# Hyperbaric, Hypobaric, and Isobaric Spinal Anesthesia

**Understanding how the density of local anesthetics and patient positioning can control the distribution of a local anesthetic within the subarachnoid space is essential to the successful performance of spinal anesthesia. After describing how hyperbaric, hypobaric, and isobaric solutions affect the spread, duration, and quality of spinal analgesia and anesthesia, the authors offer guidelines for employing commonly used local anesthetic solutions.**

**Donald H. Lambert, M.D., Ph.D.,** Assoc. Prof. of Anaesthesia, Harvard Medical School; Staff Anesthesiologist, Brigham & Women's Hospital, Boston

**Benjamin G. Covino, M.D., Ph.D.,** Prof. of Anaesthesia, Harvard Medical School; Chairman, Department of Anesthesia, Brigham & Women's Hospital, Boston

In 1885, Corning accidentally administered the first spinal anesthetic while experimenting with the action of cocaine upon the spinal nerves of a dog. However, August Bier is considered the father of spinal anesthesia. In 1889, he reported on how he and his assistant performed spinal anesthesia on each other. He was also the first to report the results of operations conducted under spinal anesthesia. In 1907, Barker, in England, and Chaput, in France, independently described the use of local anesthetics made more dense than cerebrospinal fluid as a gravity-control method for limiting the segmental spread of spinal anesthesia. Since these modest beginnings, anesthesiologists have taken advantage of how the density of local anesthetics and patient position can control the distribution of a local anesthetic within the spinal subarachnoid space.

## Density, Specific Gravity, and Baricity

In a recent review, Greene listed the many factors that affect the spread of local anesthetics injected into the cerebrospinal fluid. The density of the local anesthetic is apparently one of the more important factors in this regard. Local anesthetics used for spinal anesthesia are described as hypobaric, isobaric, or hyperbaric. Hypobaric solutions are less dense than cerebrospinal fluid, whereas isobaric and hyperbaric solutions are equally dense and more dense than cerebrospinal fluid, respectively.

At this point, it may be useful to define what is meant by density, specific gravity, and baricity. *Density* is the weight in grams of 1 mL of a solution (gm/mL) at a specified temperature.

*Specific gravity* is a ratio. It is the density of a solution at a specified temperature divided by the density of water at that same temperature.

*Baricity* is also a ratio. It is the density of a local anesthetic solution at a specified temperature divided by the density of cerebrospinal fluid at that same temperature. Some authors have used specific gravity to determine the baricity of local anesthetic solutions. Baricity, in this case, is the ratio of the specific gravity of a local anesthetic solution at a specified temperature to the specific gravity of cerebrospinal fluid at the same temperature. This is less accurate than determining baricity from density (see Greene for detailed explanation).

According to these definitions, an isobaric local anesthetic solution used for spinal anesthesia has a baricity of unity, whereas hypobaric and hyperbaric solutions have baricities less than and greater than unity, respectively. It is important to note that density varies *inversely with temperature.* Therefore, a local anesthetic that has the same density as cerebrospinal fluid

**The Density and Baricity of Local Anesthetics Commonly Used for Spinal Anesthesia**

| Agent | Usual Concentration (%) | Glucose Concentration (%) | Density (37°C) | Baricity (37°C) |
|---|---|---|---|---|
| CSF | — | — | 1.0003 | 1.0000 |
| Procaine | 2.5 | DW | 0.9986 | 0.9983 (HO) |
| Procaine | 10.0 | — | 1.0107 | 1.0104 (H) |
| Lidocaine | 2.0 | S | 1.0007 | 1.0004 (I) |
| Lidocaine | 5.0 | 7.5 | 1.0265 | 1.0262 (H) |
| Bupivacaine | 0.5 | S | 0.9993 | 0.9990 (HO*) |
| Bupivacaine | 0.75 | 8.25 | 1.0230 (C) | 1.0227 (H) |
| Tetracaine | <0.33 | DW | <0.9980 | <0.9977 (HO) |
| Tetracaine | 0.5 | S | 1.0000 | 0.9997 (HO*) |
| Tetracaine | 0.5 | 5.0 | 1.0136 | 1.0133 (H) |
| Dibucaine | 0.066 | S | 0.9967 | 0.9964 (HO) |
| Dibucaine | 0.5 | S | 0.9992 | 0.9990 (HO*) |
| Dibucaine | 0.25 | 5.0 | 1.0111 | 1.0108 (H) |

CSF density (37°C) 99.9% confidence limits = 0.9998 to 1.0008
Dibucaine is no longer manufactured
CSF = cerebrospinal fluid; DW = distilled water; S = saline; HO = hypobaric; I = isobaric; H = hyperbaric; HO* = solution considered to be clinically isobaric; C = approximate value calculated from specific gravity

Table 1

at 37°C will be more dense (hyperbaric) at room temperature (the temperature at which local anesthetics usually are injected) than cerebrospinal fluid at 37°C. However, the clinically important density of local anesthetic solutions is that which is measured at 37°C because, during spinal anesthesia, local anesthetic solutions rapidly equilibrate with the temperature of cerebrospinal fluid.

The density of normal human cerebrospinal fluid with 95% confidence limits at 37°C is 1.0001 to 1.0005. Therefore, local anesthetic solutions with a baricity less than 0.9998 (99.9% confidence limits) at 37°C will be hypobaric in *all* patients. Similarly, local anesthetic solutions at 37°C with a baricity greater than 1.0008 (99.9% confidence limits) will be reliably hyperbaric in *all* patients. Because of the normal variability in the density of cerebrospinal fluid, it is difficult to know precisely that a local anesthetic solution will, in fact, be isobaric in *all* patients. Nevertheless, local anesthetic solutions with densities between 0.9998 and 1.0008 behave functionally as if they have the same density as cerebrospinal fluid.

Today, the local anesthetics most commonly used for spinal anesthesia in the United States are lidocaine, bupivacaine (Marcaine®, Sensorcaine®), and tetracaine (Pontocaine®). Procaine (Novocain®) is also available for spinal anesthesia, but of late it has not enjoyed the popularity it once had. Dibucaine (Nupercaine®) is another once-popular spinal anesthesia agent. However, its manufacture recently has been discontinued.

Local anesthetic solutions used for spinal anesthesia generally are formulated with sodium chloride to make them isotonic. Most of these solutions are either isobaric (lidocaine, tetracaine, and dibucaine) or are very close to isobaric (bupivacaine is very slightly hypobaric). Procaine for spinal anesthesia is formulated as a 10% solution and because of the high (10%) local anesthetic concentration is therefore hyperbaric. Hyperbaric solutions of lidocaine, tetracaine, bupivacaine, and dibucaine are prepared by adding dextrose in sufficient quantity to increase their density to greater than 1.0008.

**Guidelines for Employing Hyperbaric and Isobaric Solutions in Spinal Anesthesia**

| Surgical Site | Solution | C (%) | Usual Dose (mg) | Usual Volume (mL) | Usual Duration No EPI (hours) | Usual Duration 0.2 mg EPI (hours) |
|---|---|---|---|---|---|---|
| Above L-2 | Hyperbaric | | | | | |
| | Bupivacaine | 0.75 | 10–15 | 1.5–2 | 2 | 2 |
| | Tetracaine | 0.5 | 10–15 | 2–3 | 2 | 3 |
| | Lidocaine | 5.0 | 50–75 | 1–1.5 | 1 | 1 |
| Below L-2 | Isobaric | | | | | |
| | Bupivacaine | 0.5 | 15 | 3 | 3–4 | 4–6 |
| | Tetracaine | 0.5 | 15 | 3 | 3–4 | 4–6 |
| | Lidocaine | 2.0 | 60 | 3 | 1–2 | 2–3 |

EPI = epinephrine; C = concentration

Isobaric solutions of bupivacaine and lidocaine are not yet approved by the FDA for spinal anesthesia. However, this use has been reported in numerous publications. Solutions intended for spinal anesthesia should *not* contain any preservatives or antioxidants, such as methylparaben, sodium bisulfite, or sodium metabisulfite.

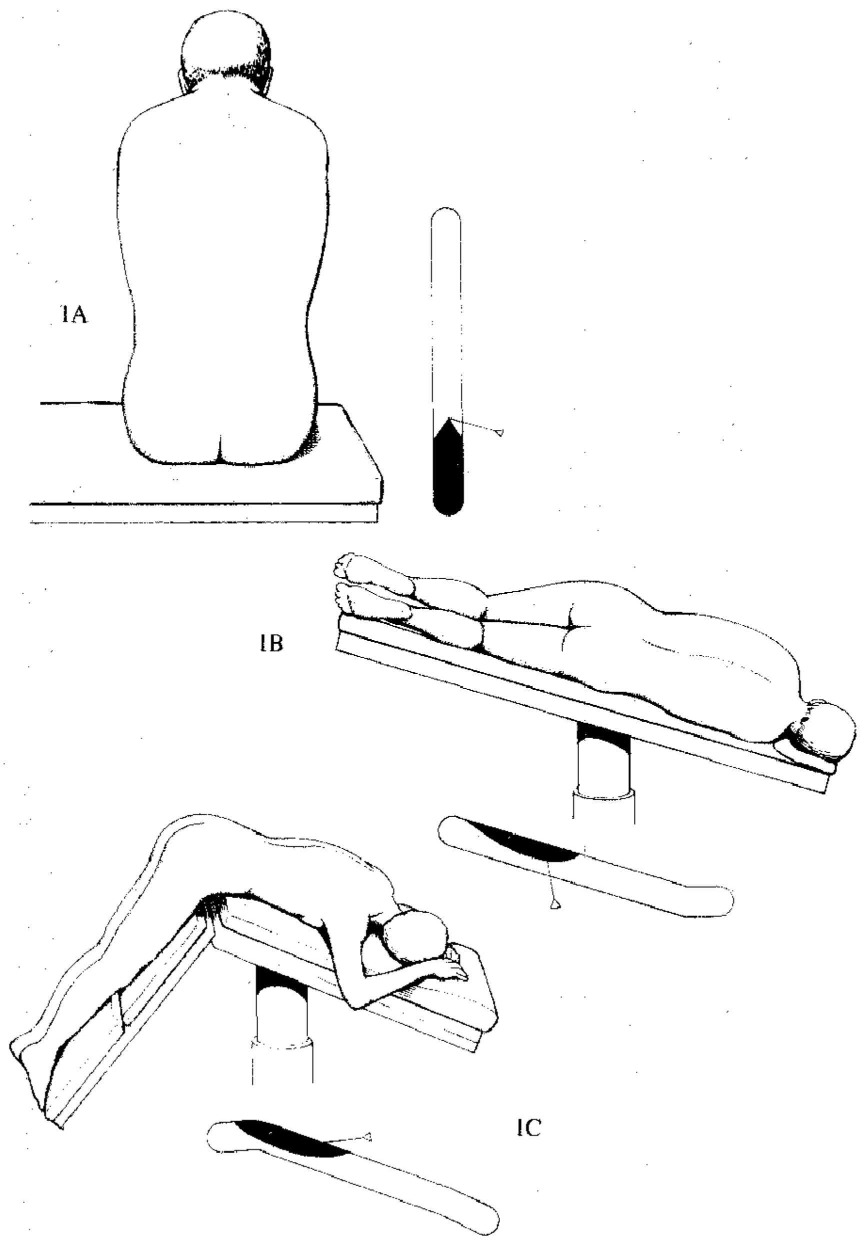
Table 2

Other agents may be used to make a local anesthetic solution hyperbaric. For example, 1% tetracaine sometimes is made hyperbaric by mixing it in a 1:1 ratio with 10% procaine. Hypobaric solutions of procaine, tetracaine, and dibucaine are prepared by diluting them with distilled water to a density of less than 0.9998. Dilution of lidocaine with distilled water to make it hypobaric results in concentrations of lidocaine too low to provide adequate spinal anesthesia. The adequacy of spinal anesthesia with a hypobaric solution of bupivacaine is not well documented at this time. Table 1 summarizes the density and baricity of commonly used spinal anesthetic solutions.

## The Effect of Baricity and Patient Position on Spinal Anesthesia

One method for gaining an appreciation of the behavior of hyperbaric, isobaric, and hypobaric local anesthetic solutions when injected into patients is to prepare a spinal cord model from venous drainage tubing employed during cardiac surgery. This tubing is a reasonable approximation of the diameter of the spinal canal. It can be cut to length, bent into the shape of the spinal curves, and fastened to a piece of plywood or Lucite™. A spinal needle can be inserted in an area meant to represent the lumbar region to introduce the various local anesthetic solutions. The tubing is filled with normal saline or Ringer's lactate solution, both of which are reasonable substitutes for cerebrospinal fluid, i.e., they have approximately the same density as cerebrospinal fluid. Indeed, Barker, in 1907, used similar models to devise his gravity-control method for spinal anesthesia. These gravity-control principles are employed daily in the routine practice of spinal anesthesia in operating rooms across the world.

By utilizing this plastic tubing model and injecting local anesthetic solutions colored with methylene blue dye, one can observe the effect of baricity, gravity (patient position), and the shape of the spinal curves on the distribution of local anesthetics within the spinal subarachnoid space. With this model, it can be shown that isobaric solutions remain in the vicinity of the injection site, hyperbaric solutions gravitate to dependent areas, and hypobaric solutions "float" to the least dependent areas. The shape of the average human spinal canal with the patient in the supine position is such that there is a lumbar lordosis (high point) at the L3-4 interspace (a common site for the injection of local anesthetic solutions) and a thoracic kyphosis (low point) at the T5-6 interspace. These curves will influence the distribution of hyperbaric and hypobaric solutions within the spinal subarachnoid space. The distribution of isobaric solutions is unaffected by the shape




**1A, 1B, and 1C. The Effect of Position and Baricity on the Distribution of a Local Anesthetic Solution in the Spinal Subarachnoid Space**—The tubular figures to the right are meant to represent the dural sac, which contains the cerebrospinal fluid. The darkened areas indicate the disposition of the local anesthetic solution. 1A—The patient is in the seated position undergoing "saddle block." A hyperbaric solution, which gravitates to the most dependent area, is used. 1C—The patient is in the prone jackknife position for rectal surgery. A hypobaric solution, which "floats" to the uppermost area, is employed. 1B—The patient is in the right lateral recumbent position with head down tilt for left hip surgery. Again, a hypobaric solution is used. All three procedures could be done equally well with an isobaric solution. Isobaric solutions are unaffected by position and remain localized to the site of injection.

of the spinal canal. These interactions are shown in Figures 1A, 1B, and 1C.

For surgical procedures performed on patients who are not in the supine position, the baricity of the local anesthetic solution and gravity are employed to "direct" the local anesthetic toward the spinal nerves innervating the surgical site. For example, hemorrhoidectomy with a patient in the lithotomy position often is performed under "saddle block" spinal anesthesia. This is accomplished by administering a hyperbaric local anesthetic solution with the patient in the sitting position, thus allowing the solution to gravitate to the sacral nerves.

Alternatively, hemorrhoidectomy with a patient in the prone jackknife position and hip surgery with a patient in the lateral recumbent position often are performed under hypobaric spinal anesthesia. In these cases, the spinal anesthesia is performed with the patient positioned for the surgical procedure, which results in the surgical site (and the spinal nerves to be anesthetized) being uppermost. After injection, the hypobaric solution "floats" up to the nerves innervating the surgical site.

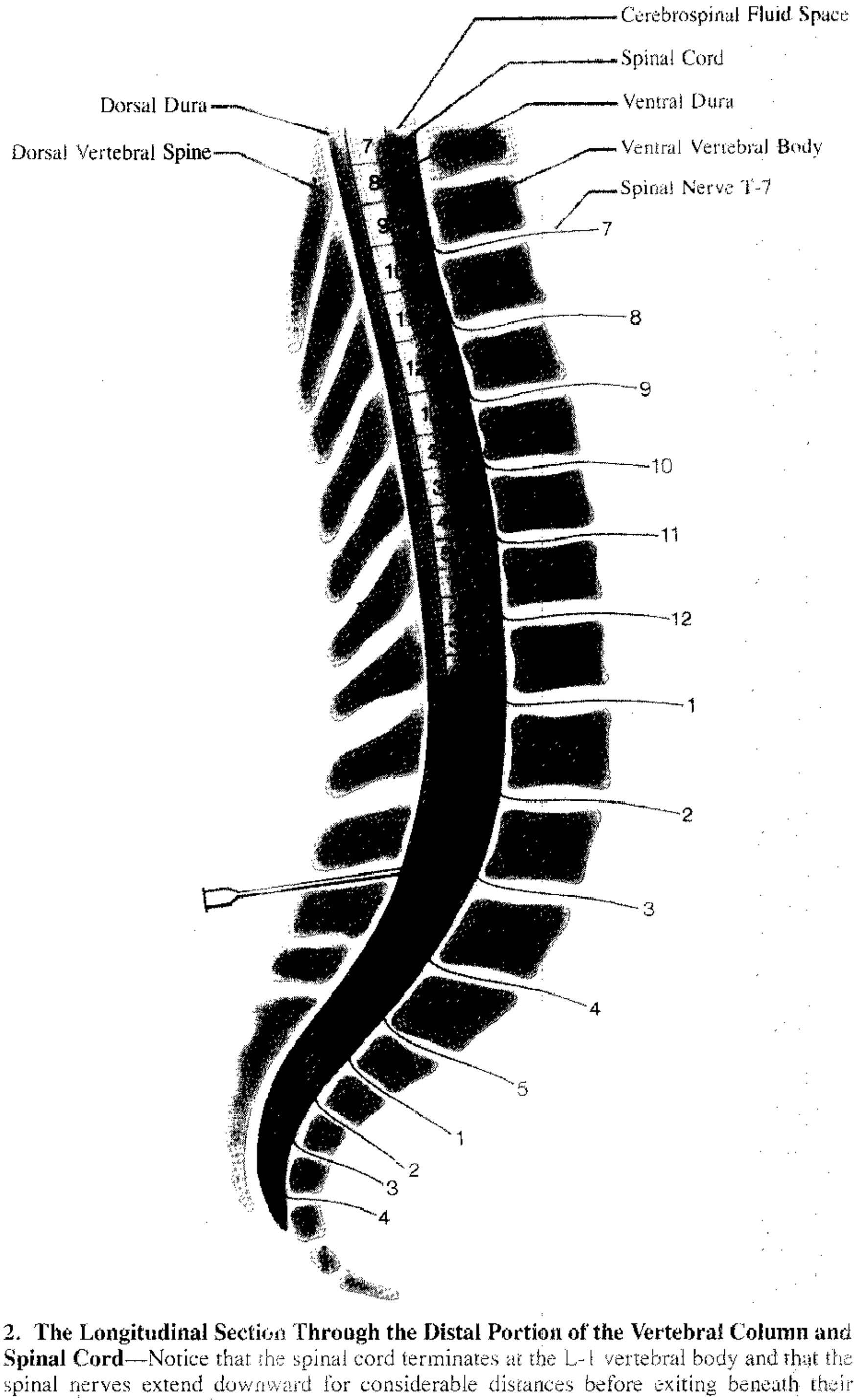
It is important to note that surgery performed on areas innervated by nerves below the L-1 dermatome may be performed easily with an isobaric solution. Since these solutions are unaffected by patient position, the spinal anesthesia can be induced in the most convenient position for the patient and the anesthesiologist, and the patient can then be turned to the position dictated by the surgical procedure. Because spinal nerves L-1 to S-5 pass through the cerebrospinal fluid into which the isobaric solution is injected, anesthesia in all of these dermatomes will result (Figure 2).

The local anesthetic solutions commonly employed for spinal anesthesia in the United States today are shown in Table 1. Hyperbaric solutions of lidocaine and tetracaine are probably the most common solutions employed for spinal anesthesia. Hyperbaric solutions achieved their popularity because of the belief that it is easier to control the spread of these solutions.

## The Clinical Profile of Hyperbaric, Hypobaric, and Isobaric Solutions

Studies have compared the effects of isobaric, hypobaric, and hyperbaric tetracaine in patients in whom position was maintained constant. Injections were made in the midline at the L2-4 interspace with patients in the lateral position. After the intrathecal injection was made, the patients were placed in the supine, horizontal position. The hyperbaric solution showed the most rapid initial onset of anesthesia. The mean interval until analgesia was detected in the lower thoracic dermatomes was approximately six minutes for hyperbaric tetracaine, compared with nine minutes for the isobaric solution and ten minutes for hypobaric tetracaine. However, the maximum level of analgesia occurred within 12 to 14 minutes with all solutions.

Differences were seen among the various solutions with regard to




**2. The Longitudinal Section Through the Distal Portion of the Vertebral Column and Spinal Cord**—Notice that the spinal cord terminates at the L-1 vertebral body and that the spinal nerves extend downward for considerable distances before exiting beneath their respective vertebral bodies. Isobaric local anesthetics injected into the spinal subarachnoid space at the L3-4 interspace clinically occupy the hashed area shown in red and block all spinal nerves distal to L-1. Furthermore, isobaric solutions tend to remain localized and are unaffected by patient position.

the maximum spread of anesthesia. The hyperbaric solution of tetracaine showed the greatest spread, achieving an average maximal dermatomal level of T-6. This is consistent with hyperbaric solutions gravitating to the lowest point (thoracic kyphosis) of the spinal canal (vide supra). The isobaric solution extended only to the T-11 dermatomal level, whereas the hypobaric solution extended only to the T-12 level.

Regression of anesthesia was also different. Two-segment regression occurred in an average of 153 minutes with the hyperbaric solution. The isobaric solution showed an average regression time of 163 minutes, whereas the hypobaric solution demonstrated the longest regression time of 199 minutes. The total duration of analgesia varied from 285 minutes for hyperbaric tetracaine to 332 minutes for the isobaric solution and 360 minutes for the hypobaric solution.

The duration of complete motor block also differed. The mean duration of motor blockade was 239 minutes with hyperbaric tetracaine, 309 minutes with isobaric tetracaine, and 290 minutes with hypobaric tetracaine. These data illustrate a very important principle often not appreciated by anesthesiologists. Distributing the local anesthetic over a greater distance, as occurs with hyperbaric tetracaine, results in lesser amounts of the local anesthetic penetrating the nerves affected and therefore decreases the duration of anesthesia and analgesia.

A comparison of hyperbaric and isobaric solutions of bupivacaine and lidocaine has shown results similar to those obtained with tetracaine. Hyperbaric bupivacaine and lidocaine produce a more extensive spread of anesthesia and are more suitable for abdominal surgical procedures. Isobaric bupivacaine and lidocaine provide a more restricted spread of anesthesia and are more suitable for orthopedic or vascular surgical procedures involving the lower limbs. The duration of the isobaric solutions exceeds that of the hyperbaric solutions. In addition, the degree of motor block is more profound when the isobaric solution is employed (see Table 2).

In summary, baricity will influence the onset, spread, and duration of anesthesia provided patient position is kept constant. In general, hyperbaric solutions will provide a more rapid initial onset and a greater spread of anesthesia but a shorter duration of anesthesia and analgesia. Thus, these solutions are primarily useful for abdominal surgical procedures of limited duration. The hypobaric solution shows the slowest onset and most restricted dermatomal spread but the longest duration of anesthesia. Therefore, hypobaric solutions are useful mainly for surgical procedures performed on patients in the jackknife position, such as hemorrhoidectomy. Isobaric solutions have become increasingly popular in recent years. Their dermatomal spread is not as extensive as that which occurs with hyperbaric solutions, but their duration of anesthesia in the lumbosacral areas is prolonged significantly. Thus, isobaric solutions are of particular value for orthopedic procedures performed on the lower limbs.

## Guidelines for the Use of Hyperbaric and Isobaric Solutions

As a practical example of utilizing the effects of baricity, here is our outlined approach to spinal anesthesia. Surgery is divided into procedures above or below the first lumbar (L-1) dermatome.

- *Above the L-1 Dermatome*—1) Hernias; 2) any intra-abdominal surgery; 3) radical orchiectomy (groin incision); 4) gynecologic surgery requiring a T-10 dermatomal level of anesthesia, such as a D&C, circlage, or cone biopsy; 5) cesarean section; and 6) vaginal delivery.

A hyperbaric solution is used for these surgical or obstetrical procedures. Hyperbaric solutions gravitate to the thoracic kyphosis in the supine patient, therefore assuring an adequate level of spinal anesthesia, which is T-6 in the average patient. However, it may vary in some patients.

- *Hyperbaric Solutions*—1) Lidocaine 5%, dextrose 7.5% (manufactured premixed); 2) Bupivacaine 0.75%, dextrose 8.25% (manufactured premixed); and 3) Tetracaine 0.5%, dextrose 5% (mix equal volumes of 1% tetracaine and 10% dextrose).
- *Below the L-1 Dermatome*—1) All lower limb orthopedic surgery (includes hip surgery); 2) genitourinary surgery (transurethral resection of the prostate, transurethral resection of a bladder tumor, cystoscopy, penile implant, scrotal

orchiectomy); 3) perineal surgery (Bartholin cyst); 4) lower limb vascular surgery (femoral-popliteal bypass graft); 5) amputations involving the lower limbs; and 6) rectal surgery.

For the previously mentioned surgical procedures, an isobaric solution is ideal. As indicated, these solutions tend to remain in the lower dermatomes, providing intense, prolonged anesthesia.

• *Isobaric Solutions*—1) Lidocaine 2% (epidural solution); 2) Bupivacaine 0.5% (epidural solution); and 3) Tetracaine 0.5% (mix equal volumes of 1% tetracaine and preservative-free saline).

Any procedure performed below the L-1 dermatome, which usually is done with a hypobaric solution, can be carried out equally well with an isobaric solution. Therefore, we rarely employ hypobaric solutions except for the occasional patient in whom anesthesia is induced in the jackknife position.

The differences among lidocaine, bupivacaine, and tetracaine are mainly in terms of the duration of anesthesia that can be expected. Table 2 summarizes the agents used, the dosages employed, and the probable durations to be expected with these agents for surgery performed at sites above or below the L-1 dermatome. Hyperbaric and isobaric lidocaine will provide surgical anesthesia of approximately one to two hours, respectively. Tetracaine and bupivacaine are similar in terms of anesthetic duration. The hyperbaric solutions provide approximately two hours of surgical anesthesia above the L-1 level, whereas the isobaric solutions provide three to four hours' duration below the L-1 level.

Differences do exist between tetracaine and bupivacaine. Epinephrine appears to prolong the anesthetic duration of tetracaine to a greater extent as compared with bupivacaine above the L-1 dermatome. Sensory analgesia below L-1 appears more pronounced with bupivacaine. For example, the frequency of tourniquet pain is significantly lower in bupivacaine-treated patients compared with tetracaine-treated patients. On the other hand, the intensity of motor blockade appears to be more profound when tetracaine is employed for spinal anesthesia.

In summary, lidocaine is useful for short-duration surgical and obstetrical procedures, i.e., 30 to 90 minutes. Hyperbaric tetracaine is probably still the most useful solution for abdominal surgical procedures of two to four hours' duration, although hyperbaric bupivacaine is also a good agent for abdominal surgery. Isobaric bupivacaine is particularly valuable for lower limb vascular and orthopedic procedures of two to five hours' duration. ◀

**References**
1. Lund PC: Principles and Practice of Spinal Anesthesia. Springfield, Ohio, Charles C. Thomas, 1966.
2. Greene NM: Physiology of Spinal Anesthesia, 3rd Edition. Baltimore, Williams & Wilkins, 1981.
3. Greene NM: Distribution of local anesthetic solutions within the subarachnoid space. Anesth Analg 64:715-730, 1985.
4. Levin E, Muravchick S, Gold MI: Density of normal human cerebrospinal fluid and tetracaine solutions. Anesth Analg 60:814-817, 1981.
5. Davis H, King WR: Densities of common spinal anesthetic solutions at body temperature. Anesthesiology 13:184-188, 1952.
6. Ernst EA: In-vitro changes of osmolality and density of spinal anesthetic solutions. Anesthesiology 29:104-109, 1968.
7. Rosenberg H: Density of tetracaine-water mixtures and the effectiveness of 0.33% tetracaine in hypobaric spinal anesthesia. Anesthesiology 45:682-684, 1976.
8. Brown WT, Wildsmith JAW, et al: Effect of baricity on spinal anaesthesia with amethocaine. Br J Anaesth 52:589-596, 1980.
9. Sheskey MC, Rocco AG, et al: A dose-response study of bupivacaine for spinal anesthesia. Anesth Analg 62:931-935, 1983.
10. Wildsmith JAW, McClure JH, et al: Effect of posture on the spread of isobaric and hyperbaric amethocaine. Br J Anaesth 53:273-278, 1981.

**The Authors**

**Donald H. Lambert, M.D., Ph.D.**

Dr. Lambert is Associate Professor of Anaesthesia at Harvard Medical School and a staff anesthesiologist in the Department of Anesthesia at Brigham & Women's Hospital in Boston. He received his M.D. and his Ph.D. in physiology and biophysics from the University of Vermont College of Medicine in Burlington. Dr. Lambert's clinical research activity has been primarily in the area of spinal anesthesia.

**Benjamin G. Covino, M.D., Ph.D.**

Dr. Covino is Professor of Anaesthesia at Harvard Medical School and Chairman of the Department of Anesthesia at Brigham & Women's Hospital in Boston. He received his M.D. from the University of Buffalo School of Medicine and his Ph.D. in physiology from Boston University School of Medicine. Dr. Covino completed his training in anesthesiology at the Massachusetts General Hospital. He has performed extensive studies and published widely in the field of anesthesiology, particularly the pharmacology and toxicity of local anesthetic agents.