may have compressed the plexus at the root or trunk level (fig. 3). After the chest tube was repositioned, by withdrawing it approximately 5 cm, the pain was immediately relieved. Partial ulnar nerve injury persisted for more than 3 weeks, ruling out neuropraxia. Also considered in our differential diagnosis was the adequate placement of the thoracostomy tube when the patient was in the left lateral decubitus; however, when the patient was placed supine, the tube may have further compressed the neural bundle. We propose that the mechanism of injury was secondary to the chest tube placement rather than patient positioning. As noted by Kroll *et al.*,[12] the exact mechanism of nerve injury is often unclear; however, since anesthesiologists share in the task of positioning, any problem with patient care in associated brachial plexus palsy should be a joint postoperative effort.

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Response of Fetal Heart Rate to Maternal Administration of Esmolol

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Increases in blood pressure (BP) in the patient with an intracranial arteriovenous malformation (AVM) may precipitate intracranial hemorrhage. Esmolol, an ultra-short-acting β-adrenergic blocking agent, has been shown to effectively blunt the increase in systemic BP associated with tracheal intubation and emergence from anesthesia after intracranial surgery.[1,2]

The effect of esmolol on fetal heart rate (FHR) after maternal administration has not been reported previously. We describe the use of esmolol in a 22-week pregnant woman undergoing resection of a cerebellar AVM and its effect on FHR.

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Case Report

A 31-yr-old woman (gravida 2, para 1) had an intrauterine pregnancy at 22 weeks complicated by a subarachnoid hemorrhage. The patient was scheduled for a suboccipital craniectomy for excision of a cerebellar AVM. By ultrasound, the weight of the fetus was estimated to be 350 g.

Maternal BP on the ward prior to surgery ranged between 90/50 and 110/65 mmHg. The patient arrived in the operating room oriented without neurologic deficit. The patient was monitored with electrocardiogram, BP cuff, pulse oximeter, indwelling radial artery catheter, and mass spectrometer. FHR was monitored continuously intraoperatively and for the first 24 h postoperatively using a Hewlett-Packard 8041A FHR monitor. It is our practice to blunt the hemodynamic response to tracheal intubation and to treat emergence hypertension in the patient with an intracranial AVM by using short-acting agents such as esmolol and nitroprusside. Because the fetal response to esmolol was unknown, we elected to administer esmolol prior to inducing anesthesia to determine its effect on FHR in this patient. The patient was positioned supine with left uterine displacement. Prior to the administration of any anesthetic agents, maternal BP was 142/62 mmHg and heart rate (HR) was 94 beats per min. FHR ranged between 139–144 beats per min, and variability was present (fig. 1, awake control 1).

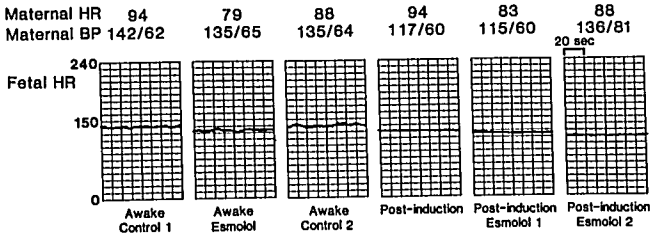

FIG. 1. The Awake Esmolol panel shows a decrease in maternal heart rate (HR) and blood pressure (BP) as well as a small decrease in fetal HR after the administration of esmolol. Variability of fetal HR was preserved during the esmolol infusion. The three panels on the right show loss of variability and a decrease in fetal HR after the administration of thiopental and esmolol.

With patient permission, esmolol was administered 500 μg/kg as an intravenous (iv) bolus and an infusion was begun at 50 $\mu g \cdot kg^{-1} \cdot min^{-1}$. Every 2–3 min thereafter, an additional 500-μg/kg iv bolus was administered and the infusion increased by 50 $\mu g \cdot kg^{-1} \cdot min^{-1}$. Within 10 min after the first dose of esmolol, the patient had received a total of four bolus doses of esmolol, 500 μg/kg each, and was receiving a 200-$\mu g \cdot kg^{-1} \cdot min^{-1}$ infusion of esmolol. At this time, maternal BP and HR had decreased to 135/65 mmHg and 79 beats per min, respectively. FHR decreased to 131–137 beats per min, and variability was still present (fig. 1, awake esmolol). To verify that the observed reduction in FHR was due to the administration of esmolol, the esmolol infusion was discontinued. Within approximately 11 min after discontinuation of the infusion, FHR had returned to near baseline (137–143 beats per min) and maternal BP and HR were 135/64 mmHg and 88 beats per min, respectively (fig. 1, awake control 2).

Anesthesia was induced with thiopental 8 mg/kg iv administered in increments over 3–4 min, and vecuronium 0.25 mg/kg iv was administered to facilitate tracheal intubation. After induction of anesthesia, maternal BP decreased to 117/60 mmHg, and FHR demonstrated loss of variability and a gradual reduction to approximately 130 beats per min (fig. 1, postinduction). To blunt the pressor response to laryngoscopy and intubation, esmolol 2 mg/kg iv was administered as a bolus. Two minutes after the administration of esmolol, FHR was 125–128 beats per min (fig. 1, postinduction esmolol 1). Adequate visualization of the vocal cords was not achieved during the first attempt at laryngoscopy. Supplemental thiopental 1.5 mg/kg and esmolol 2 mg/kg iv were administered, repeat laryngoscopy performed, and the trachea successfully intubated. Peak values of maternal BP and HR after laryngoscopy and intubation were 136/81 mmHg and 88 beats per min, respectively, and FHR had decreased to approximately 120 beats per min (fig. 1, postinduction esmolol 2).

Anesthesia was maintained with isoflurane, fentanyl, and vecuronium. Surgical exposure was satisfactory, and the AVM was resected completely. Throughout anesthesia and surgery, FHR varied between 112 and 120 beats per min.

During closure of the surgical wound and emergence from general anesthesia, maternal BP was controlled with a combination of esmolol and nitroprusside infusions. Figure 2 indicates maternal BP and HR and contains representative tracings from the FHR monitor during the final 30 min of anesthesia and surgery, soon after maternal emergence and extubation, and during the 1st h in the recovery room. Maternal BP increased during surgical closure as the inspired concentration of isoflurane was gradually reduced. Maternal BP was initially controlled at 120/44 mmHg with nitroprusside 0.7 $\mu g \cdot kg^{-1} \cdot min^{-1}$. FHR at this time was approximately 120 beats per min (fig. 2, anesthetized control).

In response to increasing maternal BP, three iv bolus doses of esmolol, 500 μg/kg each, were administered over the next 4 min along with a continuous infusion of esmolol 150 $\mu g \cdot kg^{-1} \cdot min^{-1}$, and the nitroprusside infusion was increased to 1.8 $\mu g \cdot kg^{-1} \cdot min^{-1}$. Approximately 15 min after instituting esmolol therapy, FHR had decreased only slightly, from approximately 120 to 116 beats per min (fig. 2, anesthetized esmolol 1). After an additional 500 μg/kg bolus of esmolol and increase in esmolol and nitroprusside infusion rates to 200 and 2.5 $\mu g \cdot kg^{-1} \cdot min^{-1}$, respectively, FHR remained essentially unchanged (fig. 2, anesthetized esmolol 2).

The patient emerged from general anesthesia and the trachea was extubated in the operating room. Six minutes after emergence and extubation, the nitroprusside infusion was discontinued, hydralazine 20 mg iv was administered, and the esmolol infusion maintained at 200 $\mu g \cdot kg^{-1} \cdot min^{-1}$. FHR had increased slightly, to 120–122 beats per min at this time (fig. 2, postemergence).

The patient received morphine sulfate 4 mg iv soon after arrival in the recovery room for control of pain. Approximately 1 h after maternal emergence from anesthesia, FHR had gradually increased to 130–132 beats per min, and maternal BP remained controlled at 122/57 mmHg (fig. 2, recovery 1). The esmolol infusion was discontinued several minutes later, and a second dose of hydralazine, 20 mg iv, was administered. FHR increased to 132–137 beats per min after discontinuation of the esmolol infusion (fig. 2, recovery 2).

During the 37th week of pregnancy, the patient underwent an emergency cesarean section because of uterine rupture and fetal distress. A 2,880-g baby boy was delivered with 1- and 5-min Apgar scores of 2 and 7, respectively. Both mother and her son were well at last follow-up, 9 months later.

DISCUSSION

The effect of esmolol on FHR in humans has not been previously reported for its administration to patients with normal uteroplacental circulation. However, the effect of esmolol on fetal hemodynamics has been investigated in chronic sheep models by several investigators. Ostman and co-workers examined the transplacental passage and hemodynamic changes after administration of esmolol to gravid ewes.[3] After an infusion of esmolol 500 $\mu g \cdot kg^{-1} \cdot min^{-1}$ for 4 min and then 300 $\mu g \cdot kg^{-1} \cdot min^{-1}$ for 6 min, FHR and BP decreased maximally by 12 and 7%, respectively, while fetal acid–base parameters remained unaffected. The maximal reduction in maternal

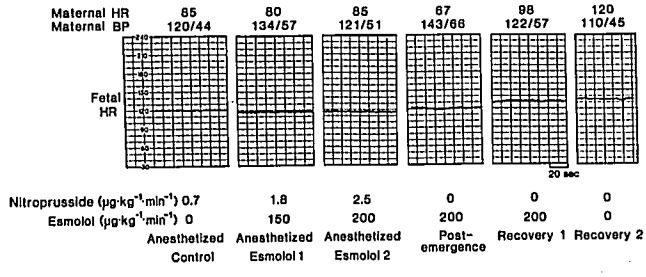

FIG. 2. The three panels on the left show control of maternal blood pressure (BP) with a combination of nitroprusside and esmolol during surgical closure. A small decrease in fetal heart rate (HR) occurs after the administration of esmolol. The three panels on the right reveal an increase in fetal HR after maternal emergence from anesthesia and discontinuation of the esmolol infusion.

mean arterial BP was 7%. At the completion of the infusion, the fetal-to-maternal blood concentration of esmolol was 0.13, and at 10 min after completion of the infusion, esmolol was undetectable in the fetus. FHR was not significantly different from its preinfusion control value at 15 min after the discontinuation of the esmolol infusion. The authors concluded that transplacental passage of esmolol was relatively small and that elimination from the fetus was rapid.[3]

In chronically instrumented pregnant ewes, Eisenach and Castro observed a dose-dependent decrease in maternal BP and FHR after 15-min stepped infusions of esmolol (4–200 $\mu g \cdot kg^{-1} \cdot min^{-1}$).[4] A maximal decrease in FHR of 27% and decrease in fetal arterial oxygen tension (Pa_{O_2}) from 18 to 14 mmHg and fetal *p*H from 7.37 to 7.31 occurred after the 200-$\mu g \cdot kg^{-1} \cdot min^{-1}$ infusion of esmolol. The maximum decrease in maternal mean arterial BP was 22% at the 200-$\mu g \cdot kg^{-1} \cdot min^{-1}$ infusion rate. In contrast to Ostman's study, FHR remained below control levels 30 minutes after termination of the esmolol infusion.

We had the opportunity to observe the effect of esmolol on FHR when administered to our patient under several circumstances. Prior to the administration of any anesthetic agents, FHR decreased less than 10 beats per min, or less than 7%, in response to the administration of four bolus doses of esmolol, 500 $\mu g/kg$ each, and a stepwise increase in esmolol infusion from 50 to 200 $\mu g \cdot kg^{-1} \cdot min^{-1}$ over the course of 10 min. Although maternal HR decreased from 94 to 79 beats per min after the administration of esmolol, maternal mean arterial BP was changed only minimally. FHR returned to near-control values within approximately 11 min after the termination of the esmolol infusion. This response is consistent with the animal data of Ostman and co-workers, who observed a similar reduction in FHR after a 10-min infusion of esmolol.[3]

During the induction of anesthesia, it is difficult to separate the effect of thiopental from that of esmolol on FHR. As seen in figure 1, there was a progressive reduction in FHR from approximately 140 to 120 beats per min after the administration of thiopental and esmolol (postinduction esmolol 2 *vs.* awake control 2). Thus, although there was a reduction in FHR, there was no evidence of severe fetal bradycardia after the administration of esmolol with thiopental for induction of anesthesia.

Based on their observations, Eisenach and Castro have suggested that a significant and prolonged reduction in FHR may occur with prolonged infusions of esmolol.[4] During emergence and recovery from anesthesia, our patient received four bolus doses of esmolol, 500 $\mu g/kg$ each, in addition to infusion of esmolol at 200 $\mu g \cdot kg^{-1} \cdot min^{-1}$ for more than 1 h. We observed a small reduction in FHR, less than 5 beats per min, after institution of the esmolol infusion (fig. 2, anesthetized esmolol 2 *vs.* anesthetized control). Despite the duration of the esmolol infusion, we observed no further decrease in FHR. However, undoubtedly there was a reduction in the depth of fetal anesthesia between the time that the esmolol infusion was initiated and terminated.

Compared to the longer-acting β-adrenergic antagonists, advantages to the use of esmolol are its much shorter duration of action and a lower lipid solubility,[5] which may result in reduced placental transfer. It has been suggested that maternal administration of β-adrenergic antagonists could, in theory, produce a significant reduction in FHR if sensitivity to β blockade is increased because of an immature fetal adrenergic system.[3] It must be noted that although we did not observe a FHR tracing suggestive of fetal distress after esmolol administration, we were unable to assess changes in fetal oxygenation and acid–base status. For this reason as well as the anecdotal nature of this report, the current case does not establish the safety of this drug in humans.

In conclusion, after the maternal administration of esmolol in bolus doses of up to 2 mg/kg and by continuous infusion of up to 200 $\mu g \cdot kg^{-1} \cdot min^{-1}$ in a patient in the second trimester of pregnancy, esmolol produced small decreases in FHR in a 350-g preterm fetus. Esmolol may be an appropriate adjunctive drug in the hemodynamic management of the pregnant patient with normal uteroplacental circulation. The response observed in this preterm fetus may well be different than that observed in the term fetus. Until additional data on esmolol in humans become available, it seems prudent to monitor FHR in pregnant patients receiving esmolol.

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