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Percutaneous fetal access and uterine closure for fetoscopic surgery

Lessons learned from 16 consecutive procedures in pregnant sheep

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Abstract
Background: Maternal morbidity and preterm labor from fetal surgery might be minimized by a percutaneous technique for fetal access and uterine closure.
Methods: In each of 16 ewes, we inserted three trocars percutaneously into the amniotic cavity using ultrasound and fetoscopic guidance. In six ewes, percutaneous uterine closure after the procedure was attempted. We assessed feasibility and acute complications of our technique during surgery and at autopsy.
Results: We achieved percutaneous fetal access in 14 ewes and closed the uterus percutaneously in all six ewes attempted. Fetal injury was related to amnioinfusion or fixation of chorioamniotic membranes. Other complications were trocar dislodgment and damage to uterine wall and chorioamniotic membranes. The latter complication was prevented using balloon-tipped trocars.
Conclusions: Percutaneous intraamniotic access and uterine closure for fetoscopic surgery can be achieved reliably with little maternal and fetal morbidity in sheep. Minor modifications are desired to apply this approach in humans.

Key words: Fetoscopy — Fetal surgery — Percutaneous fetal access — Uterine closure — Sheep

Despite remarkable advances in the development of open fetal surgery, the suppression of preterm labor after hysterotomy remains the main obstacle for this approach in human fetuses [1]. Conversely, fetoscopic operative approaches have the potential to reduce the incidence of preterm labor because fetal access is achieved by maternal laparotomy and transuterine trocar placement via small uterine incisions [2–4].

The development of a solely percutaneous technique not requiring maternal laparotomy should even further decrease maternal morbidity from fetoscopic surgery. Therefore, the purpose of this experimental study was to assess the feasibility and acute complications of percutaneous fetal access and uterine closure for fetoscopic surgery in pregnant sheep.

Methods

Surgical preparation

We studied the feasibility and acute complications of percutaneous fetal access and uterine closure in a total of 16 ewes between 86 and 121 days of gestation (term = 145 days). The study protocol had been approved by the local Committee on Animal Research and was performed according to institutional guidelines. We sedated each ewe with an intramuscular injection of ketamine hydrochloride (10–20 mg/kg) and intubated and administered general anesthesia with 0.5–2.0% halothane and 100% oxygen. We positioned the ewe supine and performed a detailed transabdominal ultrasound study (Sonos 1500, Hewlett-Packard, Palo Alto, CA) to determine fetal number and position, amniotic fluid volume, as well as the fetal abdominal insertion site and placental origin of the umbilical cord.

Amnioinfusion

If the amniotic fluid volume was judged too small to permit safe placement of the initial trocar, we performed amnioinfusion with saline. Under ultrasound guidance, we inserted an 18-gauge needle into the amniotic cavity and confirmed free intraamniotic needle position by unhindered amniotic fluid withdrawal and injection of a small amount of air. We then infused 500–800 ml warm normal saline at rates of approximately 150 ml/min into the amniotic cavity until a satisfactory amniotic fluid pocket was obtained.

Trocar insertion

In each animal, we inserted three 5-mm trocars into the amniotic cavity. In order to enter the amniotic sac during trocar insertion, the chorioamniotic membranes were fixed to the uterine wall with T-fasteners (Ross Product Division-Abbot Laboratories, Columbus, OH). We then incised the maternal skin and fascia 3–5 mm in the center of the exit sites of the T-fastener

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sutures. While pulling up on the sutures, we inserted the trocar through the small incision into the amniotic cavity. The trocars were secured inside the amniotic cavity by either a radially dilating balloon (Entec Corporation, Madison, CT) or flanges (Dexide Inc., Forth Worth, TX) attached to the trocar tip.

We monitored the insertion of the initial T-fasteners and trocar with transabdominal ultrasound (Fig. 1) and placement of subsequent devices under direct observation with a 5-mm, 0° fetoscope connected to a xenon light source (Karl Storz, Culver City, CA) (Fig. 2). In order to prevent injury to maternal intraabdominal contents and uterine vessels, we improved the visibility of trocar insertion by low pressure (4–8 cm H_2O) gaseous insufflation of the amniotic cavity and transillumination of the uterine and abdominal walls.

Uterine closure

In six ewes, we assessed a method of percutaneous uterine closure of the trocar insertion sites after completion of our operations (Fig. 3). We disengaged the trocars, withdrew them from the amniotic cavity into the maternal abdomen, and engaged them again. We then insufflated the maternal abdomen and released the T-fastener sutures into the maternal abdomen. We closed the uterine trocar insertion sites by tying the T-fastener sutures across the wall defect with laparoscopic instruments. After uterine closure, we removed the trocars from the abdominal cavity and closed the abdominal trocar insertion sites with simple interrupted sutures.

Study variables

We recorded the number of animals in which percutaneous fetal access was successful and inspected the maternal abdomen for bleeding or injury to other organs. We assessed adverse fetal effects from amnioinfusion or T-fastener insertion and determined the incidence and etiology of trocar dislodgment during a fetoscopic procedure.

After completion of our study, we sacrificed the ewes with pentobarbital overdose. At autopsy, we examined the uterine trocar insertion sites for injury to the uterine wall and integrity of the chorioamniotic membranes. In the six ewes in which uterine closure after fetoscopic surgery was tested, we assessed the trocar insertion sites for intraabdominal or transvaginal amniotic fluid leakage by direct observation and transabdominal ultrasound.

Results

We performed successful percutaneous fetal access in 14 of the 16 ewes (87.5%) and inserted a total of 42 trocars (three trocars per ewe) into the amniotic cavity without chorioamniotic membrane separation. We did not observe injuries to maternal viscera or significant bleeding complications in mother or fetus from percutaneous fetal access or uterine closure.

Amnioinfusion and T-fastener insertion

To facilitate trocar insertion we performed amnioinfusion in 11 of the 15 ewes (73.3%) and observed complications from this procedure in one fetus. Despite having confirmed a free intraamniotic needle position by ultrasound, saline was injected into a hindleg of this fetus.

In three studies, we punctured fetal parts during ultrasound-guided T-fastener insertion (3/42 T-fasteners = 7.1%). In two studies, we inserted a T-fastener into a fetal hindleg (Fig. 4). In one of our early studies, one T-fastener was inserted into the fetal abdomen resulting in perforation of the abdominal wall during ultrasound-guided placement of the first trocar (1/42 trocars = 2.4%). However, there was no injury to fetal abdominal contents. Once percutaneous access was established, the malpositioned T-fasteners were recovered without difficulty.

Trocar insertion

During the 16 procedures, we inserted a total of 27 balloon-tipped trocars in nine ewes and a total of 15 flanged trocars in five ewes (three trocars per ewe). During three procedures, intrauterine manipulation with laparoscopic instruments resulted in balloon rupture of one of the balloon-tipped trocars (3/27 balloon-tipped trocars = 11.1%). In one of these procedures, the trocar dislodged from the amniotic cavity into the maternal abdomen, thus deflating the amniotic cavity. As a result, we had to abandon the fetoscopic approach. In the other two cases of balloon rupture, we exchanged the trocars without jeopardizing the fetoscopic approach.

In five ewes, manipulation of the flanged trocars resulted in notable damage to the uterine wall and tearing of the chorioamniotic membranes. In three of these ewes, the chorioamniotic membranes separated from the uterine wall and slipped off the trocar tip, interfering with intraamniotic instrument insertion and insufflation. Conversely, we did not observe damage to the uterine wall or chorioamniotic membranes from manipulation of balloon-tipped trocars.

In two ewes, insertion of one trocar (2/42 trocars = 4.8%) resulted in bleeding of small cotyledonal vessels into the chorioamniotic space and hematoma formation. At autopsy about 20 cc of blood was recovered from the chorioamniotic space in each case.

We failed to achieve satisfactory percutaneous fetal access and had to convert to an open operative approach in two ewes. In the first ewe, we placed the initial trocar into the chorioamniotic space and were not able to advance the device farther into the amniotic cavity. To avoid further chorioamniotic membrane separation, we performed maternal laparotomy, and placed all trocars into the exteriorized uterus. In the second ewe, although we placed the initial trocar into the amniotic cavity, fetal visualization and surgical manipulation were prevented by a large intraamniotic membrane. This membrane had not been appreciated at the initial ultrasound study and also necessitated conversion to the open operative approach.

Uterine closure

We closed the uterine trocar insertion sites percutaneously by tying the T-fastener sutures across the trocar insertion sites in all of the six ewes in which this approach was tested. In two of these ewes, the T-fasteners were inserted through the major omentum which we subsequently tied onto the external uterine wall. The six ewes were allowed to continue gestation for 1 day to 2 weeks before elective termination. During this period we did not observe intraabdominal or transvaginal amniotic fluid loss as assessed by transabdominal ultrasound and daily observation.

Discussion

This study in pregnant sheep demonstrates that after an initial learning phase percutaneous fetal access and uterine

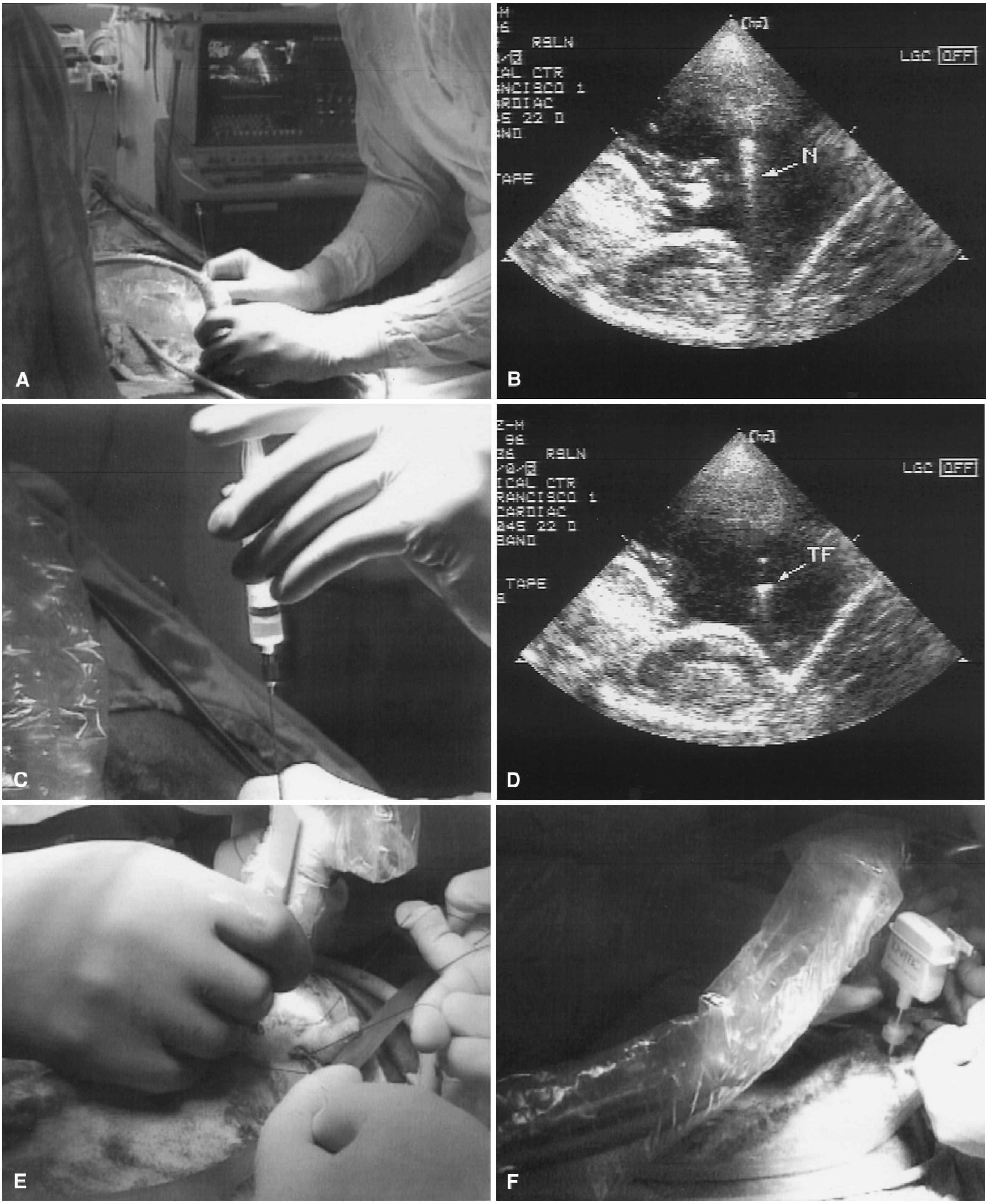
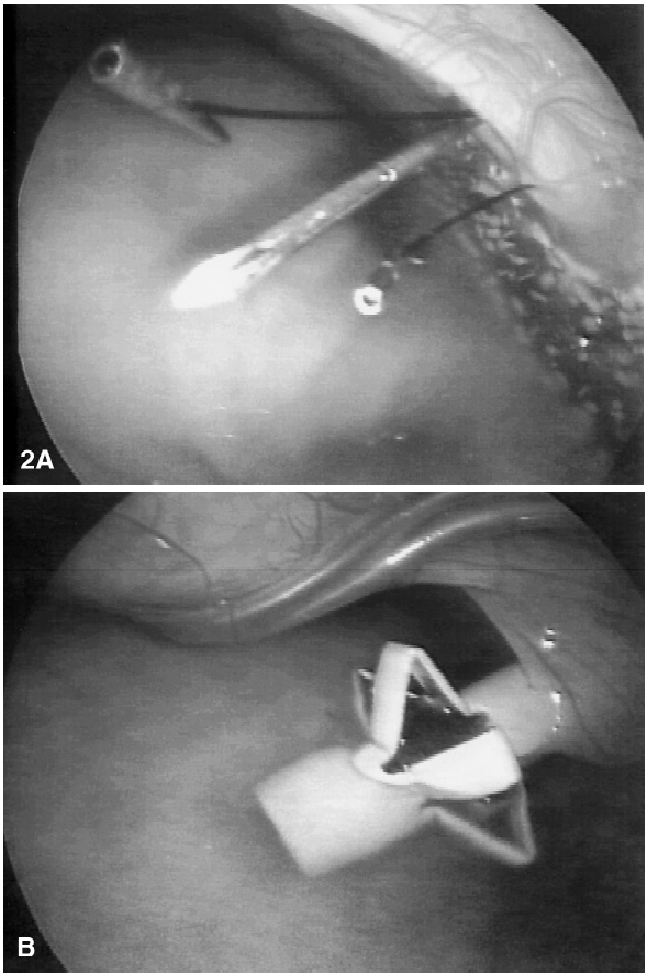


Fig. 1. Ultrasound-guided insertion of initial T-fasteners and trocar (A). To prevent chorioamniotic membrane separation during trocar insertion, the membranes were fixed to the uterine wall using T-fasteners released from an 18-gauge needle. The needle (*N*) can be recognized inside the amniotic cavity (B). Appropriate intraamniotic needle position was confirmed with amniotic fluid withdrawal and air injection (C) before the T-fastener (*TF*) is released (D). Then the maternal skin and fascia were incised 3–5 mm in the center of the exit sites of the T-fastener sutures (E). While pulling up on the sutures, the trocar was inserted into the small incision (F). The trocars were secured in the amniotic cavity by either a radially dilating balloon or flanges attached to the trocar tip.



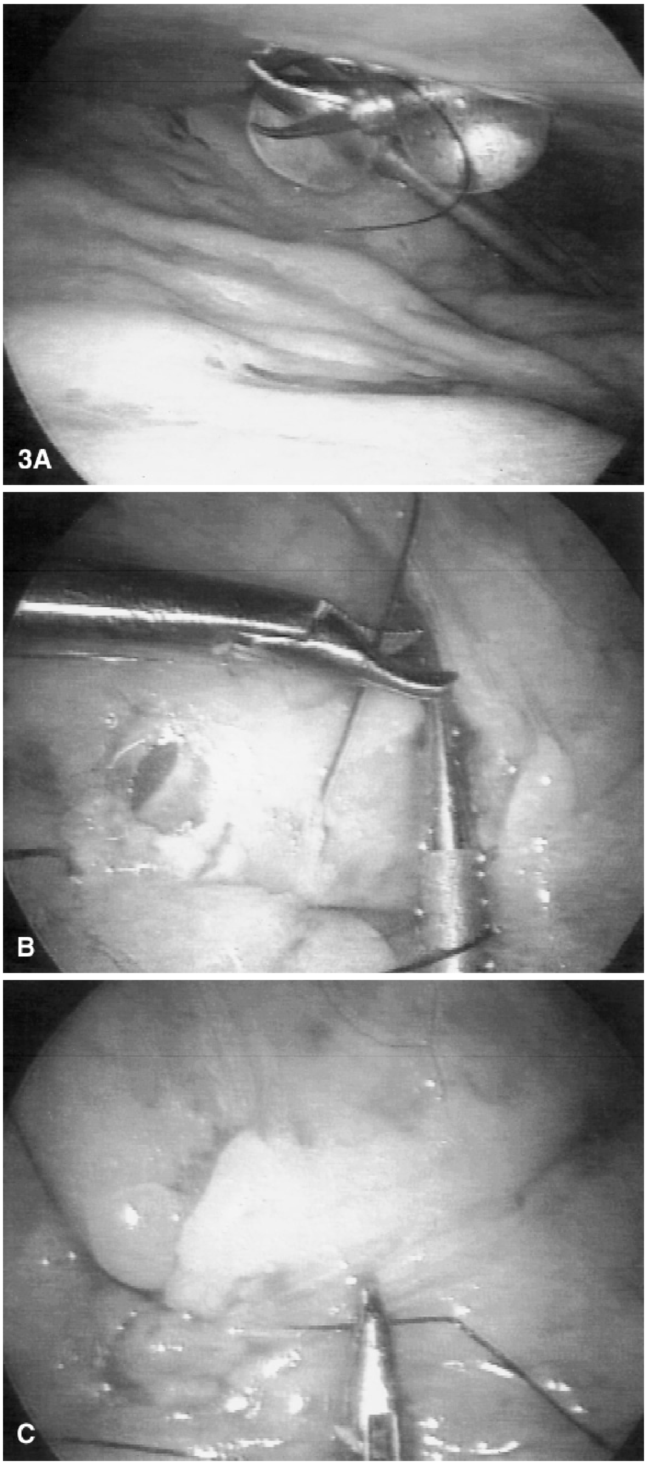


Fig. 2. Fetoscopy-guided insertion of T-fasteners and trocar. Whereas the insertion of the initial T-fasteners and trocar were monitored with transabdominal ultrasound, insertion of subsequent devices was accomplished under direct observation with a 5-mm, 0° fetoscope connected to a xenon light source. Two T-fasteners, the 18-gauge needle (A) and an expanded 5-mm flanged trocar (B), can be recognized inside the amniotic cavity. In order to prevent injury to maternal intraabdominal contents and uterine vessels, low-pressure gaseous insufflation of the amniotic cavity and transillumination of the uterine and abdominal walls were performed.

Fig. 3. Percutaneous uterine closure of the trocar insertion sites after completion of the operations. The trocars are disengaged, withdrawn from the amniotic cavity into the maternal abdomen, and engaged again (A). The maternal abdomen is insufflated and the T-fastener sutures are released into the maternal abdomen. Uterine closure is achieved by tying the T-fastener sutures across the uterine trocar insertion sites with laparoscopic instruments (B). After closure of all trocar insertion sites (C), the trocars are removed from the abdominal cavity and the abdominal trocar insertion sites are closed with a single stitch.

closure for fetoscopic surgery can be achieved reliably with little maternal and fetal morbidity. The percutaneous approach can be readily applied to various animal models to advance fetal surgery from open to percutaneous fetoscopic procedures; only a minor technical modification (i.e., absorbable T-fasteners) is desired to utilize this approach in humans. In those, the percutaneous approach should substantially decrease maternal morbidity from fetal surgical procedures since laparotomy and hysterotomy are not required. As a consequence, percutaneous fetal access may also result in less preterm labor and premature delivery than the open operative approach.

Technique of percutaneous fetal access

Intraoperative maternal transabdominal ultrasound monitoring, T-fastener fixation of the chorioamniotic membranes, and trocars that can be engaged in the amniotic cavity were

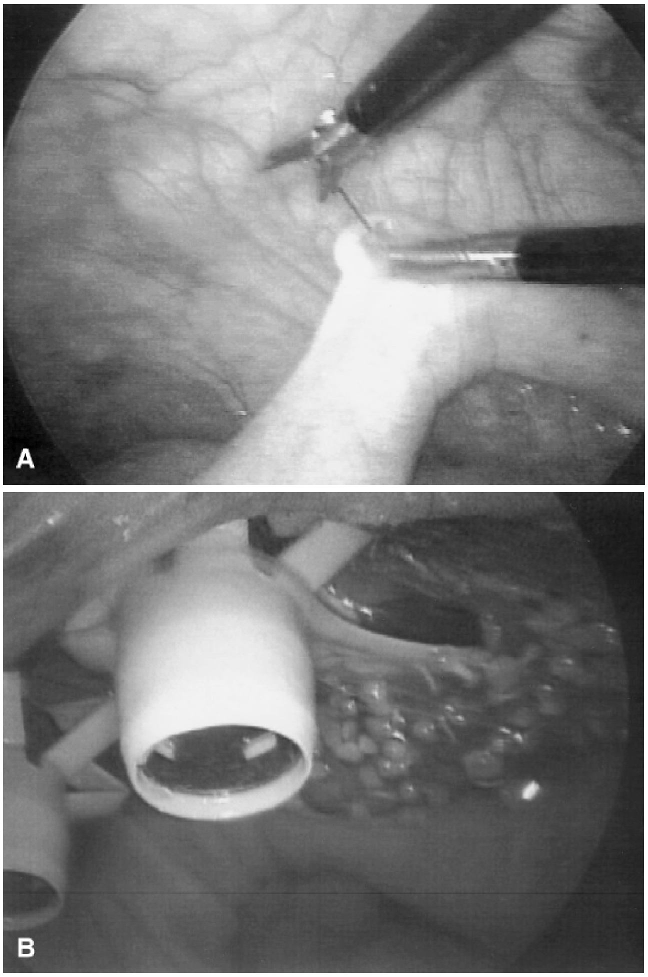


Fig. 4. Complications of percutaneous fetal access. In two studies, fetal limbs were punctured during ultrasound-guided T-fastener insertion. (A) shows a T-fastener inserted into a fetal hindleg. Once the percutaneous fetal access was established, the malpositioned T-fasteners were easily recovered. In five ewes, manipulation of a trocar with radially expanding flanges resulted in notable damage to the uterine wall and tearing of the chorioamniotic membranes (B). In three of these ewes, the chorioamniotic membranes slipped off the trocar tip and subsequently interfered with intraamniotic instrument insertion and insufflation. We did not observe this complication with the use of balloon-tipped trocars in subsequent procedures.

the prerequisites for our technique. Successful insertion of the initial T-fasteners and trocar depends on the identification of a sufficiently large pocket of amniotic fluid; the accurate definition of fetal lie by maternal transabdominal ultrasound permits selection of the most strategic insertion site if several adequate pockets are available. Amnioinfusion is commonly required to increase the size of amniotic fluid pockets.

Careful ultrasound examination prior to insertion of the initial T-fasteners and trocar is important to recognize any membranes dividing the amniotic cavity. Failure to appreciate amniotic cavity septation may result in unfavorable intraamniotic or extraamniotic position of the initial trocar and can necessitate conversion to an open operative approach. Augmenting intramniotic fluid volume and shifting of fetal position, however, may provide alternative entry sites for the initial trocar in the presence of amniotic cavity septation.

To avoid larger maternal or fetal vessels underneath the insertion sites, Doppler color flow mapping with low Nyquist limits during ultrasound-guided T-fastener and trocar insertion is useful. Once the initial trocar is placed into the amniotic cavity, direct fetoscopic observation and transillumination of the uterine and maternal abdominal walls with the fetoscopic light source serve the same purpose. Nevertheless, small uterine and placental vessels may not be avoided. Despite Doppler color flow mapping and direct fetoscopic observation, trocar insertion resulted in bleeding of small cotyledonal vessels into the chorioamniotic space and hematoma formation during two of our procedures. This minor complication is invited by the architecture of the ovine placenta with cotyledons scattered over the interior uterine wall and may not be encountered in humans in whom the placenta is localized.

Feasibility and complications of percutaneous fetal access during a surgical procedure

During our operations, the percutaneously placed trocars did not need to be supported by an assistant because they were stabilized by the abdominal wall. This advantage is lost if the percutaneous setup cannot be achieved and the trocars need to be placed into the exteriorized uterus.

Whereas avoidance of chorioamniotic membrane separation is the key to successful percutaneous fetal access, this complication can result from trocar manipulation during the actual operation. In three of five studies, intraoperative manipulation of flanged trocars resulted in notable damage to the uterine wall and chorioamniotic membranes. The membranes separated from the uterine wall, slipped off the trocar tip, and interfered with instrument insertion or insufflation. This complication was prevented by balloon-tipped trocars in subsequent procedures. The broad, soft base of the balloon protects the uterine wall and chorioamniotic membranes by distributing shear stress and traction forces from instrument manipulation over a larger uterine surface area. Yet the balloon-tipped trocars are prone to balloon rupture, which was observed during three of nine procedures in which these trocars were used. This complication resulted in loss of the percutaneous fetoscopic setup in one case, necessitating conversion to an open operative approach. Despite the risk of balloon rupture, we currently favor balloon-tipped trocars because they were less traumatic in our study, and we recommend frequent balloon assessment during the procedure.

Feasibility and complications of percutaneous uterine closure after fetoscopic surgery

In tying the T-fastener sutures across the uterine trocar insertion sites utilizing laparoscopy, we found a novel and effective method for percutaneous closure of the uterus. We did not observe postoperative intraabdominal or transvaginal amniotic fluid leakage using this technique. Leakage, however, was commonly observed in earlier experiments of our group when 5–10-mm trocars were removed without closing their insertion sites.

Limitations of percutaneous fetal access and uterine closure

Our study is limited to the assessment of acute complications from percutaneous fetal access and uterine closure in sheep. Because the ovine uterus is remarkably resistant to preterm labor, we cannot extrapolate the incidence of postoperative preterm labor and premature delivery that may arise from our approach in humans. However, a recent study in rhesus monkeys has shown that preterm labor is remarkably reduced after maternal laparotomy and endoscopic access for fetal surgery even in the absence of tokolysis [3, 5]. A similarly favorable result might be expected for the even less invasive percutaneous approach.

To perform percutaneous fetal access and uterine closure in humans, the placenta ought to be located posteriorly. In case of an anterior placenta, laparotomy and transuterine placement of the trocars may be required for safe trocar insertion. In addition, absorbable T-fasteners are desired to avoid foreign body retention.

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