

## Optimum Concentration of Bupivacaine for Combined Caudal-General Anesthesia in Children

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Caudal epidural anesthesia has become widely accepted as a means of providing postoperative pain relief and intraoperative supplementation to general anesthesia for children. To determine the best concentration of bupivacaine for combined general-caudal anesthesia in children, 122 children aged 1-8 yr scheduled for outpatient inguinal herniorrhaphy were randomized to receive, in a double-blind fashion, caudal anesthesia with bupivacaine in one of six concentrations (0.125, 0.15, 0.175, 0.2, 0.225, or 0.25%). After incision, a programmed reduction in inspired halothane resulted, if tolerated by the subject, in an inspired halothane concentration of 0.5% 10 min after incision. End-tidal halothane concentration at hernia sac ligation for subjects receiving 0.175% bupivacaine ( $0.55 \pm 0.03\%$ ) was less than that for subjects receiving 0.15% bupivacaine ( $0.75 \pm 0.05\%$ ;  $P < 0.05$ ). Subjects receiving 0.175% bupivacaine also were discharged earlier from the postanesthesia care unit (PACU) ( $27 \pm 1$  min) than were subjects receiving 0.15% bupivacaine ( $38 \pm 5$  min;  $P = 0.05$ ). Children receiving  $\geq 0.2\%$  bupivacaine tended to complain more of leg weakness after surgery; however, the difference did not reach statistical significance (39 of 67 vs. 16 of 47;  $P = 0.057$ ). The incidence of complaints of leg weakness and paresthesia was positively correlated with bupivacaine concentration ( $r = 0.706$ ;  $P = 0.05$ ). Subjects receiving 0.125% bupivacaine had higher pain scores on arrival to the PACU than did those receiving 0.2% bupivacaine ( $P = 0.05$ ); there were no other differences in pain scores. Subjects receiving 0.175% bupivacaine ambulated sooner ( $129 \pm 6$  min) than did subjects receiving 0.125 and 0.2% bupivacaine ( $202 \pm 20$  min,  $207 \pm 21$  min;  $P \leq 0.01$ ). Subjects receiving 0.175% bupivacaine also were discharged home sooner ( $167 \pm 8$  min) than were subjects receiving 0.125 and 0.15% bupivacaine ( $248 \pm 26$  min,  $255 \pm 40$  min;  $P \leq 0.05$ ). Discharge home was delayed in subjects with ineffective intraoperative caudal supplementation ( $262 \pm 27$  min vs.  $196 \pm 8$  min;  $P < 0.01$ ) and in subjects who received supplemental analgesics ( $253 \pm 16$  min vs.  $177 \pm 17$  min;  $P < 0.001$ ). Although all concentrations were effective for combined general-caudal anesthesia in children, we conclude that 0.175% bupivacaine offers the best combination of effectiveness and rapid recovery and discharge for pediatric surgical outpatients. (Key words: Anesthesia; pediatric. Anesthetic techniques: epidural-caudal. Anesthetics, local: bupivacaine.)

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CAUDAL EPIDURAL ANESTHESIA has gained wide acceptance in pediatric anesthesia as a technique for providing postoperative pain relief and reducing general anesthetic requirements for surgical procedures below the umbilicus.<sup>1-3</sup> Wolf *et al.* have shown that 0.125% bupivacaine administered caudally at the end of surgery provides postoperative pain relief equal to that from 0.25% bupivacaine but with less leg weakness and with reduced time until standing is possible.<sup>4</sup> Kapsten *et al.* have shown that 0.25% bupivacaine is as effective as 0.375% bupivacaine for intraoperative caudal supplementation to general anesthesia in children\*\*; however, they did not investigate bupivacaine concentrations of less than 0.25%.

While caudal anesthetic techniques have in general been well received by surgeons and children at our institution, persistent paresthesia and weakness in the lower extremities have proven distressing to some patients. Less commonly, postoperative urinary or fecal incontinence, possibly due to weakness of the sphincter muscles, has been embarrassing to older children. Since we routinely use caudal epidural anesthesia as an adjunct to general anesthesia in order to reduce inhalation anesthetic requirements,<sup>3,5,6</sup> we were reluctant to use bupivacaine concentrations of less than 0.25% for intraoperative supplementation without first determining their effectiveness. Lower concentrations of bupivacaine might facilitate earlier discharge by reducing leg weakness and paresthesia; however, if intraoperative general anesthetic requirements were increased with the use of lower bupivacaine concentrations, discharge might be delayed due to prolonged emergence. We therefore undertook a prospective, randomized, double-blinded comparison of six concentrations of bupivacaine between 0.125 and 0.25% to determine which would provide effective intraoperative anesthetic supplementation combined with minimization of distressing side-effects, rapid emergence from anesthesia, and early discharge home.

### Materials and Methods

This study protocol was approved by the university's Human Studies Committee, and written informed consent

\*\* Kapsten JE, Broadman LM, Hannallah RS, Norrie WC, Mundy GL, Bellman AB, Anderson KD, Guzzetta PC: Is there an optimum concentration of bupivacaine for caudal analgesia in outpatient surgery for children? (abstract). *Can Anaesth Soc J* 33:S114, 1986.

was obtained from each subject's parents. One hundred twenty-two healthy children between the ages of 1 and 8 yr scheduled for unilateral or bilateral inguinal herniorrhaphy in our same-day surgery (SDS) unit were enrolled. Subjects were randomized to receive supplemental caudal anesthesia with bupivacaine in one of six concentrations (0.125, 0.15, 0.175, 0.2, 0.225, or 0.25%) combined with 1:200,000 epinephrine. Study solutions were prepared in the hospital pharmacy using stock 0.25% bupivacaine, preservative-free normal saline, and epinephrine.

All children received a standardized anesthetic. Induction of anesthesia was achieved with inhalation of halothane in 70% nitrous oxide and oxygen. When an adequate level of anesthesia was obtained, the children were turned to the lateral position, and caudal epidural anesthesia was administered using the "no-touch" technique of Broadman<sup>††</sup> with  $0.66 \text{ ml} \cdot \text{kg}^{-1}$  (the volume calculated to achieve a  $T_{10}$  level) of the study solution.<sup>7</sup> Following caudal block, an intravenous catheter was inserted, and the surgical site was prepared. Anesthesia was maintained with inhalation of halothane and 70% nitrous oxide in oxygen by mask. A Bain circuit was used for children weighing less than 20 kg; a circle absorber system was used for larger children. Fresh gas flows in all cases were at least  $3 \text{ l} \cdot \text{min}^{-1}$ . In order to allow onset of caudal anesthesia in all subjects, 10–15 min was allowed to elapse between the caudal block and surgical incision; inspired halothane was maintained at 1.5% during this interval.

After surgical incision the inspired halothane was reduced to 1.0% unless patient response (increases in heart rate or blood pressure that did not stabilize in 1 min; arrhythmias; stridor; vocalization; or movement) made a reduction impossible. One or more of the anesthesiologist authors (JBG, CMD, JBB, or DLP) was present during and managed the programmed reduction in inspired halothane. If possible, the inspired halothane concentration was reduced to 0.75% 5 min after incision and to 0.5% 10 min after incision. This concentration was maintained until skin closure, when the halothane was discontinued. Heart rate (from the electrocardiogram) and blood pressure (from an oscillometric blood pressure device) were recorded at incision and at 5 and 10 min after incision. The end-tidal halothane ( $ET_{\text{hal}}$ ) concentration at ligation of the hernia sac was recorded; respiratory gases were sampled at the elbow connector and were measured using a central mass spectrometer.

The effectiveness of intraoperative caudal anesthesia was graded using the scoring system outlined in table 1. Beginning with the completion of surgery, the time to awaken from anesthesia, time to discharge from the pos-

†† Broadman LM: Pediatric regional anesthesia and postoperative analgesia, The American Society of Anesthesiologists Refresher Courses in Anesthesiology. Edited by Barash PG. Philadelphia JB Lippincott, 1986, pp 43–60.

TABLE 1. Caudal Effectiveness Score

Score	Definition
0	Impossible to reduce halothane concentration at any time during surgery
1	Halothane concentration increased after initial reduction
2	Halothane concentration reduced; HR or BP increase $\geq 20\%$ of baseline
3	Halothane concentration; HR and BP increase $<20\%$ of baseline

HR = heart rate; BP = blood pressure.

tanesthesia care unit (PACU), time to first ambulation, and time to discharge home were recorded. Blood pressure is not routinely monitored in our SDS unit; therefore, the pain scoring system of Hannallah *et al.*<sup>8</sup> was modified by deletion of the blood pressure change category. These modified scores were recorded on arrival to and on discharge from the PACU and every 30 min in the SDS. Subjects could receive acetaminophen at the discretion of the PACU or SDS nurse; administration of opioid analgesics required an order from an anesthesiologist. Supplemental analgesic requirements in the PACU and the SDS as well as incontinence and complaints of leg paresthesia or weakness also were recorded. Parents were contacted the day after surgery; analgesic requirements at home and difficulties with ambulation, if any, were noted.

Demographic data are presented as means  $\pm$  standard deviation. Parametric results are presented as means  $\pm$  standard error of the mean; nominal and ordinal results are presented as proportions. Parametric results were analyzed using one-way analysis of variance followed by unpaired Student's *t* tests and Student-Newman-Keuls tests. Nominal data were analyzed with  $\chi^2$  contingency tables. The Yates correction for continuity was used for  $2 \times 2$  tables. Ordinal data were analyzed using the Kruskal-Wallis statistic. Correlations were examined using linear regression by least squares for parametric data and Spearman's rank-order correlation coefficient for nonparametric data. The Bonferroni correction was used when making multiple comparisons; reported *P* values incorporate the Bonferroni correction. Results were considered significant for corrected  $P \leq 0.05$ .

## Results

Subject distribution and demographics are shown in table 2. There was no difference in age, weight, pause before surgery, or duration of surgery for subjects receiving any of the six bupivacaine concentrations. Heart rate response 5 min after incision was significantly greater for 0.2% bupivacaine ( $24 \pm 14\%$ ) than for 0.25% bupivacaine ( $12 \pm 10\%$ ;  $P < 0.02$ ). There were no other differences in heart rate or blood pressure responses.

TABLE 2. Subject Demographics

	Bupivacaine Concentration (%)						P
	0.125	0.150	0.175	0.200	0.225	0.250	
Number	16	15	19	20	26	26	
Age (months)	46 ± 25	50 ± 25	42 ± 23	51 ± 23	48 ± 28	40 ± 22	NS
Weight (kg)	16.7 ± 5.2	16.0 ± 4.0	15.9 ± 3.6	17.1 ± 5.0	16.7 ± 4.8	15.5 ± 4.8	NS
Pause before surgery (min)	13 ± 2	11 ± 2	12 ± 2	11 ± 2	12 ± 5	12 ± 2	NS
Duration of surgery (min)	19 ± 9	26 ± 20	23 ± 9	19 ± 8	19 ± 9	18 ± 8	NS

NS = not significant.

There was no difference in the distribution of caudal effectiveness scores for any of the six concentrations. However, caudal effectiveness scores were positively correlated with increasing bupivacaine concentrations ( $\rho = 0.239$ ;  $P < 0.02$ ). The caudal effectiveness score proved effective in separating subjects by their anesthetic requirements; effectiveness scores of 0 or 1 were associated with higher  $ET_{hal}$  concentrations at hernia sac ligation ( $0.90 \pm 0.06\%$  vs.  $0.60 \pm 0.02\%$  for scores of 2 and  $0.56 \pm 0.2\%$  for scores of 3,  $P < 0.001$ ).

Anesthetic requirements and recovery times are shown in table 3. Subjects receiving 0.175% bupivacaine had a lower mean  $ET_{hal}$  concentration at hernia sac ligation and a lower mean time to discharge from PACU than did subjects receiving 0.15% bupivacaine. Subjects receiving 0.175% bupivacaine ambulated sooner than did subjects receiving 0.125 and 0.2% bupivacaine. The mean time to discharge home was less for subjects receiving 0.175% bupivacaine than for those receiving 0.125 and 0.15% bupivacaine. Discharge home was significantly delayed in subjects with caudal effectiveness scores of 0 or 1 ( $262 \pm 27$  min) compared to those with scores of 2 or 3 ( $202 \pm 10$  or  $191 \pm 11$  min, respectively;  $P < 0.01$ ). While there was no difference in time to discharge home for subjects with or without complaints of leg weakness or paresthesia, time to discharge was significantly correlated with time to voluntary ambulation (time to discharge =  $108 \text{ min} + 0.6 \cdot \text{time to ambulation}$ ;  $r = 0.539$ ;  $P < 0.001$ ). Discharge home was significantly delayed in subjects who required supplemental analgesics ( $253 \pm 16$  min vs.  $177 \pm 17$  min;  $P < 0.001$ ).

Subjects receiving 0.125% bupivacaine had higher pain scores on arrival to the PACU than did subjects receiving 0.2% bupivacaine ( $P = 0.05$ ). There were no other differences in pain scores. There was no association between caudal effectiveness scores and pain scores or supplemental analgesic requirements. There was no difference in supplemental analgesic requirements in the PACU (12 of 122 subjects: 7 acetaminophen, 2 fentanyl, and 3 morphine), in the SDS (48 of 122: all acetaminophen), or at home (54 of the 112 subjects contacted: all acetaminophen) and no difference in incontinence (15 of 109 subjects who were or were being toilet-trained) for subjects receiving any of the six bupivacaine concentrations.

Complaints of paresthesia and leg weakness were more common with higher concentrations of bupivacaine ( $P = 0.07$ ), and the incidence of complaints of leg weakness was positively correlated with bupivacaine concentration (incidence =  $0.008 + 2.5 \cdot \text{concentration}$ ;  $r = 0.706$ ;  $P = 0.05$ ). Concentrations of bupivacaine  $\leq 0.175\%$  did not differ in the rate of complaints of leg weakness and paresthesia (16 of 47 subjects;  $P = 0.62$ ); bupivacaine concentrations  $\geq 0.2\%$  also did not differ in the rate of complaints of leg weakness and paresthesia (39 of 67;  $P = 0.22$ ). While the overall rate of complaints of leg weakness and paresthesia appeared lower for bupivacaine concentrations  $\leq 0.175\%$ , the difference did not reach statistical significance ( $P = 0.057$ ). There was no association between caudal effectiveness scores and complaints of leg weakness or paresthesia. There were no differences in complaints of difficult ambulation at home (16 of 111) for subjects receiving any of the six concentrations.

TABLE 3. Anesthetic Requirements and Recovery Times

	Bupivacaine Concentration (%)						P
	0.125	0.150	0.175	0.200	0.225	0.250	
$ET_{hal}$ at hernia sac ligation (%)	$0.68 \pm 0.06$	$0.75 \pm 0.05$	$0.55 \pm 0.03^*$	$0.62 \pm 0.05$	$0.67 \pm 0.05$	$0.59 \pm 0.04$	0.07
Awakening (min)	$21 \pm 3$	$20 \pm 2$	$18 \pm 2$	$21 \pm 2$	$18 \pm 1$	$17 \pm 2$	N.S.
Discharge from PACU (min)	$33 \pm 4$	$38 \pm 5$	$27 \pm 1^\dagger$	$34 \pm 3$	$34 \pm 2$	$28 \pm 1$	0.05
First ambulation (min)	$202 \pm 20$	$163 \pm 17$	$129 \pm 6^\ddagger$	$207 \pm 21$	$158 \pm 9$	$194 \pm 28$	0.04
Discharge from SDS (min)	$248 \pm 26$	$255 \pm 40$	$167 \pm 8^\S$	$208 \pm 18$	$204 \pm 15$	$204 \pm 17$	0.05

PACU = postanesthesia care unit; SDS = same-day surgery.

\*  $P < 0.05$  versus 0.15%.

†  $P = 0.05$  versus 0.15%.

‡  $P \leq 0.01$  versus 0.125 and 0.2%.

§  $P \leq 0.05$  versus 0.125 and 0.15%.

## Discussion

Children at our institution are expected to be awake and alert, free of pain, able to tolerate oral fluids, and able to ambulate as appropriate for age before discharge home from the SDS. When the surgical site is appropriate, combination of regional and general anesthetic techniques offers several advantages for SDS patients. Because intraoperative inhalation anesthetic requirements are reduced, time to emergence from general anesthesia may be reduced.<sup>3,5,6</sup> The pain relief afforded by regional techniques lessens the need for opioid analgesics and consequently lessens their side effects—somnolence and nausea.<sup>3</sup> For brief procedures, such as inguinal herniorrhaphy, duration of pain relief is the same whether caudal anesthesia is performed before or after surgery.<sup>5</sup> Ideally, such combined techniques should neither produce distressing side effects nor delay discharge by interfering with ambulation. The optimum concentration of local anesthetic would therefore be the concentration that combines maximal anesthetic supplementation and pain relief with minimal side effects and results in the earliest ambulation and discharge.

In our study, we considered supplementation to general anesthesia to be effective provided that the inspired halothane concentration was reduced according to plan (an effectiveness score of 2 or 3). Moderate hemodynamic responses to incision and surgery were accepted as long as the response stabilized and the resultant heart rate and blood pressure did not present a threat to the well-being of the subject. Reduction in inspired halothane concentration was abandoned in the face of severe progressive hemodynamic responses, dysrhythmia, vocalization, stridor, or movement. No effort was made to differentiate between unsuccessful blocks and inadequate supplementation; however, each block was either performed or closely supervised by an anesthesiologist familiar with the technique. It is possible that children requiring supplemental analgesics in the PACU, especially those requiring opioid analgesics, may have had unsuccessful blocks; however, there was no association between intraoperative caudal effectiveness scores and pain scores or analgesic requirements.

All concentrations provided adequate postoperative pain relief in that the majority of subjects required no supplemental analgesics and that the vast majority who did required nothing stronger than acetaminophen. The only difference in pain scores was a relative advantage for 0.2% bupivacaine versus 0.125% bupivacaine on arrival to the PACU. We have not further studied the pain scores, modified from Hannallah *et al.*,<sup>8</sup> used in this study; therefore, we do not know what effect, if any, our modification had on the scoring system's sensitivity and specificity. However, the analgesic effectiveness of caudally administered 0.125% bupivacaine has been well documented

by Wolf *et al.*<sup>4</sup> Although our study supports their results, our primary focus was on intraoperative supplementation, side effects, and discharge home.

Children in our SDS unit are not required to urinate prior to discharge; therefore, we did not address the issue of delayed micturition. The incidence of incontinence did not differ for subjects receiving any of the six concentrations. Motor strength *per se* was not evaluated; rather, we evaluated subjective complaints of weakness and the objective end points of ambulation and discharge home, since these were the issues we wished to address in optimizing local anesthetic concentration.

In view of our desire in designing this study to minimize time to discharge, it should be noted that 0.175% bupivacaine resulted in a mean time to discharge home > 80 min less than that seen with 0.125 or 0.15% bupivacaine. There are several possible explanations for the delayed discharge seen in subjects receiving these lower concentrations. One explanation would be that the difference is simply a coincidence; it is possible that some unknown attribute, shared in a disproportionate fashion by subjects receiving 0.175% bupivacaine and unrelated to bupivacaine concentration, might account for the earlier discharge. Examples of such an attribute might include reduced MAC for halothane, increased susceptibility to caudal epidural anesthesia, or a lower incidence of block failure. This possibility cannot be excluded, although given the other ways in which 0.175% bupivacaine offered relative advantages, it appears extremely unlikely.

A second possible explanation is that subjects receiving 0.125 and 0.15% bupivacaine had delayed discharge home due to differences in postoperative pain relief that were not detected using our pain scoring system; a more sensitive pain measurement system might have detected differences in pain relief that our pain assessment technique missed. Discharge home was delayed in subjects who required supplemental analgesics; however, analgesic requirements were not affected by bupivacaine concentration. While no specific criteria for analgesic administration were used in the study, all subjects were cared for in the same PACU and SDS unit. Although a requirement for supplemental analgesics was associated with delayed discharge home, we do not believe that the delay observed with 0.125 and 0.15% bupivacaine can be attributed to inadequacy of pain relief.

A third possible explanation is suggested by the observation that both caudal effectiveness scores and complaints of leg weakness and paresthesia were positively correlated with bupivacaine concentration. This suggests a bimodal distribution of concentration effects on time to discharge: delayed discharge due to prolonged emergence would increase with decreasing bupivacaine concentrations, whereas delayed discharge due to leg weakness would increase with increasing bupivacaine concentrations. If so, there might be a point in our bupivacaine concentration

range at which the combined effects would be at a minimum. The increase in  $ET_{hal}$  concentration at hernia sac ligation with 0.15% compared to 0.175% bupivacaine and the correlation between bupivacaine concentration and caudal effectiveness score suggest at least some decrease in effectiveness with lower concentrations. That discharge was delayed in subjects with ineffective caudal supplementation offers further support for this hypothesis. However, no association was seen between increasing bupivacaine concentrations and decreasing  $ET_{hal}$  concentrations at hernia sac ligation. Because halothane concentrations were measured during mask ventilation with high fresh gas flows, it is possible that the true  $ET_{hal}$  concentration at hernia sac ligation was higher than that recorded; if so, differences in halothane requirements might have been undetected. In addition, in some subjects hernia sac ligation occurred prior to or at the completion of the programmed reduction in inspired halothane; a lower  $ET_{hal}$  concentration might have been tolerated had surgery proceeded at a more leisurely pace.

Although our data suggest that higher bupivacaine concentrations are associated with an increased incidence of complaints of leg numbness and paresthesia, the lack of an association between such complaints and delayed discharge seems to contradict the above hypothesis. On the other hand, time to discharge was positively correlated with time to voluntary ambulation. This contradiction may be explained in part by the fact that we assessed time to voluntary ambulation—a subjective end-point—rather than ability to stand at a specific time—an objective end-point. The subjective factors that determine patient complaints of leg weakness and paresthesia may be different from those relating objective lower extremity motor strength and time to discharge. Alternatively, time to voluntary ambulation may depend more on emergence from general anesthesia than on the degree of leg weakness. While we cannot prove that delayed discharge home in subjects receiving 0.125 and 0.15% bupivacaine compared to those receiving 0.175% bupivacaine is due to such a combination of divergent effects, we find this explanation consistent both with our intuition and with our results.

A study such as ours, comparing small differences in local anesthetic concentration, may be difficult to interpret. With multiple comparisons, two groups may differ significantly from each other even though neither differs from any of the other groups. Our results indicate few differences among groups given any of the concentrations studied. However, in each instance where a difference was noted, the difference favored 0.175% bupivacaine.

In conclusion, we have demonstrated that effective intraoperative regional supplementation to general anesthesia is associated with earlier discharge home after pediatric outpatient inguinal herniorrhaphy. All six concentrations studied proved effective for intraoperative supplementation to general anesthesia in the majority of

subjects; however, the differences suggest specific roles for some of the studied concentrations. Our study suggests that bupivacaine concentrations  $\leq 0.175\%$  are associated with a lower incidence of complaints of leg weakness and paresthesia; in conjunction with the work of Wolf *et al.*,<sup>4</sup> this suggests that these lower concentrations of bupivacaine should be used when caudal anesthesia is given in situations where leg weakness and paresthesia may have a negative impact on postoperative recovery and discharge. If leg weakness and the possibility of delayed postoperative ambulation are not considerations in the anesthetic plan, there is little reason, other than limitation of total local anesthetic dose, to use bupivacaine concentrations  $< 0.25\%$ . If limitation of the total local anesthetic dose is a consideration, bupivacaine concentrations as low as 0.125% can provide satisfactory intraoperative supplementation in the majority of children; however, bupivacaine concentrations  $< 0.175\%$  are associated with significantly delayed discharge home for pediatric outpatients. Since with higher concentrations there is no increase in effectiveness and since with lower concentrations there is significant delay before discharge home, we conclude that 0.175% bupivacaine is the optimum concentration for combined caudal-general anesthesia in children having outpatient surgery.

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