative oral adjuvants used?	Yes	No
Preoperative systemic opioid type	Fentanyl	Hydromorphone
(Postoperative) intrathecal opioid type	Morphine	Hydromorphone
(Postoperative) intrathecal local used	Bupivacaine	Bupivacaine
(Postoperative) intrathecal clonidine used	No	No
Preoperative pain scores (NRS)	3	4.5
Postoperative pain scores (NRS)	5	2
Individual change in NRS	+2	−2.5
Length of stay (d)	12	12
No. of postoperative d until discharge (d)	11	1
Preoperative IV morphine equivalent (mg/d)	174.2	31.5
Predicted postpump IV morphine equivalent continuous only (mg/d)	316.7	111.6
Predicted IT pump dose ordered no bolus, continuous only (mg/d)—hydromorphone	3.2 mg/d of morphine	0.89 mg/d of hydromorphone
Actual IT pump dose ordered (mg/d)—hydromorphone	5.6 mg/d of morphine	1.6 mg/d of hydromorphone

NRS = numerical rating scale; IT = intrathecal.