our patient, it is, therefore, possible that the interruption of aberrant reflex activity originating from a unilateral irritative lesion that had recruited internunicial pool neurons could, thus, remove the contralateral symptomatology. This would appear to explain the bilateral relief of symptoms in our patient achieved with a unilateral block. Reflex disturbances in long-established pain syndromes may manifest contralateral symptoms as a mirror image to the original lesion.[18] Our patient had contralateral symptoms, although her pain was not a particularly long-established syndrome. Her relatively recent history no doubt contributed to our successful interruption of aberrant reflex activity that we postulate initiated her contralateral pain in the first place. Postpartum, she has related no complaint of burning dysesthesia, but only median nerve distribution finger tip numbness. Future electrodiagnostic evaluation will determine the need for carpal tunnel decompression.

In summary, we have presented a pregnant woman who spontaneously developed a bilateral reflex sympathetic dystrophy. Diagnostic studies identified median nerve compression and carpal tunnel syndrome. Serial right stellate ganglion blockade provided our patient complete and progressively prolonged relief from her bilateral RSDS, allowing her to experience a more comfortable third trimester and postpartum period.

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Bupivacaine for Caudal Analgesia in Infants and Children: The Optimal Effective Concentration

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Three of the important variables that determine the effectiveness of caudal blocks for postoperative analgesia are: the specific local anesthetic, the volume of solution, and the concentration of local anesthetic solution. The effects of the first two variables have been studied previously in infants and children receiving caudal blocks.[1–6] However, the optimal concentration of local

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TABLE 1. Demographic Data

	Concentration of Bupivacaine Solution*		
	0.25%	0.125%	0.0625%
Age (yr)	3.5 ± 2.3	3.6 ± 2.1	3.9 ± 2.3
Weight (kg)	15.7 ± 5.0	15.4 ± 5.2	16.8 ± 5.8
Number of patients undergoing:			
1) Orchidopexy or hernia repair	17	12	19
2) Hypospadius or circumcision	18	23	16
Total number of patients per group	35	35	35

Data are mean ± SD.
* Containing 1:200,000 epinephrine.

anesthetic solution for a specific volume of solution (*i.e.*, the optimal dose) has not been established.

The optimal concentration of a local anesthetic should provide effective analgesia, minimal motor blockade, and few side effects. Kapsten *et al.* suggested that a 0.25% solution of bupivacaine may be the optimal concentration for caudal blocks because it provides effective analgesia without delayed discharge from the hospital.[7] However, the lowest concentration they studied was 0.25% bupivacaine. Vater and Wandless reported weakness in the lower extremities (50% of the patients were unable to stand within 2 h postoperatively) and delayed micturition (32% of the patients did not void within 8 h postoperatively) in patients who received a caudal block with 0.25% bupivacaine in a volume of 0.5 ml/kg.[8] In our day surgery unit, prolonged weakness in the lower extremities occurred in several patients who received a caudal block with 0.25% bupivacaine, and this delayed their discharge from hospital. Previous investigators reported that the intensity of both sensory and motor blockade decreased as the concentration of bupivacaine decreased.[9] While lower concentrations of bupivacaine may effectively eliminate motor blockade in the lower extremities, we were concerned that these same concentrations may not provide adequate sensory blockade. Therefore, we sought to determine the optimal effective concentration of bupivacaine for a specific volume of solution for caudal analgesia in infants and children.

MATERIALS AND METHODS

With approval from the Human Review Committee, a randomized double-blind study was undertaken. Informed written consent was obtained from the parents of 114 infants and children, between 6 months and 10 yr of age undergoing elective superficial lower abdominal and/or genital surgery (table 1). Patients were excluded from this study if a history of allergic reactions to local anesthetics, bleeding diathesis, aspirin ingestion in the preceeding week, or pre-existing neurological or

spinal diseases were present. All children were ASA physical status I or II, fasting and unpremedicated. Anesthesia was induced by iv administered drugs (pentothal, atropine, succinylcholine) and was maintained with either halothane or isoflurane, nitrous oxide, and oxygen with or without a muscle relaxant. Narcotics were not administered at any time. Local anesthetics were used only for the caudal block. Fluids were administered iv in both the intraoperative and postoperative periods to replace the preoperative fluid deficit and ongoing fluid losses.

At the completion of surgery, but before termination of general anesthesia, the patient was placed in the lateral decubitus position. Under sterile conditions, a 22- (for patients 6 months to 2 yr of age) or 20-gauge (for patients 2–10 yr of age) teflon intravenous catheter with an inner stylet was inserted through the sacrococcygeal ligament into the caudal space. The stylet was then removed and the catheter was advanced 0.5–1 cm. Each patient was randomly assigned to receive one of three solutions of bupivacaine: 0.25%, 0.125%, or 0.0625%. The 0.125% and 0.0625% concentrations were prepared by diluting 0.25% plain bupivacaine with either sterile water or normal saline without preservatives. Epinephrine was added to each solution to provide a concentration of 1:200,000.[10] The volume of local anesthetic solution administered to each child was 0.75 ml/kg.

After administration of the caudal block, heart rate was monitored continuously and systolic arterial blood pressure was monitored every 5 min until the patient awakened. In the recovery room, heart rate and systolic arterial blood pressure were recorded every 5 min for the first 20 min after the caudal block and every 15 min thereafter for 1 h by nurses who were unaware of the concentration of bupivacaine used.

One hour after the caudal block was administered, blinded measurements of postoperative pain and motor strength in the lower extremities were recorded by one of the authors. Additional blinded measurements were recorded by designated ward nurses hourly for 5 h and again at 12 h after the caudal block. Postoperative pain was assessed using a scoring system described by Hannallah *et al.*[11] Motor strength in the lower extremities was scored only in those children who were old enough to stand before surgery, according to the following scale: paralyzed or movement only with gravity; movement against gravity but not able to stand; and able to stand.

The time from administration of the caudal block to supplemental analgesia (im codeine) was recorded for each child during the 12-h period after surgery. Codeine im (1 mg/kg) was administered at the discretion of the nurses in the recovery room and on the urology ward to any patient whose pain score was > 3. Based on
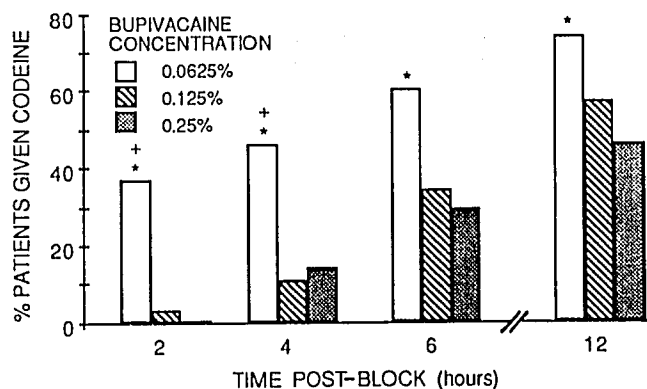
FIG. 1. The percent of patients given codeine was significantly less in the 0.25% group at all times and in the 0.125% group at 2 and 4 h compared to the 0.0625% group. There was no significant difference between the 0.125 and 0.25% groups at any time. *$P < 0.05$, 0.0625% versus 0.25%; +$P < 0.05$. 0.0625% versus 0.125%.

previous experience, a pain score ≤ 3 was considered adequate analgesia.

The time from arrival in the recovery room to first micturition during the 12-h period following the caudal block was recorded (except in those patients with urinary catheters).

To determine the number of patients required in each group, power analysis was performed.[12] This analysis was based on the following assumptions: 20% of the patients given 0.25% bupivacaine will require at least one dose of codeine within 12 h after surgery, 50% of those given 0.0625% bupivacaine will require codeine, $\beta < 0.20$, and $\alpha < 0.05$. Power analysis indicated that the minimum number of patients in each group should be 38.

Statistical significance ($P < 0.05$) was determined for non-parametric data (based on the raw data) by Chi-square analysis (with the Yates correction for 2 × 2 tables), and for parametric data by one-way ANOVA with the Student-Newman-Keuls test.[13] Randomization was performed using random number tables.[13]

RESULTS

Of the 114 patients who were enrolled in this study, 105 patients were included in the final analysis; 35 in each of the three treatment groups. Nine patients were excluded from the study.

The caudal block was abandoned in two patients (1.8%): one because of a dural puncture, and one because of a bloody tap. Both complications resulted from insertion of the catheter more than 2 cm into the caudal space. Access to the caudal space could not be identified in two additional patients. These four patients were removed from the study and their trial numbers were reassigned to subsequent patients. Five additional patients were excluded because of incomplete data, and their numbers were not reassigned.

The mean ages and weights did not differ signifi-

FIG. 2. The percent of patients with adequate analgesia (pain score ≤ 3 and no codeine) in the 0.25% group was significantly greater than the 0.0625% group, except at 3 and 5 h after block. The percent of patients with adequate analgesia in the 0.125% group was significantly greater than the 0.0625% in the first 4 h. There was no significant difference between the 0.125% and 0.25% groups at any time. *$P < 0.05$, 0.0625 versus 0.25%; +$P < 0.05$, 0.0625% versus 0.125%.

cantly among the three groups (table 1). The number of patients within each group undergoing either superficial lower abdominal or genital surgery did not differ significantly (table 1). Patients undergoing plastibell circumcisions were excluded from the study.
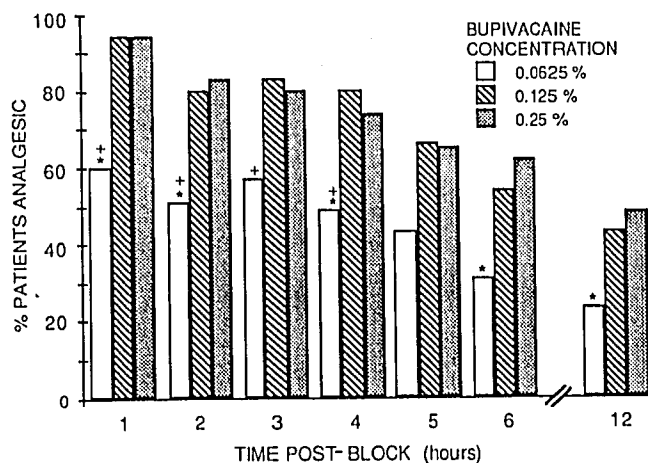
The percent of patients who required codeine by 2 and 4 h after the block was significantly less in the 0.25% and 0.125% groups than in the 0.0625% group ($P < 0.05$) (fig. 1). The reduced codeine requirements in the 0.25% and 0.125% groups were maintained throughout the study, although, by 12 h, only the 0.25% group differed significantly from the 0.0625%
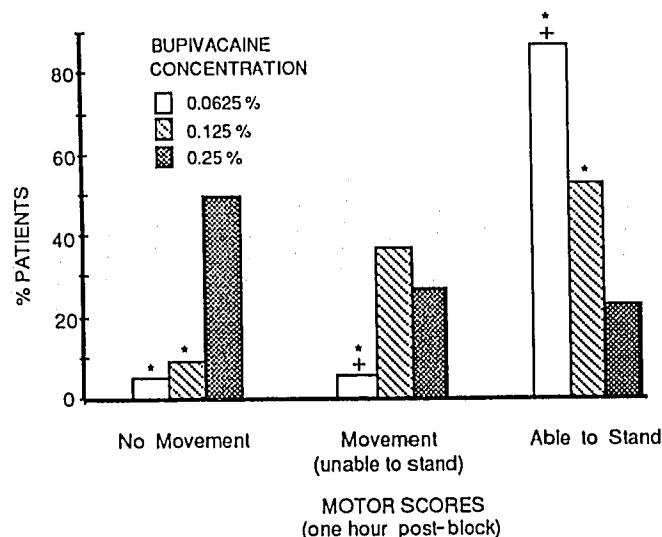

FIG. 3. Motor strength in the lower extremities was assessed 1 h after the block. The percent of patients able to stand was inversely related to the concentration of bupivacaine used: 0.25% < 0.125% < 0.0625%. *$P < 0.05$, compared to 0.25%; +$P < 0.05$, compared to 0.125%.

group. The codeine requirements did not differ significantly between the 0.25% and 0.125% groups at any time.

Adequate caudal analgesia (i.e., pain score ≤ 3 and no codeine required) was present in significantly more patients in the 0.25% group at 1, 2, 4, 6, and 12 h and in the 0.125% group in the first 4 h after the block compared to the 0.0625% group ($P < 0.05$) (fig. 2). The adequacy of caudal analgesia did not differ significantly between the 0.25% and 0.125% groups at any time.

Motor strength in the lower extremities differed among the three groups 1 h after the block (fig. 3). A significantly greater number of patients were unable to move their lower extremities against gravity in the 0.25% group than in either the 0.0625% or 0.125% groups ($P < 0.05$). The number of patients able to stand 1 h after the caudal block differed significantly among the three groups: 0.25% < 0.125% < 0.0625% ($P < 0.05$). None of the patients demonstrated weakness in the lower extremities by 12 h after the caudal block.

The mean (±SD) time to first micturition after surgery did not differ significantly among the three groups: 4.9 ± 3.6 h for 0.25% bupivacaine, 5.1 ± 2.2 h for 0.125% bupivacaine, and 6.3 ± 2.6 h for 0.0625% bupivacaine.

There were no instances of hypotension, bradycardia, residual paralysis, or toxic reactions to bupivacaine during or after administration of caudal blocks.

DISCUSSION

Previous studies have shown that, during epidural anesthesia, both sensory and motor blockade decrease as the concentration of bupivacaine decreases from 0.75% to 0.25%.[9] We expected a similar relationship to hold true for caudal anesthesia. However, Broadman et al. found that, during caudal anesthesia, sensory blockade did not decrease as the concentration of bupivacaine decreased from 0.375% to 0.25%. We extended their study to concentrations of bupivacaine 0.25% and lower, and found that sensory blockade did not decrease between 0.25% and 0.125%, but did decrease significantly with 0.0625%. Because motor blockade in the lower extremities decreased directly in proportion to the concentration of bupivacaine in this study, we concluded that 0.125% bupivacaine provides adequate analgesia and minimal motor blockade for caudal anesthesia in children.

We found that motor blockade decreased as the concentration of bupivacaine decreased from 0.25% to 0.0625%. We assessed motor strength in the lower extremities by determining whether the patient could stand. If the patient was able to bear his/her own weight, then full lower extremity strength was judged to be present. These results are consistent with previous data that showed that motor blockade increased with increasing concentrations of local anesthetic.[9]

We were concerned that the volume of bupivacaine used may have been insufficient for those patients requiring analgesia for superficial lower abdominal surgery. We selected a volume of 0.75 ml/kg of caudal solution based on a volume requirement of 0.056 ml/kg/segment (as determined for caudal blocks with lidocaine)[5] and a sensory level of 13 spinal segments. This volume of local anesthetic provided adequate analgesia and a similar duration of block for both superficial lower abdominal and genital surgery.

Toxic drug complications from local anesthetics have been reported following caudal blockade.[14-16] These complications have been attributed in part to accidental intravenous, intraosseous, and intrathecal injections. Although accidental vascular injections in children may result in toxic blood concentrations, pharmacokinetic studies have shown that the maximum blood concentration after the caudal administration of 2.5 mg/kg bupivacaine (1 ml/kg of a 0.25% solution) is well below the toxic blood concentration of bupivacaine (2–4 μg/ml).[17,18] We predict that the maximum blood concentration of bupivacaine after the dose recommended in this study ≈ 1 mg/kg (0.75 ml/kg of a 0.125% solution) should be even lower than in the above studies. Thus, efforts to minimize the risks of complications during caudal anesthesia must be directed towards those measures that reduce accidental intravenous, intraosseous, or intrathecal injections.

Discharge criteria for outpatient surgery varies among pediatric centers. In some centers, patients who receive a caudal block may be discharged home before recovery of motor strength in the lower extremities. It is our practice to delay discharge from the hospital until motor strength in the lower extremities recovers. We believe that this practice should prevent a child from being discharged home with an unrecognized neuropraxia. Furthermore, injury as a result of premature ambulation may be avoided.

In summary, we found that bupivacaine 0.0625% was ineffective for caudal anesthesia. However, bupivacaine 0.125% with 1:200,000 epinephrine provided equipotent analgesia and significantly less motor blockade than 0.25% bupivacaine for caudal block in infants and children after superficial lower abdominal or genital surgery. Therefore, we recommend 0.125% bupivacaine with epinephrine for caudal block in infants and children.

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Auditory Alarms during Anesthesia Monitoring

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The trend in anesthesia care is toward increasing use of technologic non-invasive monitors. The American Society of Anesthesiologists has recently published recommended standards for basic patient monitoring, which include arterial blood pressure, electrocardiography, an oxygen analyzer, and a ventilator disconnection alarm.‡ Monitors that are encouraged, but not mandatory, include pulse oximetry, capnography, and spirometry. Most monitors are fitted with alarm systems, usually with preset and modifiable thresholds, which produce an auditory signal when a high or low limit is passed. This survey evaluates the significance of auditory alarms that sound during routine anesthetic management.

MATERIALS AND METHODS

After institutional approval, 50 patients were studied, ASA physical status I–III, ages 1 month to 10 yr. These were all elective general surgical, ophthalmic, dental, or orthopedic cases; no patient had any significant cardiac or respiratory disease. Five monitors with auditory alarms were routinely used: electrocardiography (ECG) (Datascope® model 870, Paramus, NJ), automatic oscillometric blood pressure (BP) (Critikon Dinamap® 847, Tampa, FL), oxygen analyzer (Ohio® oxygen monitor 401, Madison, WI), pulse oximetry (Nellcor®, Hayward, CA), and ventilator low inspiratory pressure (disconnect alarm) (Ohio, Madison, WI). Non-monitoring equipment with auditory alarms commonly used included intravenous infusion pumps and electrocautery. The initial alarm limits are shown in table 1. Once one of the upper alarm limits had sounded, new upper alarm limits could be set by the anesthesiologist in charge of the case. The lower alarm limits could not be