of different anaesthetic techniques for the individual patient in front of them.

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Umbilical artery flow monitoring with transesophageal echocardiography during maternal cardiac surgery

Pregnancy in women with mechanical prosthetic valves is associated with a high risk of maternal mortality due to valve thrombosis if anticoagulant use is irregular.[1] While cardiac surgical maternal risks are approximately the same as those in non-pregnant women, fetal mortality associated with cardiopulmonary bypass (CPB) can be up to 19%.[2,3] Fetal heart rate (FHR) monitoring using transesophageal echocardiography (TEE) has been reported in our institution, and end-diastolic velocity (EDV) is a more sensitive peri-operative fetal monitor than FHR.[4]

A 27-year-old patient (G_5P_0) at 30 weeks-of-gestation presented with severe aortic stenosis. She had undergone aortic valve replacement and ventricular septal defect (VSD) repair 15 years previously. She took warfarin irregularly, and had stopped taking all medications 10 months previously to conceive. She refused termination of pregnancy and was scheduled for aortic valve replacement.

Baseline blood pressure was 102/57 mmHg, heart rate was 84 beats/min. After positioning supine with left-lateral tilt of 30 degrees, general anesthesia was induced with 150 mg propofol, 70 mg rocuronium and 50 μg sufentanil. Anesthesia was maintained by continuous intravenous infusion of 4 mg/kg/h propofol, 3 μg/kg/min of cisatracurium, 0.4 μg/kg/min remifentanil and intermittent sufentanil when anesthesia depth decreased. A TEE probe was inserted, positioned at the deep gastric level and rotated until the placenta was seen and the umbilical artery was identified using color Doppler (Fig. 1a). Fetal heart rate was calculated and positive EDV could be observed by using the pulsed-wave Doppler signal (Fig. 1b).

Heparin was administered to achieve an active clotting time >480 s and normothermic CPB was established, at which point maternal blood pressure was 92/56 mmHg, heart rate was 85 beats/min while FHR was 120 beats/min with a positive EDV. As pump flow increased, EDV gradually disappeared, FHR remained unchanged, while maternal blood pressure was 79/45 mmHg and heart rate was 91 beats/min (Fig. 2a).

The fetal heart rate (FHR) significantly decreased following aortic-cross clamping since the pump flow was temporarily decreased (Fig. 2b). As mean arterial pressure (MAP) increased (from 54 to 74 mmHg), FHR also increased but with absence of end-diastolic velocity (AEDV) that persisted throughout the rest of the operation.

The operation continued without incident. As CPB was terminated, the patient's blood pressure was 100/60 mmHg and heart rate was 98 beats/min, the FHR had increased to 133 beats/min. The hemodynamic changes are summarized in Fig. 3.

The patient was then transferred to the cardiac intensive care unit where she stayed for one night with continuous cardiotocography monitoring and intermittent transabdominal ultrasound examination. Fetal heart rate was sustained at 140–150 beats/min and the EDV

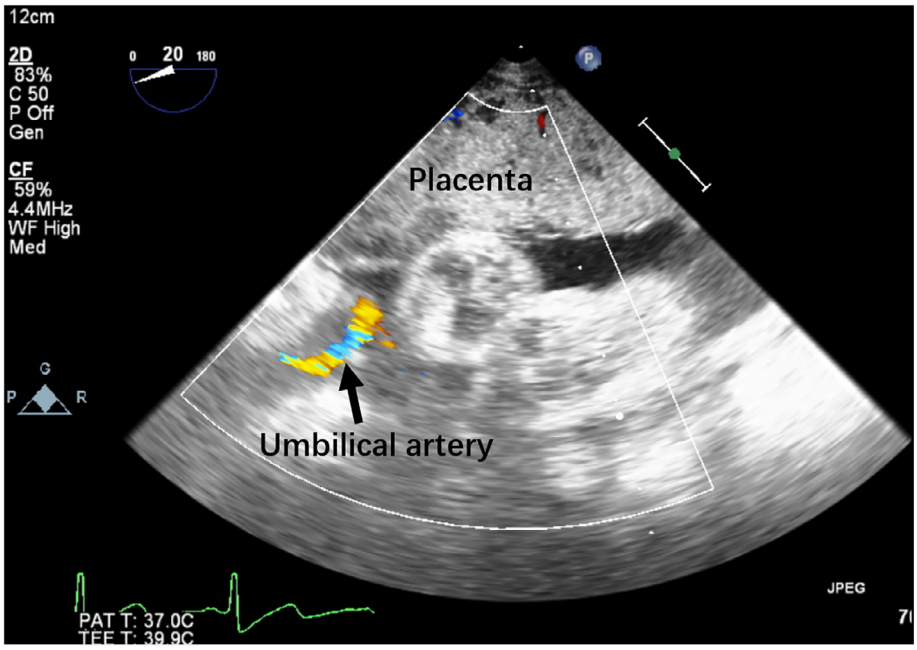

Fig. 1a Placenta seen and umbilical artery identified

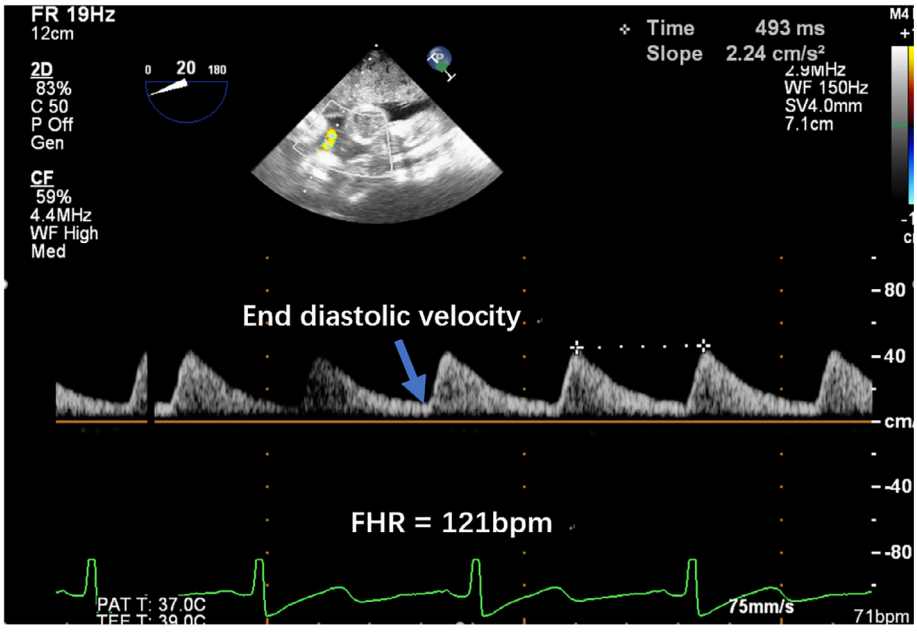

Fig. 1b Positive end diastolic volume was present in umbilical artery Doppler studies, fetal heart rate (FHR) was calculated

reappeared 4 h postoperatively. She was subsequently transferred to the general ward where she remained for another four days, with three-day continuous cardiotocography monitoring and intermittent FHR monitoring on the last day. She was then discharged home in good condition using warfarin for anticoagulation. Follow-up three days later was unremarkable, and cardiotocography monitoring was normal.

She was re-admitted at 34+2 weeks-of-pregnancy with decreased fetal movements for 15 hours. She underwent emergency cesarean delivery. Severely meconium-stained amniotic fluid was found and the fetus was born with Apgar scores of 2, 4, 4 at 1, 5 and 10 min respectively. Intracranial hemorrhage was confirmed by ultrasound on the neonatal intensive care unit and the baby died 20 h later.

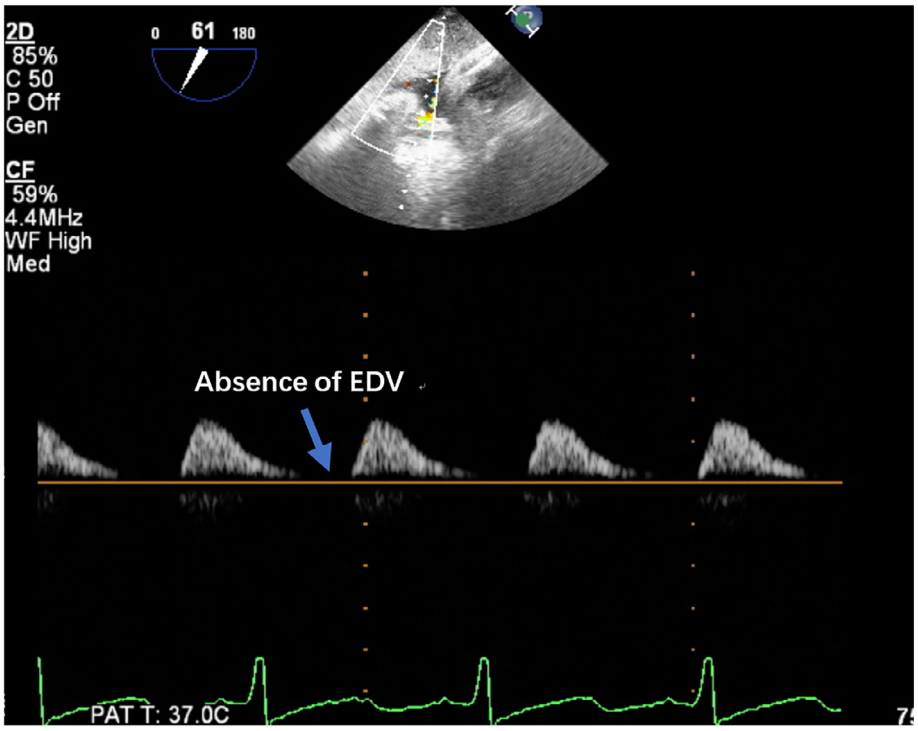

Fig. 2a As cardiopulmonarey bypass was initiated, the end-diastolic volume gradually disappeared while fetal heart rate was approximately unchanged

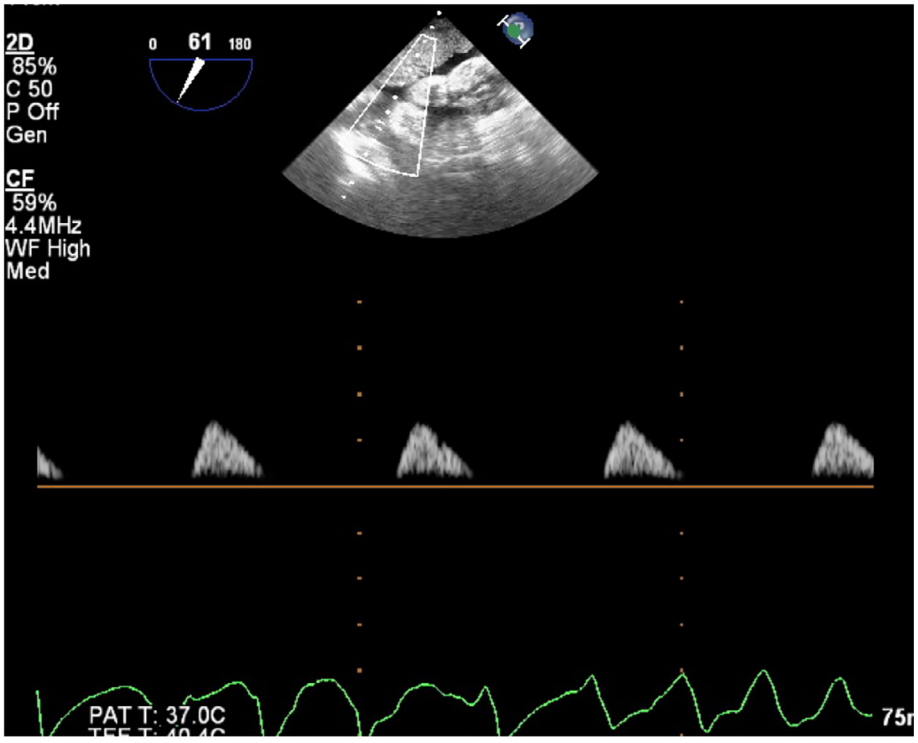

Fig. 2b Fetal heart rate dropped abruptly and significantly at the very beginning of aortic-cross clamping

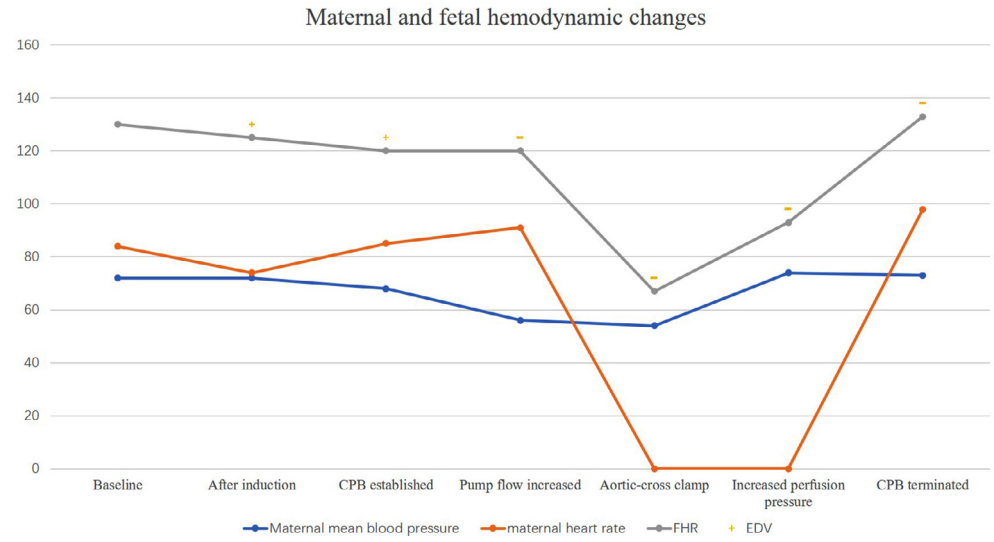

Fig. 3 Maternal and fetal hemodynamic changes. Where "+" means end-diastolic volume (EDV) was present and "−" means absence of end-diastolic volume (AEDV). CPB: cardiopulmonary bypass. FHR: fetal heart rate

For pregnant women undergoing non-obstetric surgery, fetal heart rate monitoring is recommended[5] as an indicator of fetal compromise.[6,7] Electronic fetal monitoring and ultrasound are used and although they have similar specificity, ultrasound has greater sensitivity.[8]

In this case, TEE in real time was used to detect changes in umbilical artery blood flow Doppler signals. Results were interpreted by a multi-disciplinary team including ultrasound physicians, obstetricians and fetal medicine specialists. Arterial flow waveform depends on the forward ejection of blood from the fetal heart, vessel elasticity and blood viscosity. During systole, blood velocity reaches a maximum after valve opening, whereas during diastole flow decelerates to the nadir (the EDV) when the cardiac contraction can no longer maintain forward flow against the elastic properties of the downstream vascular bed and the viscosity of the blood.

Umbilical arteries represent the downstream resistance of the placental circulation, since no somatic arteries arise from their origin, and their resistance is normally low. Placental dysfunction increases resistance and umbilical artery flow will fall and ultimately cease. If resistance rises further, the rigid placental circulation recoils after distension by pulse pressure and reversed end-diastolic flow occurs; fetal compromise increases as placental resistance increases. Absence of end-diastolic volume is a sign of fetal compromise and it may precede abnormal cardiotocography by up to 24 days.[8–10]

We found EDV measured using TEE may be a useful intra-operative monitor of fetal blood supply. Although FHR was within the normal range, AEDV was present (Fig. 2). Management included increasing maternal temperature and perfusion pressure, but although FHR increased, EDV did not recover. The association between decreased or absent EDV and short- or long-term fetal prognosis is unknown but AEDV is associated with intrauterine growth retardation[11] and growth-restricted fetuses prior to 34 weeks-of-gestation with AEDV are at increased risk of fetal death.[12]

Transesophageal echocardiography may represent a supplemental peri-operative fetal monitor, and EDV monitoring may detect abnormalities with the potential to improve fetal outcome in cardiac surgery during pregnancy.

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Peri-operative considerations for in utero repair of myelomeningocele

Myelomeningocele (MMC), the most severe form of spina bifida, occurs in approximately 1 in 1000–2000 births and is associated with significant disability and morbidity.[1] A randomized trial published on 2011 (the MOMS trial) changed clinical practice by showing that open fetal surgery of MMC, conducted between 19 and 26 weeks' gestation, improved a number of important outcomes, but was associated with maternal and fetal risks.[2] Prenatal repair decreased the rate of death or the need for a shunt at 12 months of age, decreased the rate of hindbrain herniation, doubled the rate of the ability to walk independently, and produced a level of function that was two or more levels better than expected according to anatomic levels. However, prenatal surgery increased the risks of preterm birth, placental abruption, pulmonary edema, and uterine thinning or dehiscence at the uterine scar.[3–6] Open fetal surgery is a complex and invasive procedure for the mother and the fetus that requires general anesthesia and invasive hemodynamic monitoring.[7] It is not known as yet what is the best anesthetic technique for these cases. Experience in ex-utero intrapartum (EXIT) fetal surgery can be exploited regarding techniques for uterine relaxation.[8]

A successful outcome requires a multidisciplinary approach and several topics need to be taken into consideration. These include uterine relaxation, fetal and maternal anesthesia, a latex-free environment (avoiding a first lifetime exposure) and fetal neuroprotection to reduce the potential consequences of preterm birth.

We wish to describe the case of a 38-year-old, gravida 3 and para 2, American Society of Anesthesiologists class II patient, who had a prenatal diagnosis of MMC (at L5) with moderate ventriculomegaly (13 mm); an Arnold Chiari malformation type II; and normal karyotype. After maternal counseling, informed consent was obtained and the patient underwent open fetal surgery at 25+3 weeks' gestation. A magnetic resonance image at 29+4 weeks' gestation showed that the Arnold Chiari malformation had disappeared: the rest of the pregnancy was uneventful. A cesarean delivery was performed at 36 weeks' gestation because of spontaneous uterine contractions. The newborn weighed 2750 g; had Apgar scores of 7 and 8; and he was able to move his lower limbs, with no need for a ventricular valve or neonatal MMC surgery. A multimodal approach was performed using nitroglycerin and sevoflurane as the main drugs for intra-operative uterine relaxation; using atosiban instead of magnesium sulfate at the end of surgery (based on better efficacy, without maternal complications)[9] and indomethacin to prevent preterm birth. This strategy could be useful to reduce exposure of the fetus to high concentrations of halogenated agents, while providing good operating conditions, taking into consideration a late-2016 United States of America Food and Drug Administration alert regarding the potential for damaged brain development in children exposed to certain general anesthetic agents in the third trimester of pregnancy. Multimodal uterine relaxation captures the effectiveness of individual agents in optimal dosages and attempts to minimize side effects. This approach promotes the concept that agents with different mechanisms of action may have synergistic uterine relaxation effects when used in combination. It should be further validated with controlled randomized trials, although they would be challenging.

Rapid sequence intubation was performed using fentanyl, propofol and rocuronium. Anesthesia maintenance was achieved by target-controlled infusion of remifentanil, sevoflurane and fentanyl. Bispectral index was used to monitor depth of anesthesia. As there is a known risk of pulmonary edema, advanced hemodynamic monitoring equipment was used to estimate systolic volume variation for a restrictive goal-directed fluid therapy strategy. Norepinephrine was used to maintain maternal blood pressure. Additional drugs were needed for fetal anesthesia and immobilization: