Review

Anesthesiology

Anesthesia for Cesarean Section

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I. History

Cesarean section is defined as the delivery of an infant through incisions in the abdominal and uterine walls. The early history and origin of the term, cesarean section, are cloaked in myth and fantasy. Ancient legend and mythology endowed individuals born in this way with supernatural powers. Contrary to popular legend, the term, cesarean section, is derived neither from the birth of Julius Caesar in 100 B.C. nor from the lex caesarea (a Roman law of 715 B.C.)138 that mandated the procedure for women dying in the last few weeks of pregnancy. Rather, the term arose in the Middle Ages from the Latin verb, caedere, "to cut," and its derivative, caesura, a cut or pause in a line or verse. Since the word "section" is also derived from a Latin word, secare, "to cut," the term, cesarean section, is a tautology.108

Some ascribe the first successful abdominal delivery to Jacob Nufer, a Swiss swine-gelder, in the year 1500, while according to others, the first such procedure was performed by a German barber named Trautman in 1610.16 The operation was rarely performed and was almost universally fatal until the late nineteenth century. Thereafter, with improved surgical technique, cesarean section slowly took its place in obstetrics. In 1976, Jones commented, "I would like to say that during my professional career of 40 years, cesarean section has changed from an operation of necessity to an operation of choice, with better maternal results and certainly with better fetal results. Indeed, we have come a long way."124

II. Obstetric Considerations

In recent years, the frequency of cesarean delivery has increased markedly.88,104,115,121,124,102,216 From an incidence of 3–8 per cent ten years ago, incidences at present have increased to 9–25 per cent throughout the United States.216 With an average national rate of 15 per cent in 1977, the number of cesarean sections in this country exceeds 500,000 per year, making cesarean section one of the commonest of surgical procedures. Where previously repeat cesarean sections accounted for about half of the total, most of the recent increase is in primary cesarean section. At present, the ratio of primary to repeat sections is approximately 2–2.5 to 1.104,124

The doubling to tripling of cesarean section rates has been accompanied by reductions in maternal mortality rates from 37.1/100,000 in 1960 to 12.8/100,000 in 1975 and in infant mortality rates from 26.0/1,000 births in 1960 to 16.1 in 1975.185 How much of this improvement relates to better obstetric care, the introduction of fetal biophysical and biochemical diagnostic techniques, the legalization of abortion, and the emergence of neonatology, and how much to increased frequency of abdominal delivery remain controversial.

Shamsi et al.216 have reviewed 40 years’ experience with primary cesarean section (table 1). They found a higher incidence of primary sections for fetal distress in 1972 with the introduction of electronic fetal

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Table 1. Indications (Percentages) for Primary Cesarean Section

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fetopelvic disproportion</td>
<td>ca. 40</td>
<td>33.1</td>
<td>35.2</td>
<td>33.6</td>
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<tr>
<td>Fetal distress</td>
<td>20.4</td>
<td>19.8</td>
<td>30.8</td>
<td>13.3</td>
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<tr>
<td>Dysfunctional labor</td>
<td>4.9</td>
<td>8.0</td>
<td>8.7</td>
<td>16.0</td>
</tr>
<tr>
<td>Abnormal presentations</td>
<td>11.6</td>
<td>17.0</td>
<td>6.8</td>
<td>8.0</td>
</tr>
<tr>
<td>Placenta previa</td>
<td>ca. 40</td>
<td>5.8</td>
<td>4.1</td>
<td>3.1</td>
</tr>
<tr>
<td>Cord prolapse</td>
<td>4.6</td>
<td>1.4</td>
<td>1.7</td>
<td>1.9</td>
</tr>
<tr>
<td>Abruptio placenta</td>
<td>3.8</td>
<td>1.7</td>
<td>1.7</td>
<td>2.4</td>
</tr>
<tr>
<td>Toxemia</td>
<td>2.7</td>
<td>0.9</td>
<td>3.1</td>
<td>1.5</td>
</tr>
<tr>
<td>PROM/amnionitis</td>
<td>1.5</td>
<td>6.0</td>
<td>2.7</td>
<td>1.2</td>
</tr>
<tr>
<td>Multiple gestation</td>
<td>0.3</td>
<td>0.9</td>
<td>0.6</td>
<td>4.7</td>
</tr>
<tr>
<td>Rh isoimmunization</td>
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<td>0.6</td>
<td>2.7</td>
<td>3.0</td>
</tr>
<tr>
<td>Diabetes</td>
<td>1.2</td>
<td>0.7</td>
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<td>1.1</td>
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<tr>
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<td>ca. 20</td>
<td>10.3</td>
<td>4.5</td>
<td>3.8</td>
</tr>
</tbody>
</table>

* Reproduced from Shamsi et al.216 with permission of the author and publisher.

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monitoring. With more experience, however, the section rate for that indication was more than halved by 1977, while the rate for other indications, notably dysfunctional labor and multiple gestations, increased. Most investigators believe that these changes in obstetric practice have undoubtedly contributed to the improvements in maternal and perinatal mortality and morbidity rates.

At the same time, others have cautioned that cesarean section is not without risk. For example, Evrard and Gold,48 who reviewed 11 years’ experience in Rhode Island, concluded that the risk of maternal death from cesarean delivery was 26 times greater than that associated with vaginal delivery, with most of the excess mortality the result of sepsis. One death resulted from aspiration during anesthesia.

Another cause for concern is the relation between elective cesarean section, prematurity, and respiratory distress syndrome of the newborn. Studies over the past 25 years have shown a substantially higher incidence of respiratory distress syndrome after cesarean delivery (5 to 22 per cent; average 9 per cent) compared with vaginal delivery (6 to 7 per cent).18,103,137 Gluck,39 in 1977, attributed this difference not to cesarean delivery itself but rather to delivery at a time when the infant’s lungs are immature. The prevention of iatrogenic respiratory distress syndrome owing to elective early delivery requires objective confirmation of gestational age by ultrasonography or of fetal lung maturity by tests of surfactant in amniotic fluid, rather than reliance on purely clinical methods as in the past.

### III. General Considerations

Successful anesthesia for cesarean delivery can be accomplished in a number of ways. Common to all is the need for expert technical skills and understanding of maternal and fetal physiology, pathophysiology and pharmacology, the subject of several recent detailed reviews170,173,189,197 and textbooks.2,3,24,25,100,102,121 The present review is intended not to be encyclopedic, but rather to examine critically the rationales for generally accepted clinical practices as they have evolved to the present time.

Selection of anesthesia depends on the experience of the anesthetist and obstetrician, the indication for and urgency of the cesarean section, and maternal preference. Some survey data,103,196 as well as our experience at the Boston Hospital for Women, are presented in table 2.

<table>
<thead>
<tr>
<th>Technique</th>
<th>ACOG Local Infiltration or Field Block</th>
<th>Survey of 39 Obstetric Anesthesia Training Centers (1976)</th>
<th>Boston Hospital for Women (1979)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spinal anesthesia</td>
<td>52</td>
<td>24</td>
<td>36</td>
</tr>
<tr>
<td>Epidural anesthesia</td>
<td>3</td>
<td>32</td>
<td>26</td>
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<tr>
<td>General anesthesia</td>
<td>32</td>
<td>43</td>
<td>38</td>
</tr>
<tr>
<td>Combination</td>
<td>10</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

* 180.
† 105.

The outcome has been assessed by Apgar scores,9 acid–base status,8,9 and time to sustained respiration. In recent years, attention has been focused on more subtle indicators of newborn function, i.e., neurologic and behavioral changes attributable to maternally administered analgesics and anesthetics.26,27,71,107,209,210,211 It should be pointed out that although such changes have been described, they are usually transient; their biological significance remains unknown and is a matter of considerable controversy.

A final general point in this discussion is the role of the father or other consort when delivery is to be by cesarean section. In most hospitals, the concept of
family-centered maternity care has taken hold and the presence of the father at a vaginal delivery is the norm. In recent years, this privilege has been extended to delivery by cesarean section in many institutions, including the Boston Hospital for Women. It is our practice to visit both mother and father prior to the surgical procedure to explain the details of the procedure. The father is permitted to be present only when regional anesthesia is planned and successful. If general anesthesia is necessary, the father is not permitted to attend the delivery. Our experience with this practice has been on the whole quite satisfactory, although complications may occur.3,72

IV. Local Infiltration or Field Block

Never a very widely used anesthetic technique, local infiltration or field block of the abdomen for cesarean section still has a few advocates.36,40,206 Ranney and Stanage200 reported their experiences with 218 patients in whom they used 60–100 ml procaine, 1 per cent. In most instances, anesthesia was supplemented with thiopental and nitrous oxide following delivery of the infants, more than 90 per cent of whom had Apgar scores of 9 or 10 at 1 minute. Perhaps of value in the absence of trained anesthesia personnel, the technique is not generally recommended because of the difficulty in assuring adequate anesthesia and the need to use local anesthetic in large quantities, with the possibility of a toxic reaction.

V. Spinal Anesthesia

The principal advantages of spinal anesthesia for cesarean section are simplicity, speed, reliability and minimal fetal drug exposure.99 The parturient remains awake, and the hazards of aspiration are minimized. Disadvantages include the high incidence of hypotension, intrapartum nausea and vomiting, and the possibility of post-lumbar-puncture headache.

A. Cardiovascular Effects

Following induction of spinal anesthesia for cesarean section, the incidence of maternal hypotension, usually defined as a decrease in systolic blood pressure to below 100 torr or by more than 30 torr from the preanesthetic value, is as high as 80 per cent in some series.41 Hemodynamic studies by Ueland et al.326 in 12 patients revealed an average reduction in blood pressure from 124/72 to 67/38 torr with the patient in the supine position 5 to 10 minutes following induction of spinal anesthesia. The average cardiac output decreased 34 per cent (from 5,400 to 3,560 ml/min), stroke volume decreased 44 per cent (from 62 to 35 ml), while heart rate increased 17 per cent (from 90 to 109 beats/min). Turning the patient into the lateral position resulted in an average increase in cardiac output of 2,600 ml/min and an increase in stroke volume of 42 ml/min, and a reduction of heart rate to 78 beats/min. Arterial blood pressures in the lateral position averaged 100/60 torr. In the same 12 patients, before spinal anesthesia, turning the patient from the supine to the lateral position resulted in average increases of 34 per cent in cardiac output and 44 per cent in stroke volume, with a 5 per cent decline in heart rate.

It is clear that the hemodynamic changes that almost always follow spinal anesthesia for cesarean section result from block of sympathetic vasomotor activity accentuated by compression of the inferior vena cava by the gravid uterus when the patient is in the supine position. The importance of aortocaval compression by the uterus in the pregnant patient has been amply documented.21,66,113,134,144

The significance of maternal hypotension lies in the threat to the well-being of both mother and fetus if the reductions in blood pressure and cardiac output are not promptly recognized and corrected.81,101 Several investigators have reported lowering of Apgar scores, prolongation of time to sustained respiration, and fetal acidosis following even brief episodes of maternal hypotension.40,66,150,178 Despite such episodes of hypotension and minimal fetal acidosis, a recent preliminary study by Corke showed no effect on newborn neurobehavioral function at 2 to 4 hours of age.48 Since spinal anesthesia offers major clinical advantages for cesarean delivery, efforts have been directed at preventing maternal hypotension. Two techniques have achieved widespread acceptance.

The first involves amelioration of vena caval compression by displacement of the uterus to the left, either manually, by tilting the patient on a wedge or a blanket roll, or by the use of a mechanical uterine displacer.57,80,132 Each of these methods has its advocates, but none is completely successful in preventing hypotension.

The second technique involves patient prehydration and acute volume expansion, usually with 1,000 ml of lactated Ringer's solution infused rapidly in 15 to 30 min before inducing anesthesia. Wollman and Marx245 reported no hypotension in their series of ten patients in whom this was done in combination with left uterine displacement. Others have reported less success with this combination of methods, with a decline in the frequency of hypotension to the range of 50 to 60 per cent of patients.41,66,190 Both prehydration and left uterine displacement have become clinically accepted steps in the management of spinal anesthesia for cesarean section.

Still controversial, however, is the value of the administration of a prophylactic vasopressor. At one time, the intramuscular injection of a drug such as methoxamine or phenylephrine was a routine part of
the management of spinal anesthesia for cesarean delivery. With the recognition that these vasopressors could adversely affect uterine blood flow\(^{160,190}\) and could result in severe postpartum hypertension,\(^{40}\) their use waned. The demonstration by Ralston \textit{et al.}\(^{190}\) that ephedrine in hypotensive pregnant ewes restored maternal blood pressure and uterine blood flow without harm to the fetus reawakened interest in its prophylactic use. Gutsche\(^{601}\) reported that the intramuscular injection of 50 mg ephedrine before induction of spinal anesthesia for cesarean section resulted in a decline in the incidence of maternal hypotension to 24 per cent. Others, however, fail to see the rationale for its administration to all patients, since only 50 per cent will have hypotension if adequately prehydrated and tilted. There is, however, general agreement that if hypotension should develop, it should be promptly treated by a combination of increased rate of intravenous fluid infusion, further uterine displacement, if possible, and the administration of small intravenous doses of ephedrine, 5–10 mg.

The incidence of hypotension during spinal anesthesia for cesarean section in patients in active labor is lower than in that in patients not in labor.\(^{41}\) A possible explanation may be the autotransfusion of approximately 300 ml blood into the maternal systemic circulation with intermittent uterine contractions.

Also of note are the hemodynamic changes that follow delivery of the infant.\(^{218}\) On the average, cardiac output increases by 50 per cent, stroke volume by 67 per cent, and arterial blood pressure by 20 mmHg, while heart rate is reduced 10 beats/min in comparison with the values obtained with the abdomen open immediately prior to delivery. Cardiac output immediately after delivery (8,410 ml/min) averages 16 per cent higher than that measured with the patient in the lateral position before anesthesia (7,240 ml/min) and 55 per cent higher than the preanesthesia value in the supine position (5,400 ml/min). These elevated values of cardiac output and blood pressure had persisted for an hour post partum, at which time measurements ceased. The changes following delivery presumably result from the increase in venous return consequent to relief of obstruction of the vena cava by the gravid uterus and an increase in systemic blood volume (estimated at 500–600 ml) secondary to contraction of the uterus. These post-delivery hemodynamic changes may contribute to the occurrence of postpartum hypertension and may be important in patients with heart disease.

\textbf{B. Other Complications}

Nausea and vomiting frequently accompany spinal anesthesia.\(^{201}\) The mechanism is unclear but may involve hypotension with decreased cerebral blood flow, traction on the peritoneum or other viscera, or autonomic imbalance resulting from block of sympathetic nerve fibers in the presence of intact vagal innervation. Preanesthetic atropine does not alter the incidence of this distressing complication.\(^{601}\) The administration of oxygen by face mask may help,\(^{601}\) and also results in improved fetal acid–base and blood-gas values.\(^{601}\) Correction of hypotension usually relieves the symptoms.

Post-lumbar-puncture headache remains an annoying postpartum problem. Its relationship to needle size has been amply demonstrated. Present practice mandates lumbar puncture in the parturient with the smallest possible needle, usually 25- or 26-gauge, to minimize the frequency of headache.\(^{601,162}\)

\textbf{C. Technical Factors}

A sensory level between the fourth and sixth thoracic dermatome is necessary for adequate anesthesia. This level is achieved in the pregnant patient with doses of local anesthetic well below those required in the nonpregnant patient. Drugs in current use include tetracaine (6–10 mg) and lidocaine (50–80 mg); bupivacaine has also been used, in doses of 7–9 mg.\(^{194}\)

It has been generally assumed, although not proven, that fetal exposure to local anesthetic following its subarachnoid administration to the mother is minimal or absent owing to the small doses used and limited absorption into the systemic circulation. Recently, this concept has been challenged by Giassi and colleagues,\(^{94}\) who studied blood levels of lidocaine following its administration into either the subarachnoid or the epidural space in 20 nonpregnant patients. Maximal blood levels were not different in the two groups although peak levels were achieved sooner after epidural injection (5–10 min) than after subarachnoid placement (15 min). Similar studies in pregnant patients have not been done. Even if such absorption into the systemic circulation does occur in the pregnant patient, one would expect maternal and fetal blood levels substantially lower than those following epidural block because of the much larger doses of local anesthetic used in the latter technique.

An important observation is that of Sprague,\(^{200}\) who compared results with a standard anesthetic technique in four groups of patients undergoing cesarean section with spinal anesthesia. In Group I, anesthesia was induced with the patient's right side down; the patient was then immediately turned into a left-side-down, semilateral position with a 12-cm wedge under the right hip. In Group II, anesthesia was induced with the patient's right side down, followed immediately by the supine position with manual displacement.
of the uterus to the left. Anesthesia was satisfactory in both of these groups. In Group III, anesthesia was induced with the patient's left side down, followed by immediate positioning as in Group I with a wedge under the right hip. In these patients, the sensory level on the right side was consistently 4 to 5 dermataomes lower than that on the left, and anesthesia was inadequate. In Group IV, anesthesia was induced with the left side down, followed by placement in the supine position with manual displacement of the uterus to the left. Although the level of anesthesia was initially adequate, two of the 15 patients in this group needed supplemental general anesthesia late in the procedure owing to pain on the right side. Sprague and colleagues concluded that in order to avoid placing the patient in the supine position, spinal anesthesia should be induced with the patient in the right lateral position. Subsequent placement in the left semilateral position with a wedge under the right hip allows for immediate left uterine displacement and for more even distribution of the local anesthetic through the subarachnoid space.

In summary, spinal anesthesia for cesarean section remains a widely used technique. Generally accepted contraindications include patient refusal, hypovolemia, coagulation disorders, some forms of neurologic disease, and those congenital cardiac disorders where hypotension may initiate or increase right-to-left shunt. Good neonatal outcome is expected when hypotension is prevented by uterine displacement, prehydration, and possibly, prophylactic ephedrine administration. Prompt recognition of hypotension and its appropriate treatment are imperative. Administration of oxygen to the mother is also beneficial, may help to ameliorate maternal and fetal effects of an episode of hypotension, and provides preoxygenation should induction of general anesthesia be needed.

VI. Epidural Anesthesia

The development, physiology, pharmacology, and technical aspects of epidural anesthesia are extensively discussed in Bromage's recent monograph. Anbro et al., almost 30 years ago, reported their experiences with epidural anesthesia for cesarean section, emphasizing its safety in comparison with contemporary practice of general anesthesia. Its use has increased gradually in the ensuing years for a number of reasons: extensive experience in pain relief for labor and vaginal delivery; increased participation by anesthesiologists in obstetric care; improved local anesthetics; better understanding of physiology of epidural anesthesia in the obstetric patient. In comparison with spinal anesthesia, the advantages attributed to lumbar epidural anesthesia for cesarean delivery are the avoidance of dural puncture and the lesser incidence and severity of maternal hypotension. Blood loss is less than that associated with general anesthesia. Among the putative disadvantages are the increased complexity of the technique, with greater chance of failure; slower onset of anesthesia and hence longer induction to delivery (I-D) intervals; and the need for larger amounts of local anesthetic agent.

A. Cardiovascular Effects

In 1965, Stenger and colleagues found substantial differences between the effects of caudal or lumbar epidural anesthesia for cesarean section and their previous data on spinal anesthesia. Reductions in arterial blood pressure averaged 34 per cent, compared with 60 per cent in the spinal anesthesia group. Further, the hypotension was more easily corrected and did not necessitate vasopressor therapy. Finally, fetal condition was better in the epidural group, with higher oxygen content and pH in umbilical vein blood.

These observations were extended by Ueland and co-workers, who found only minor alterations in maternal hemodynamics with lumbar epidural anesthesia, compared with their previous studies in women who received either spinal or general anesthesia. Ueland attributed the lack of hypotension in his series as compared with Stenger's to the epinephrine used in the latter studies. This hypothesis has since been supported by several studies. In epidural anesthesia for cesarean section, the dose of epinephrine injected into the epidural space may be as high as 130 μg. When absorbed into the systemic circulation, the result is predominantly stimulation of beta-adrenergic receptors in the heart and blood vessels. Heart rate and stroke volume tend to increase, accompanied by decreases in total peripheral resistance and mean arterial blood pressure.

Unlike the situation with spinal anesthesia, where cardiovascular changes are largely the result of sympathetic block, with epidural anesthesia other factors may also play roles. The presence or absence of epinephrine has a clear effect, as indicated above. Bromage has suggested that the circulating levels of local anesthetic may contribute. The overall lower incidence of hypotension with epidural anesthesia compared with spinal anesthesia may also result from the slower onset of block with the former, allowing a longer time for compensatory mechanisms to respond and to modulate the effects.

Although hypotension may not be a great problem, the fetus may still be affected. Jouppila et al., using xenon-133, studied the effect of lumbar epidural anesthesia for cesarean section in nine healthy
parturients. Impairment of placental blood flow during the block was observed in seven of the nine patients, but the mean decrease (13 per cent) was not significant. The most marked changes were seen in two patients in whom hypotension developed. As with spinal anesthesia, uncorrected maternal hypotension may result in lower Apgar scores and fetal acidosis. Hollmen and associates\(^\text{112}\) have also shown subtle neurologic changes in infants born to mothers who became hypotensive during cesarean section with epidural anesthesia.

Despite the undoubted contribution of aortocaval compression by the gravid uterus to maternal hypotension and impaired placental blood flow, a recent survey by the Society for Obstetric Anesthesia and Perinatology showed that in only 43 per cent of hospitals was left uterine displacement routinely practiced during epidural anesthesia for cesarean section. The reasons presumably include the low incidence of hypotension and the fear of inadequate anesthesia if the patient is tilted or placed in the lateral position. As with spinal anesthesia, adequate prehydration, left uterine displacement, and maternal hyperoxia have become accepted clinical practices with epidural anesthesia for cesarean delivery.

**B. Choice of Agent and Technique**

Lumbar epidural block for cesarean section is provided by a catheter technique in the majority of published reports. Because of pharmacologic considerations extensively reviewed by Ralston and Shnid\(^\text{197}\) bupivacaine and chloroprocaine have emerged as the most commonly recommended local anesthetics.\(^\text{63,67,100,153,163}\) Lidocaine and mepivacaine have largely been abandoned owing to their effects on neonatal neurobehavior.\(^\text{210}\) Such effects have not been found after bupivacaine, etidocaine, or chloroprocaine.\(^\text{67,109,152,163,211}\)

Maternal position affects both adequacy of anesthesia and fetal outcome.\(^\text{118,153}\) In a recent study,\(^\text{63}\) we found that placing the mother in the lateral position during induction of lumbar epidural block for cesarean delivery did not affect the adequacy of the block and resulted in improved acid-base values in umbilical cord blood. Also, higher concentrations of bupivacaine were found in the umbilical vein blood of the more acidotic fetuses delivered to mothers who had been supine with manual displacement of the uterus. This is probably the result of "ion trapping" of the weak-base local anesthetic in the more highly acidic fetal blood.\(^\text{33}\)

By keeping patients in the semisitting position during induction of anesthesia, one can insure adequate block of the sacral nerves in order to obviate pain during delivery of the presenting part from the pelvis and traction on the vagina. An additional advantage of this maneuver may lie in the higher cardiac output in the pregnant patient in the sitting position compared with the supine position.\(^\text{238}\)

Table 3 summarizes recent reports describing agents and results with lumbar epidural anesthesia for cesarean section. Etidocaine is not suitable owing to the inadequacy of sensory anesthesia.\(^\text{21,67}\) Chloroprocaine has the advantage of quicker onset of anesthesia.\(^\text{67,110}\) Bupivacaine, with its slower onset, results in a longer induction-to-delivery interval and a longer stay in the recovery room.\(^\text{67}\) A useful technique may be induction and maintenance of anesthesia with chloroprocaine, 3 per cent, followed by bupivacaine, 0.25 per cent, at the end of the procedure or in the recovery room to provide postoperative pain relief.\(^\text{67}\) In any case, fetal outcome as defined by Apgar scores, acid-base status, and neurobehavioral testing is equally good with either bupivacaine or chloroprocaine.\(^\text{67,110,165}\)

**C. Complications**

Inadvertent intravascular injection of local anesthetic through the epidural catheter occurs in approximately 2.8 per cent of patients.\(^\text{76}\) Recently, it has been suggested that resuscitation following such a mishap with bupivacaine may be more difficult compared with lidocaine or mepivacaine;\(^\text{6}\) this possibility remains to be documented.

The incidence of dural puncture varies between 0.2 and 20 per cent, depending on the experience of the anesthetist. The incidence of post-lumbar-puncture headache in this situation following dural puncture with a 17-gauge needle may be as high as 76 per cent.\(^\text{172,182}\) In our own experience at the Boston Hospital for Women, the incidence of dural puncture during attempted epidural block was 1.5 per cent. Thirty per cent of these patients had post-lumbar-puncture headache and, of those, 22 per cent were treated with epidural blood patches.

It is not clear at this time whether the advantages and disadvantages of lumbar epidural anesthesia for cesarean section clearly make it superior to spinal anesthesia. The use of lumbar epidural block is increasing, and further studies will help to answer this question. Carefully administered lumbar epidural block, with meticulous technique, appropriate selection of local anesthetic agent and dose, adequate hydration, and avoidance of the supine position yields excellent results.

**VII. General Anesthesia**

The practice of general anesthesia for cesarean delivery has undergone considerable change in the
TABLE 3. Results with Epidural Anesthesia

<table>
<thead>
<tr>
<th>Source of Data</th>
<th>Agent and Concentration</th>
<th>Average Dose</th>
<th>Per Cent Satisfactory Anesthesia</th>
<th>Average Induction-Delivery Interval (Min)</th>
<th>Fetal/Maternal Blood Concentration Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>James et al.118</td>
<td>Bupivacaine, 0.5 per cent</td>
<td>95</td>
<td>80</td>
<td>41</td>
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<tr>
<td>Datta et al.97</td>
<td>Bupivacaine, 0.75 per cent</td>
<td>128</td>
<td>100</td>
<td>53</td>
<td>0.29</td>
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<tr>
<td>Magno et al.152,153</td>
<td>Bupivacaine, 0.75 per cent</td>
<td>104</td>
<td>50</td>
<td>50</td>
<td>0.41</td>
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<tr>
<td>McGuinness et al.168</td>
<td>Bupivacaine, 0.75 per cent</td>
<td>168</td>
<td>100</td>
<td>42</td>
<td>0.25</td>
</tr>
<tr>
<td>Datta et al.97</td>
<td>Chloroprocaine, 3 per cent</td>
<td>480</td>
<td>95</td>
<td>36</td>
<td>—</td>
</tr>
<tr>
<td>James et al.179</td>
<td>Chloroprocaine, 3 per cent</td>
<td>600</td>
<td>87</td>
<td>22</td>
<td>—</td>
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<tr>
<td>Bromage et al.21</td>
<td>Etidocaine, 1 per cent</td>
<td>200</td>
<td>20</td>
<td>—</td>
<td>0.36</td>
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<td>Datta et al.97</td>
<td>Etidocaine, 1 per cent</td>
<td>220</td>
<td>30</td>
<td>38</td>
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<tr>
<td>Lund et al.181</td>
<td>Etidocaine, 1 per cent</td>
<td>250</td>
<td>96</td>
<td>20-25</td>
<td>—</td>
</tr>
</tbody>
</table>

* An unspecified number of patients needed supplemental general anesthesia.

last three decades, with the virtual abandonment of the flammable anesthetics, ether and cyclopropane, and their replacement by techniques involving multiple drugs and newer inhalational agents. Because of nonuniformity in the selection of patients, in the use of left uterine displacement, in intravenous fluid therapy, and in control of ventilation, comparison of outcomes in reported series is difficult.

Advantages of general anesthesia include the speed with which it may be induced, its reliability, reproducibility and controllability, and the avoidance of hypotension associated with spinal or epidural anesthesia. The major disadvantages include the possibilities of maternal aspiration, problems with airway management, maternal awareness during light anesthesia, and depression of the newborn by anesthetic drugs.

A. Pulmonary Aspiration of Gastric Contents

Despite increased awareness of this serious complication and more widespread attempts at prevention, maternal mortality and morbidity from aspiration continue to occur.44,53,81,172a,214 As other causes of maternal mortality become less frequent and as the use of general anesthesia for vaginal delivery diminishes, maternal deaths from aspiration during anesthesia for cesarean delivery remain a major problem.

Several maneuvers have been advocated to minimize the frequency and severity of aspiration. Few anesthetists today would administer general anesthesia to the parturient without securing her airway, usually through rapid-sequence induction and endotracheal intubation accompanied by the Sellick maneuver.215

Since the recognition by Mendelson,166 in his classic paper of 1946, of the importance of gastric pH in acid aspiration, others have confirmed his findings.236,248 In recent years, Taylor and Pryse-Davies229 have advocated the administration of antacids during labor. In 1974, Roberts and Shirley,283 in a study of 100 patients undergoing cesarean section, showed that one could not confidently predict which patients were or were not at risk solely on the basis of a history of ingestion of food or the presence or absence of labor. From considerations such as these has emerged the widespread practice of the administration of oral antacids to patients in labor, especially in anticipation of cesarean section. Similarly, antacids have been advocated for patients scheduled for elective cesarean section.26,53,203 In most patients, the administration of antacid within four hours of the induction of anesthesia does not affect the volume of gastric content but raises the pH above 2.5, considered a critical level.203

Recent reports have disturbed complacent acceptance of this clinical regimen. The first describes two deaths in Great Britain of patients who aspirated gastric contents during anesthesia for cesarean section despite appropriate technical maneuvers and the previous administration of antacids.240 Another recent case report241 describes a patient who aspirated gastric contents under similar circumstances but who survived after several days of intensive care. A further disturbing factor is the recent demonstration in animals that suspension antacids, if aspirated, may themselves result in both physiologic and structural alterations in the lung.56

The current uncertainty in this area is well summarized in recent editorials by Cohen44 and Moir,172a who, after extensive reviews of the literature, concluded that the question of ideal management remains unanswered. Clearly, the potential for lethal aspiration is present in all patients undergoing general anesthesia for cesarean section. Some have suggested apomorphine administration or emptying of the stomach with a large-bore gastric tube.56 Endotracheal intubation in the awake patient during topical anes-
Anesthesia may offer yet another solution. The best preventive measure is the avoidance of general anesthesia in these patients unless regional anesthesia is contraindicated. Clearly, the problem remains unresolved. Its resolution must await further research to identify the patients at maximal risk and more detailed studies of the benefits and hazards of water-soluble antacids. The use of drugs to decrease gastric acidity is discussed below.

An additional hazard of general anesthesia, though less well-defined, is the difficulty or impossibility of endotracheal intubation following intravenous induction of anesthesia. 150,172 It may be possible safely to continue administering inhalational anesthesia by mask, or it may be necessary to discontinue the procedure to allow time for reassessment and the adoption of an alternative anesthetic strategy. A means of instituting transtracheal ventilation should be immediately available in every delivery room.

B. Cardiovascular Effects

In a study of 17 women undergoing repeat cesarean section at term with thiopental, nitrous oxide, and succinylcholine anesthesia, Ueland et al. 197 observed hemodynamic changes much smaller than those seen with spinal anesthesia. Both cardiac output and arterial blood pressure increased, especially during tracheal intubation and extubation, but these changes were transient and were not deemed significant. In a recent study of pregnant ewes, 218a Shnider and associates demonstrated that maternal stress was associated with increased arterial blood pressure, increased plasma levels of norepinephrine, and brief decreases in uterine blood flow, not associated with fetal asphyxia. Whether such changes occur during intubation in human beings and whether they may be modified by the use of a low concentration of a potent inhalational anesthetic are currently under investigation.

The importance of avoiding aortocaval compression in order to improve uteroplacental perfusion during general anesthesia for cesarean section was first documented by Crawford et al. 98 in 1972. In 150 patients, the data revealed greater fetal ascosis and a higher incidence of low Apgar scores in the infants born to non-tilted mothers. Crawford and co-workers emphasized that when cesarean section is being undertaken for suspected or documented intrauterine fetal asphyxia, the imposition of a further increment of asphyxia imposed by permitting the patient to lie supine could well be highly detrimental to the fetus.

The majority of Crawford's patients were tilted to the right. In 1977, Buley et al. 34 compared results with right and left lateral tilts during cesarean section and concluded that better outcomes resulted from tilting to the left. Although maternal hypotension is sel-

dom a problem during general anesthesia for cesarean section, tilting the parturient to the left appears to be of clear benefit to the fetus, probably through relief of aortic compression.

C. Preanesthetic Medication

There is little agreement about the need for and the choice of agents for preanesthetic medication prior to general anesthesia for cesarean delivery. Because of concern for the fetus and newborn, many eschew preanesthetic medication completely. Some advocate barbiturates and tranquilizers such as chlor Diazepoxide, diazepam, or hydroxyzine. 53,54,142,156,213 The benefit of such medication is not established, nor have possible effects in the newborn been thoroughly studied.

The anticholinergics, atropine and scopolamine, have been widely used without definite evidence of advantage. 100 A theoretical benefit of scopolamine may be its amnesic action. 64 Glycopyrrolate has been advocated because of its ability to decrease gastric secretion and increase the pH of gastric contents. 14,224 Recently, however, Brock-Utne and associates showed that anticholinergics reduce the tone of the lower esophageal sphincter and increase the incidence of gastroesophageal reflux. 26,75 Hypothetically, this action might increase the risk of regurgitation and aspiration. Two drugs now under trial might be beneficial for the problems of low pH and increased volume of gastric contents that are present during pregnancy. Cimetidine, a histamine receptor antagonist, inhibits gastric acid secretion and increases pH. 116,130,228 Metoclopramide has been used in Great Britain and found to facilitate gastric emptying and also increase tone in the lower esophageal sphincter. 114 Further research is needed to establish the usefulness of these new drugs and their safety in the pregnant patient.

In the absence of well-conducted and controlled clinical trials, there is little on which to base specific recommendations. In our practice at the Boston Hospital for Women, we do not routinely administer preanesthetic medication prior to cesarean delivery with general anesthesia.

D. Ventilation

The physiologic changes of pregnancy render the parturient more susceptible to rapid changes in blood-gas tensions. In particular, Archer and Marx have shown a decreased tolerance to periods of apnea, owing presumably to increased oxygen consumption and decreases in residual volume and functional residual capacity. 10 Adequate preoxygenation (100 per cent oxygen at a high flow rate for 3 min) prior to rapid-sequence induction and endotracheal intubation is mandatory.
Once the trachea is intubated and artificial ventilation is instituted, hypocarbia is easily produced. Maternal and fetal blood carbon dioxide tensions are strongly correlated in normal patients with a constant small maternal–fetal difference over a wide range of values. Deliberate voluntary hyperventilation in conscious pregnant patients results in decreased maternal and fetal blood carbon dioxide tensions and increases in maternal and fetal blood pH. Several investigators have described the effects of passive maternal hyperventilation during general anesthesia. Low et al. observed a small reduction in \( P_{\text{CO}} \) in umbilical vein blood in hyperventilated parturients (\( P_{\text{CO}} = 22 \) torr) compared with a control group (\( P_{\text{CO}} = 32 \) torr). Fetal acidosis was not observed. Motyama et al., in 1966, described a direct correlation between umbilical vein blood \( P_{\text{CO}} \) and maternal \( P_{\text{ACO}} \). Moya et al. found that moderate maternal hyperventilation with lowering of \( P_{\text{CO}} \) to 23 torr reduced fetal acidosis but had no effect on Apgar scores. More severe hyperventilation was associated with fetal metabolic acidosis. These investigators suggested that the critical level of maternal \( P_{\text{CO}} \) was 17 torr. Below that value, one was likely to find fetal acidosis and delayed onset of respiration.

In 1972, Peng and co-workers reported that maternal hypocarbia (average \( P_{\text{CO}} = 23 \) torr) was associated with a decrease in \( P_{\text{O}} \) in fetal blood, an increase in base deficit, lower 1-minute Apgar scores, and delayed onset of sustained respiration. However, Parer et al. in monkeys, failed to show a deleterious fetal effect of maternal hyperventilation.

The weight of the evidence thus suggests potential harm to the fetus from passive maternal hyperventilation during general anesthesia. Mechanisms that have been invoked to explain this phenomenon include: uterine artery vasoconstriction secondary to maternal hypocarbia and alkalosis; vasoconstriction of umbilical vessels secondary to fetal alkalosis; altered maternal hemodynamics secondary to increased intrathoracic pressure during hyperventilation; shift of the maternal oxyhemoglobin-dissociation curve to the left with alkalosis and a subsequent lessened release of oxygen by maternal blood. Whatever the cause or causes of its adverse effect, maternal hyperventilation (minute volume in excess of 100–120 ml/kg/min) should be avoided during general anesthesia for cesarean delivery, as should periods of hyperventilation or apnea.

Oxygenation of the fetus is also affected by maternal inspired oxygen concentration. Korke et al. pointed out, in 1968, that increasing maternal inspired oxygen concentration from 33 to 66 per cent increased both maternal and fetal oxygen tensions and improved fetal condition at birth. Similar results have been reported by others. A maternal inspired oxygen concentration of 65–70 per cent appears to yield optimal results. Contrary to earlier reports, maternal hyperoxygenation does not result in fetal acidosis.

### E. Anesthetic Agents

#### 1. Intravenous induction agents

Standard practice is induction of anesthesia with intravenous injection of a thiobarbiturate, usually thiopental. The most comprehensive study is that by Kosaka and associates, who concluded that after a single dose of 4–7 mg/kg, thiopental did not significantly affect fetal outcome as measured by Apgar scores. However, administration of 8 mg/kg was associated with an increased number of depressed infants. The thiobarbiturates cross the placenta rapidly and are detected in fetal blood within seconds of their administration to the mother. Their concentration in umbilical vein blood (UV) is always lower than that in maternal blood; the concentration in umbilical artery blood (UA) is lower than that in umbilical vein blood. These gradients result from the rapid decline in concentration of the thiobarbiturate in maternal blood, non-homogeneous distribution in the intervillous space, extraction of thiobarbiturate from umbilical vein blood by the fetal liver, and progressive dilution through shunting in the fetal circulation.

Holdercroft et al. found an increased incidence of depressed infants with low Apgar scores and prolongation of times to sustained respiration following induction of anesthesia with methohexital, 1.4 mg/kg, compared with 1.0 mg/kg.

Other induction agents have been used, but not extensively. In a comparative study of propanidid, 500 mg, and thiopental, 250 mg, Baraka and co-workers found no difference in neonatal outcomes when induction–delivery (I–D) intervals were less than 10 min. When I–D intervals exceeded 10 min, neonatal depression was marked after thiopental. On the other hand, both Robertson et al. and Mahomed et al. observed higher frequencies of acidicotic infants at delivery following propanidid. It has been suggested that this may be the result of reduced maternal cardiac output secondary to propanidid-induced myocardial depression.

Ketamine, the subject of several studies, has been advocated for induction of anesthesia, especially in the presence of unstable maternal hemodynamics associated with blood loss. With doses as high as 1 mg/kg, Feliz and Sinclair found no deleterious effect in the newborn, compared with thiopental, 5 mg/kg. Studies by Little et al. demonstrated placental passage of ketamine. In 1977, Ellingson et al. reported that levels of ketamine in cord blood ex-
ceeded those in maternal vein blood within 97 sec
of its injection, with maximal levels at 125 sec. The
place of ketamine in obstetrics remains unsettled.

Downing et al.,77 reported increased fetal acidosis
following administration of Althesin® (60 to 70 μl/
kg) compared with thiopental (3 to 4 mg/kg). In higher
doses (100 to 150 μl/kg), Althesin caused an unac-
tetable incidence of fetal depression.76 Holdcroft
and associates110 also observed significantly lower
umbilical vein blood and umbilical artery blood P02
values after using Althesin in a dose of 100 μl/kg.

Stovner and Vangen97 compared diazepam, 20 mg,
with thiopental, 200 mg, and found no difference in
neonatal conditions as measured by Apgar scores.
Diazepam, however, has been associated with neo-
natal hypotonia and increased susceptibility to cold
stress.61,124,213

2. Neuromuscular Blockers. Except in unusual cir-
stances, there is little observable effect on the newborn
attributable to neuromuscular blockers administered
to the mother. Studies of d-tubocurarine, alcuronium,
pancuronium, metocurine and succinylcholine sug-
ject that after a bolus injection, small quantities of
these drugs may cross the placenta, but paralyzing
doses are not reached in the fetus.87

Succinylcholine is most frequently used during in-
duction of anesthesia to facilitate endotracheal intuba-
tion. Its effects are not materially enhanced despite
the lower than normal levels of pseudocholinesterase
in maternal and fetal blood.28 Succinylcholine has been
detected in umbilical cord blood after a 300-mg bolus
dose administered to the mother. Using labelled
succinylcholine in pregnant monkeys, Drabkova et al.,78
identified the drug in fetal blood 5 to 10 min after
the intravenous injection of 2–3 mg/kg in the mother,
but the fetal concentrations were too low to be of clin-
ic significance.

Several investigators advocate the administration
of a small dose of a nondepolarizing neuromuscular
blocker before the administration of succinylcholine
in order to prevent the increase in intraabdominal
pressure associated with fasciculation.70,206 However,
this procedure is not universally accepted, since
tracheal intubation is made more difficult.82 Others
question its necessity in the pregnant patient, in whom
fasciculation does not occur as intensely as it does in
the nonpregnant patient.54,68

Common clinical practice consists of an intubation
dose of succinylcholine of approximately 2 mg/kg,
followed by intravenous infusion of a dilute solution
as needed. Three recent case reports112,194 have de-
scribed prolonged maternal neuromuscular block
following administration of succinylcholine for cesarean
delivery in the presence of atypical pseudocholineste-
erase. Similar effects were seen in the new-
borns only when they too had the atypical enzyme,
suggesting that the drug does indeed cross the
placenta.

After administration to the mother of d-tubo-
curarine, 15–60 mg, trace concentrations are found in
cord blood.43 In 1968, Older and Harris181 reported
a case of neonatal paralysis following administration
to the mother of d-tubocurarine in a total dose of 245
mg over ten hours to control convulsions. The pos-
sibility that fetal acidosis may enhance the effects of
d-tubocurarine was raised by Baraka,11 who found an
increase in free unbound plasma levels with low pH.

In 1978,79 a comprehensive study of pancuronium
was reported by Duvaldestin and coworkers, who had
examined its pharmacokinetics in 33 pregnant women
who received single intravenous bolus injections of
60–100 μg/kg prior to cesarean section. Pancuronium
was found in all samples of fetal blood, with an average
fetal:maternal concentration ratio of 0.22. The
UV/MV ratio increased with increasing 1–D interval.
At all times following injection, the UA/UV ratio was
approximately 0.66 (range: 0.2–1.0), suggesting con-
tinuing uptake of pancuronium by fetal tissues.
There was no evidence of drug effect in the newborns.

3. Inhalational Anesthetics. Nitrous oxide, either alone
or in combination with more potent agents, is the in-
halational anesthetic most frequently used for ces-
arean delivery. In 1940, Smith12 demonstrated trans-
fer of nitrous oxide from mother to fetus. Marx
and co-workers,157,181 in detailed studies of nitrous
oxide uptake and distribution, found rapid placental
passage, with a fetal:maternal concentration ratio of
nitrous oxide of 0.8 after 3 min. Umbilical artery:
umbilical vein blood nitrous oxide concentration ratios
increased progressively with increasing duration of
anesthesia, and approached 90 per cent after about
15 min of nitrous oxide administration.

The prolonged administration of nitrous oxide in
high concentration may result in low Apgar scores,
possibly contributed to by diffusion hypoxia at
birth.45,150,205 Palahniuk and Cumming186 suggested
that nitrous oxide may cause uterine vasoconstriction
owing to its effects on the sympathetic nervous system.

Various inhalational agents have been used in
combination with nitrous oxide, including enflur-
ane,45,73 fluroxene,102 halothane,52,122,128 methoxy-
fluorane,60,141,187 and trichloroethylene.60 All are reported
to produce satisfactory anesthesia with few side effects.

Halothane, 0.5 per cent, to supplement nitrous
oxide does not result in untoward uterine relaxation
or excessive postpartum bleeding.142,177

An increase in maternal serum uric acid levels
following methoxyflurane administration has been re-
ported.102 Palahniuk et al.,187 found that when
methoxyflurane was used in low concentrations (0.2–
0.5 per cent) maternal fluoride levels two hours post partum averaged 10 μmol/l, well below the levels associated with nephrotoxicity. No impairment of renal function was detected in these patients.

In a recent study by Dick et al.,\textsuperscript{73} enflurane, 1 per cent, was used to complement nitrous oxide, with good infant outcome as measured by Apgar scores, blood-gas values, and acid–base status. Enflurane rapidly passes from mother to fetus. After 7 min, its average concentration in umbilical vein blood was 60 per cent of that in maternal blood. Its concentration declined rapidly in the newborn, so that within 15 min of delivery, the concentration was a tenth that observed initially at birth.

\textbf{F. Maternal Awareness During Anesthesia}

A major problem with general anesthesia for cesarean section is the incidence of maternal awareness and unpleasant recall occasioned by the use of small doses and low concentrations of anesthetics to minimize neonatal effects. Incidences of recall have been reported to range from 17 to 36 per cent.\textsuperscript{4,24} In some series, the use of low concentrations of potent anesthetic agents has successfully prevented awareness and recall without ill effects.\textsuperscript{55,73,138}

Turner and Wilson,\textsuperscript{23} in 1969, concluded that diazepam administered as a preanesthetic medicant increased the incidence of unpleasant recall. However, Barr et al.\textsuperscript{18} recorded a low incidence of maternal recall in patients given diazepam or lorazepam intravenously immediately following delivery of the infant.

Similar results were obtained by Abouleish and Taylor,\textsuperscript{2} who found that the combination of morphine and diazepam resulted in a decrease in the incidence of recall to 3.8 per cent. These investigators also found a direct correlation between the length of the induction–delivery interval and the incidence of unpleasant recall.

The use of morphine and diazepam appears to be most effective in preventing awareness when the I–D interval is 8 min or less. When a longer I–D interval is expected or encountered, the addition of a low concentration of an inhalational agent, such as 0.5 per cent halothane, is probably more effective.

\textbf{G. Timing of Delivery}

There continue to be differences of opinion about the optimal time for delivery of the infant when general anesthesia is used for cesarean section. As early as 1967, Stenger and colleagues\textsuperscript{22} advocated minimizing the time from induction of anesthesia to delivery of the infant by preparing the skin and draping the field before inducing anesthesia. Hodges et al.\textsuperscript{106} found optimal outcome in infants delivered within 4 min of induction, and mild depression after 7 to 10 min. In 1968, in a study of pH values of fetal scalp blood samples, Teramo\textsuperscript{231} reemphasized this concept. Fothergill et al.\textsuperscript{108} in 1971, found a higher incidence of acidosis in infants when the I–D interval exceeded 15 min, as did Magno and co-workers in 1976.\textsuperscript{184} However, in all of these studies, the oxygen concentrations administered to the mothers were low (25–33 per cent), and except for a few patients in the last two series, all of the women were supine throughout the procedure. Increasing the maternal FiO\textsubscript{2} did not compensate for the disadvantages of the supine position; neonatal depression was observed with I–D intervals of only 6 min.\textsuperscript{137}

By contrast, Stenger et al.\textsuperscript{23} found no obvious correlation between clinical or biochemical indices of fetal outcome and I–D intervals ranging from 8 to 22 min. More recently, Crawford and associates\textsuperscript{99} emphasized that if aortocaval compression is avoided, if the inspired oxygen concentration is 65 to 70 per cent, and if there is no hypotension, then an I–D interval as long as 30 min has no significant effect on the acid–base status of the newborn. More important is a short U–D interval, i.e., the time from incision into the uterus until completion of delivery of the infant. In this series, a U–D interval of more than 90 sec was associated with significant lowering of Apgar scores. In a group of preliminary observations,\textsuperscript{84} we also found a higher incidence of low Apgar scores with U–D intervals of more than 90 sec. With U–D intervals of more than 180 sec, both lower Apgar scores and fetal acidosis were found during either general or spinal anesthesia.

Adverse outcomes with prolonged U–D intervals may be the result of the effects of uterine manipulation on uteroplacental and umbilical blood flows, pressure on the uterus with accentuation of aortocaval compression, inhalation of amniotic fluid as a result of gasping respirations by the fetus in utero, or compression of the fetal head during a difficult delivery.

While timing of delivery during general anesthesia does not appear critical when the maternal inspired oxygen concentration is high and the uterus is displaced to the left, optimal outcome appears associated with short I–D and U–D intervals.

In several studies, fetal outcomes after general anesthesia have been compared directly with outcomes after regional anesthesia, either spinal or epidural, by the same investigators. Under optimal conditions in healthy patients at term, James et al.\textsuperscript{118} in 1977, and Fox et al.\textsuperscript{102} in 1979, found no differences in Apgar scores or fetal acid–base status in a comparison of general anesthesia with epidural anesthesia. Belfrage
et al.\textsuperscript{11} found no alteration in continuously monitored fetal heart rate during cesarean delivery with general or epidural anesthesia. Datta and Brown\textsuperscript{166} and Marx \textit{et al.}\textsuperscript{169} reported excellent outcomes with either spinal or general anesthesia, provided hypotension did not occur in the former group. From the point of view of fetal outcome, as measured by Apgar scores and acid–base values in umbilical cord blood, excellent and excellent outcomes are to be expected with general anesthesia and regional anesthesia, given normal term pregnancy and meticulous management as described above. There are only a few reports of comparisons of neonatal neurobehavioral effects of regional anesthesia and general anesthesia for cesarean section. Palahniuk \textit{et al.}\textsuperscript{187} observed better neurobehavioral results after 0.2–0.5 per cent methoxyflurane in oxygen than after epidural anesthesia. Hodgkinson and associates\textsuperscript{108} on the other hand, reported a higher percentage of high scores after spinal anesthesia. Hollmen \textit{et al.}\textsuperscript{112} found no differences in neurologic function to seven days of age in infants born after maternal epidural or general anesthesia for elective cesarean sections at term.

In a unique prospective study of 26,760 children in the Collaborative Perinatal Project, Stanford-Binet I.Q. scores at the age of 4 years were correlated with a long series of socioeconomic, maternal, prenatal, intrapartum, neonatal, infancy, and childhood variables.\textsuperscript{32} No correlation was found between I.Q. at age 4 and delivery by cesarean section. No details of anesthetic management are reported. These data, incomplete as they are, combined with the neonatal studies cited above, suggest that anesthesia for cesarean section, when meticulously carried out, has neither short-term nor long-term effects on the offspring.

\section*{VIII. Complicated Obstetrics}

\subsection*{A. Hypertensive Disorders of Pregnancy}

There is little agreement concerning the optimal anesthetic management of cesarean section in the patient with eclampsia or preeclampsia. The incidence of cesarean section in such patients approximates 20 per cent.\textsuperscript{106}

Obstetrical management includes lowering of blood pressure, preventing or treating convulsions, and early termination of pregnancy in the more severe cases. In the United States, the cornerstones of therapy are magnesium sulfate, sedatives, especially phenobarbital, and antihypertensive drugs, chiefly hydralazine.\textsuperscript{108} Physiologic abnormalities may range in severity from mild hypertension with little else to a full-blown and complex disorder involving severe hypovolemia, intravascular coagulation, and renal and hepatic dysfunction.

For cesarean section, especially for patients who have severe forms of hypertension, most investigators advocate general anesthesia.\textsuperscript{5,15,16} Of possible advantage is the avoidance of hypotension, especially in the presence of inadequately corrected hypovolemia. On the other hand, during general anesthesia, hypertension may be exaggerated during induction of the trachea and induction of anesthesia. This may be controlled by the judicious intravenous injection of small doses of hydralazine. Currently under investigation is the possible value of nitroprusside or nitroglycerin in this situation.\textsuperscript{242}

Of concern is the augmented action of neuromuscular blockers in the patient who has been receiving magnesium sulfate. Morris and Giesecke,\textsuperscript{174} in 1968, reported a decreased need for succinylcholine in patients undergoing cesarean section after magnesium therapy. Subsequent studies in animal\textsuperscript{165,166} confirmed this clinical observation and demonstrated potentiality by magnesium of both depolarizing and nondepolarizing neuromuscular blockers. In such patients, it is best to avoid nondepolarizing drugs and to monitor neuromuscular block with a nerve stimulator.

In these cases, one should be prepared to resuscitate a depressed newborn, not only on the basis of uteroplacental insufficiency and asphyxia, but also as a result of neonatal hypermagnesemia.\textsuperscript{140} A syndrome of neonatal flaccidity, hyporeflexia, respiratory depression, and weak or absent cry following intravenous administration of magnesium sulfate for 12 to 24 hours has been described. The most severely affected infants need ventilatory support for 24 to 36 hours and may benefit from intravenous calcium therapy. Stone and Pritchard failed to find significant neonatal effects after intramuscular injection of magnesium sulfate.\textsuperscript{226}

Reported experience with spinal or epidural anesthesia for cesarean section in these patients is limited, owing to the possible hazards of these techniques in a hypertensive, hypovolemic patient. Results of a recent study\textsuperscript{126} suggest that epidural anesthesia may be safely used provided blood volume is adequately replaced with plasma expanders and electrolyte-containing solutions, with careful monitoring of central venous pressure. The use of plasma expanders in these patients is not a new idea. Czerny,\textsuperscript{63} in 1894, followed by Dieckmann,\textsuperscript{74} in 1931, and Cloeren and Lippert,\textsuperscript{42} in 1973, all reported benefit from volume expansion. Regional anesthesia has also been advocated by other investigators.\textsuperscript{5,160} Reevaluation is indicated in view of the more recent hemodynamic studies. Before induction of conduction anesthesia, the presence of coagulopathy should be ruled out.
B. Diabetes Mellitus

Pregnancy in the diabetic patient poses hazards for both mother and fetus. To avoid the high incidence of fetal death in the third trimester, cesarean section is performed in a high percentage of diabetic mothers. The fetus of the diabetic mother is at risk because of placental insufficiency concomitant asphyxia and acidosis, subject to aggravation by maternal hypotension. We and others have shown marked fetal acidosis following cesarean section with spinal or epidural anesthesia complicated by maternal hypotension.

The genesis of the fetal acidosis appears to be complex. The placenta of the ewe has the ability to produce lactic acid, especially in an hypoxic environment. In diabetes, the placenta is heavily endowed with glycogen, which may be a source of lactate. In a key paper in 1975, Shelley et al. found that plasma glucose concentrations of more than 40 mg/100 ml in mildly hypoxic lamb fetuses resulted in rapid increases in plasma lactate and decreases in pH. Currently under investigation is the wisdom of using glucose-containing intravenous fluids in the diabetic and perhaps even in the non-diabetic parturient, in face of the possibility that fetal hyperglycemia combined with fetal hypoxia may result in severe fetal acidosis.

Since hypotension may occur with either spinal or epidural anesthesia, perhaps the use of regional anesthesia for the diabetic parturient should be avoided. In the limited reported series, better outcomes have followed general anesthesia. More work needs to be done to unravel the complex metabolic, circulatory, and anesthetic interrelationships.

C. Cardiac Disease

Cesarean delivery may be necessary in the patient with corrected or uncorrected congenital or acquired heart disease. Space does not permit a detailed review of the anesthetic considerations in management of such patients, and the interested reader is referred elsewhere.

Two points, however, may be made. Patients receiving anticoagulant therapy are not candidates for regional anesthesia for cesarean section in view of the hazard of intraspinal hematoma.

Propranolol is being used with increasing frequency during pregnancy in the treatment of various disorders, including hypertension and cardiac disease. The anesthesiologist may face problems related to reduction in cardiac output and maternal myocardial reserve, as well as decreased responsiveness to beta-adrenergic stimulating drugs, in the presence of hypotension. The chronic administration of propranolol has complex effects on the fetus, which may include intrauterine growth retardation, fetal bradycardia, and neonatal hypoglycemia.

D. Multiple Gestation

The optimal management of patients with multiple gestation includes recognition of several problems. Aortocaval compression may be more profound, and hence, the incidence and degree of hypotension greater. Parturients tend not to tolerate the supine position because of aortocaval compression, as well as an increased tendency toward hypoxemia with upward displacement of the diaphragm. Adequate ventilation should be assured during general anesthesia; supplemental oxygen should be provided during regional anesthesia. In the presence of a grossly enlarged uterus, gastric emptying may be even further compromised, increasing the risk of aspiration in these patients. Finally, fetuses in multiple gestation are often premature and may have growth retardation. Partial separation of the placenta is common in the second twin. The I–D and U–D intervals should be minimized.

E. Prematurity

Cesarean section is performed with increasing frequency in prematurity, especially when complicated with a breech presentation. Decreased neonatal mortality and morbidity rates have been reported. No data exist to suggest a specific advantage to any form of anesthesia in this situation. Of interest are the problems that may arise in such patients who have been treated with beta-mimetic drugs to retard or arrest premature labor. Such therapy may result in tachycardia and decreased maternal cardiac output and may predispose to maternal hypotension. Another recently reported complication is the development of pulmonary edema in patients treated with beta-mimetics to arrest labor and corticosteroids to accelerate fetal lung maturation in utero.

F. Miscellaneous Disorders

The problems associated with severe kyphoscoliosis in pregnancy have recently been reviewed by Carlson and associates, who described successful use of epidural anesthesia for cesarean section. Although technical problems may make this approach difficult or impossible, it should be considered.

As a result of a study of a series of patients with myasthenia gravis, Rolbin et al. emphasize the possible aggravation of respiratory impairment by a high regional block, and suggest that general anesthesia may be preferable for cesarean section in these patients.
Phillips and Evans' review management and outcome of 33 patients with abruption of the placenta. All patients were aggressively managed with early cesarean delivery with general anesthesia. Maternal mortality was zero. Three infants were stillborn, while 23 of the 30 liveborn infants survived the neonatal period.

Pheochromocytoma during pregnancy carries high maternal and fetal mortality rates. Burgess and associates describe the successful management of a cesarean delivery followed by excision of the tumor. Spinal anesthesia with tetracaine was used successfully for vaginal delivery in a patient known to be susceptible to malignant hyperthermia, while Crawford reported two cases, one of vaginal and one of cesarean delivery, managed with epidural blocks. It would appear then that regional anesthesia is preferable for such patients.

IX. Conclusions

The past decade has witnessed a series of major changes in the practice of obstetrics, including a three- to fourfold increase in the incidence of delivery by cesarean section. At the same time, obstetric anesthesia has emerged as a recognized subspecialty of anesthesiology, with increasing attention focused on measuring the impacts on mother, fetus, and newborn of anesthetic interventions. The present review indicates substantial advances in our understanding of the physiology, pharmacology and clinical management of anesthesia for cesarean delivery. At the same time, the need for further studies is clear, particularly in the areas of prevention of the risks of gastric aspiration, management of patients with hypertension and diabetes, and the short- and long-term effects of analgesics and anesthetics on the premature, the compromised, and the full-term fetus and infant. Excellent results are obtained in elective cesarean section at term with well-managed spinal, epidural, or general anesthesia.

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