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Access Techniques in Endoscopic Fetal Surgery^{*}, ^{**}

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Summary

Endoscopic surgery may in the future become an attractive alternative to open fetal surgery. Herein, we present our evolving experience with minimal access techniques in sheep and nonhuman primate models. Fifty-two pregnant sheep (term = 145 d) were used. All underwent laparotomy. Cannulas were 5 mm diameter with balloon fixation device. In group I (95–105 d, n = 22, and 70–74 d, n = 19), a total of 119 cannulas were placed by open hysterotomy and purse-string suture through myometrium and membranes. In group II (n = 11), access was obtained by *Seldinger* guidewire technique. Eight cannulas were introduced over a dilator and 7 were radially expanding endoscopic cannulas. Fifteen cannulas were also placed in 5 pregnant Rhesus monkeys using *Seldinger* and radially expanding techniques. Cannula removal was followed by insertion of a collagen sponge plug and oversewing of the myometrium. Mini-hysterotomies with purse-stringing provided excellent access to the amniotic cavity, without dissection of the membranes. Classic

Seldinger technique with forward dilatation was equally effective, but caused stretching of membranes. In sheep and in primates, *Seldinger* technique with radial dilatation allowed safe access without membrane separation. Leak-proof removal of the cannulas was achieved in all primates. Open hysterotomy with purse-string and balloon-tipped cannula provides efficient and safe access to the gravid sheep uterus. *Seldinger* technique allows equally secure access, and alleviates the need for hysterotomies. Radial dilatation of the porthole eliminates forward dissection of the membranes, both in sheep and primate models. This method, and collagen plug insertion upon completion of the endoscopic procedure, may provide a truly minimally invasive approach to in-utero surgery.

Key words: Fetal surgery – Endoscopy – Access – Sheep – Primates

Résumé

L'endochirurgie offre une alternative intéressante à la chirurgie foetale «open». La présente étude résume l'évolution des voies d'accès endoscopique chez le mouton et le singe. Cinquante-deux brebis enceintes (terme = 145 j) furent utilisées. Toutes subirent une laparotomie. Les canules, toutes de 5 mm, étaient munies d'un ballonnet. Dans le groupe I (22 brebis à 95–105 j, 19 brebis à 70–74 j), 119 canules au total furent placées par hystérotomie et fixé par un point en bourse incluant le myomètre et les membranes. Dans le groupe II (n = 11), la méthode par fil guide de *Seldinger* fut utilisée. Huit canules furent introduites sur un dilateur interne, et sept étaient munies d'un système d'expansion radiale. Enfin, 15 canules furent placées chez 5 guenons rhesus par méthode de *Seldinger* avec expansion radiale. Lors de l'extraction de chaque canule, un bouchon de collagène fut introduit, suivi d'un point en Z pour le myomètre. L'endoscopie utérine «open», avec point en bourse, permit un accès étanche sans décollement des membranes. L'approche par fil guide et dilatation antérograde fut aussi efficace, mais causa un étirement des membranes. La technique de *Seldinger* avec dilatation radiale permit un accès atraumatique et étanche, tant chez le mouton que chez le primate. L'approche la plus sûre en endoscopie foetale est l'insertion de canules à ballonnet par voie «open». La méthode de *Seldinger* permet d'éviter l'hystérotomie. Avec une dilatation

radiale, plutôt qu'antérograde, aucun décollement des membranes n'est observé. Ceci, et l'utilisation de bouchons de collagène pour garantir l'étanchéité lors de l'extraction des canules, devrait permettre une approche micro-invasive de la chirurgie in utero.

Mots-clés: Chirurgie foetale – Endoscopie – Accès – Mouton – Primate

Zusammenfassung

Endoskopische Fetalchirurgie könnte in der Zukunft die offene Fetalchirurgie in einigen Bereichen ersetzen: Wir berichten hier von unserer zunehmenden Erfahrung mit dieser minimal-invasiven Technik im Tiermodell (Schaf und Affe). 52 schwangere Schafe (normale Schwangerschaftsdauer 145 Tage) wurden laparotomiert und Kanülen von 5 mm Durchmesser mit einer Ballonfixation mittels unterschiedlicher Zugänge intrauterin eingebracht. In Gruppe I (SSD 95–105 Tg., n = 22; SSD 70–74 Tg., n = 19) wurden insgesamt 119 Kanülen durch offene Hysterotomie mit Naht der Amnionhüllen und des Myometrium eingebracht. In Gruppe II (n = 11) wurden der Zugang mittels *Seldinger*-Technik gewählt. 8 Kanülen wurden mittels eines nach vorne gerichteten Dilators, 7 durch radial dehnende endoskopische Kanülen eingeführt. In einer zweiten Studie wurden auch bei

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5 schwangeren Rhesus-Affen die *Seldinger*-Technik eingesetzt. Nach Entfernung der Kanülen erfolgte der Verschluss durch Einbringen einer kollagenen Schwammplombe und Übernähtung des Myometriums. Die Mini-Hysterotomie mit einer Tabaksbeutelnaht ermöglicht einen guten Zugang zur Amnionhöhle ohne Durchtrennung der Amnionhüllen. Die klassische *Seldinger*-Technik nach Dilatation war ebenso effektiv, wobei jedoch die Amnionhüllen mit gedehnt wurden. Die *Seldinger*-Technik mittels radialer Dilatation hingegen erlaubt einen Zugang ohne Erweiterung der Amnionhüllen. Leak-freies Entfernen der Kanülen konnte in allen Primaten erreicht werden. Sowohl die offene Hysterotomie mit Tabaksbeutelnaht als auch der Ballonkatheter-Einsatz erlauben beide einen effizienten und sicheren Zugang zum graviden Schafuterus. Die *Seldinger*-Technik erlaubt, bei gleicher Sicherheit im Zugang, die Vermeidung der Hysterotomie. Die radiale Dilatation des Einstichloches eliminiert die Dissektion der Membranen, sowohl beim Schaf als auch beim Primaten. Diese Methode – in Kombination mit einer Kollagen-Plombe nach Beendigung der Endoskopie – stellt somit einen echten minimal-invasiven Ansatz zur intrauterinen Fetalchirurgie dar.

Schlüsselwörter: Fetalchirurgie – Endoskopie – Zugang – Schaf – Affe

Introduction

Endoscopic surgery may in the future become an attractive alternative to open fetal surgery (5, 9). To that end, animal models have to be designed that establish safe access, work medium (10), instruments and techniques of endoscopic fetal surgery (5, 11, 12). Herein, we present our evolving experience with the technique of minimal access to the gravid uterus in sheep and nonhuman primates.

Technique

Sheep

A total of 52 time-dated pregnant ewes (term = 145 days) were used. Anesthetic and operative techniques have been described in detail elsewhere (3, 11, 12). Briefly, the animals were premedicated with atropine (10 mcg/kg) and xylazine (0.4 mg/kg) i.m., and placed under general endotracheal anesthesia with halothane 1.5–3.0% in 100% oxygen after ketamine induction (15 mg/kg i.v.). A midline laparotomy was performed, and a gravid uterine horn was exteriorized. Access to the amniotic cavity was achieved in one of two ways: early in our experience, a purse-string technique was used (group I). This was later refined to a modified *Seldinger* technique without the need for hysterotomy (group II).

Purse-string access technique

Group I consisted of 41 ewes at two gestational ages: fetuses were either 95–105 days ($n = 22$) or 70–74 days ($n = 19$). An area devoid of placental cotyledones was chosen, on the convex aspect of the uterine horn. A 1 cm incision was made in the myometrium with electrocautery, allowing chorionic and amniotic membranes to protrude. The two membranes were opened while the uterus was stabilized to minimize spillage of amniotic fluid. A purse-string suture (2-0 polypropylene) was placed through the myometrium and both membranes, and a balloon cannula was introduced into the amniotic cavity. The balloon was inflated, and the suture was cinched down with a hemostatic clamp over a rubber shod (Fig. 1).

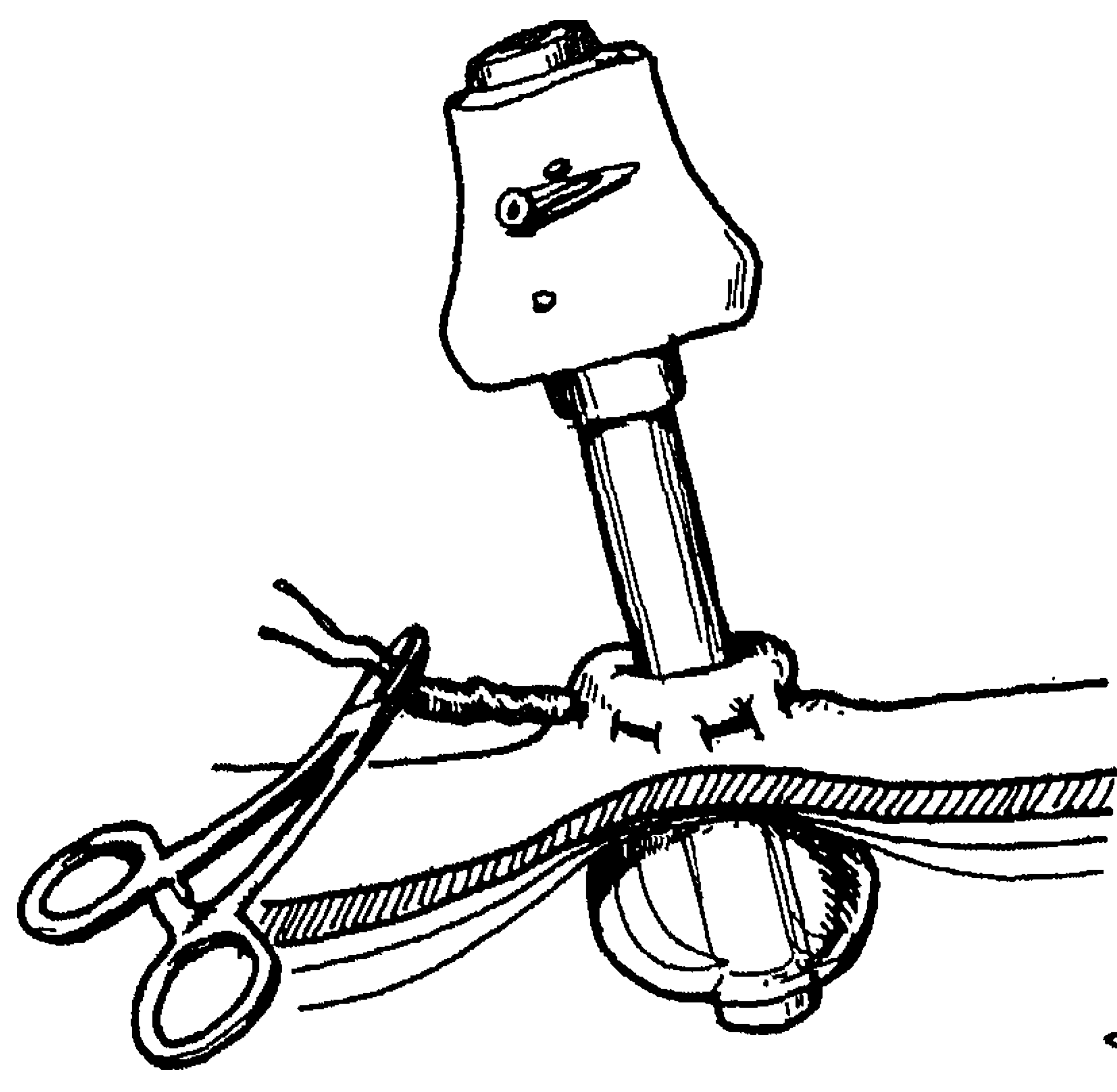


Fig. 1 Purse-string hysterotomy.

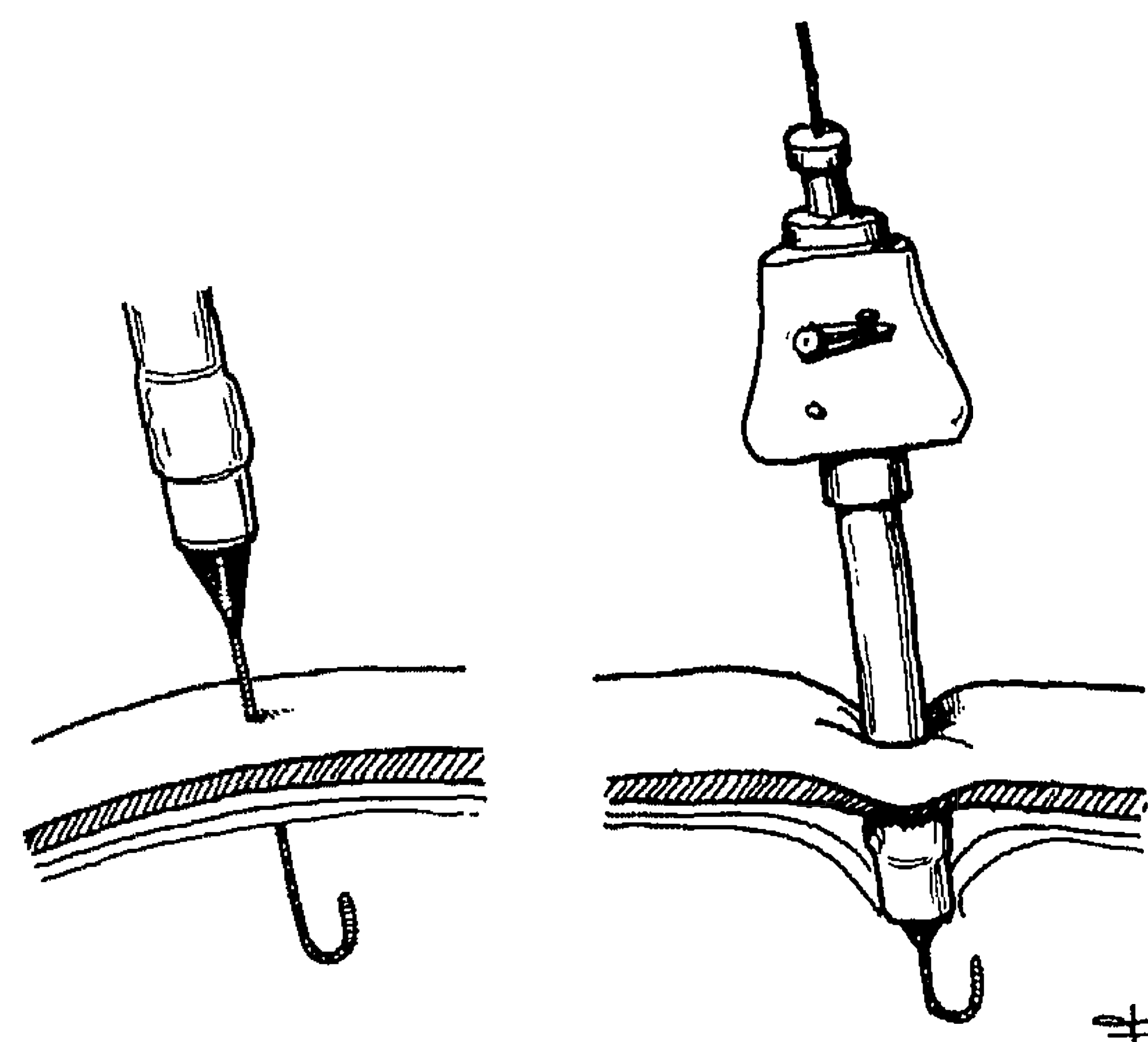


Fig. 2 *Seldinger* guidewire technique. Note tenting of the membranes by forward dilatation.

Seldinger guidewire technique

In group II ($n = 11$), access was obtained by guidewire technique. The first cannula was always placed on the uterine horn's convexity, away from the uterine vessels and placental cotyledones. Additional cannulas, however, could be introduced through the well-vascularized and cotyledone-rich concavity of the horn. An 18 gauge needle was inserted smartly at right angle with the uterine wall. A 0.035 inch J-tipped, spring wire guide (Cook Critical Care, Strombeek-Bever, Belgium) was introduced through the needle, which was removed. In eight cases, the cannula with inner dilator (Cook Critical Care) was advanced over the guidewire and into the amniotic cavity. Progressive dilatation of the hole from 18 gauge to 6 mm diameter was achieved through a combination of radial and forward expansion, thereby causing the chorionic and amniotic membranes to tent (Fig. 2), as seen from within the uterine cavity through an endoscope.

In seven cases, an expandable outer sleeve was first introduced through the uterine wall. The cannula with dilator was then advanced inside the sheath. In three cases, a (formerly) commercially available radially expanding dilator (R.E.D., Innerdyne

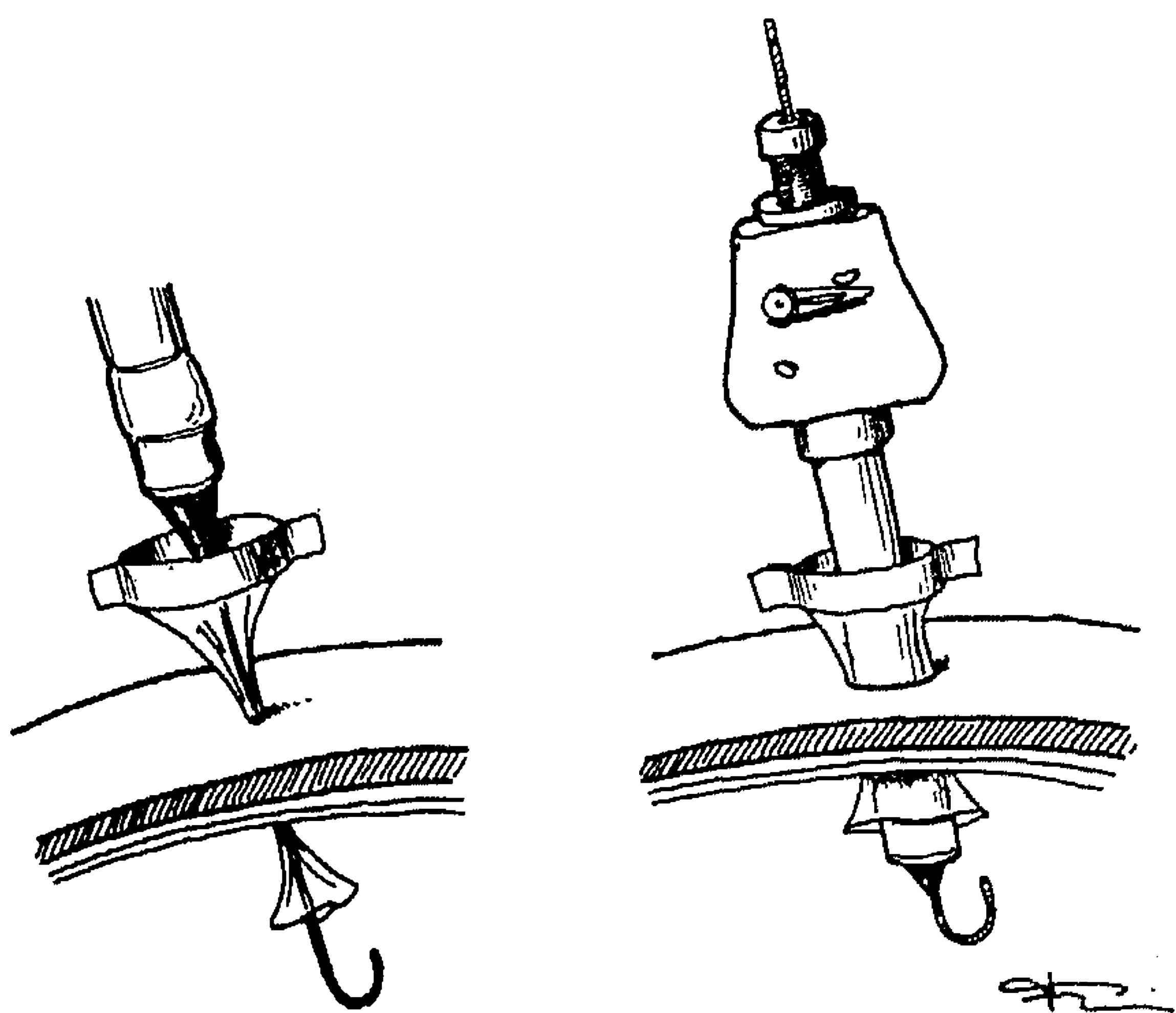


Fig. 3 Seldinger guidewire technique with outer sheath. Radial dilatation only, without membrane tenting or dissection.

Medical, Sunnyvale, California) was used. In the others, a custom-made outer plastic sheath was used for introduction of the balloon cannula. This technique provided reliable access to the amniotic cavity, without forward tenting of the membranes (Fig. 3).

Primates

Five Rhesus monkeys (*Macaca mulatta*) at 98–108 days of pregnancy (term = 165 days) underwent laparotomy under general anesthesia with 1–2% ethrane in 40% oxygen/60% nitrous oxide. The uterus was exposed, but not exteriorized, and covered with a protective plastic sheet. Access to the amniotic cavity was gained with a Seldinger technique and radially expanding plastic sheath (Fig. 3), after localization of the two placental discs by transillumination. Three 5 mm balloon cannulas were inserted in each animal, and fetoscopy was performed (16). At the completion of the procedure, a transuterine collagen plug (Spongostan, Johnson & Johnson, Dilbeek, Belgium) was placed as the cannula was removed, thereby sealing the amniotic cavity and its membranes. A figure-of-eight suture (2–0 polyglycolic acid) was placed through the myometrium. Ultrasonographic examination of the uterus was performed immediately postoperatively, at 24 hours, and weekly thereafter. No amniotic leak or dissection could be detected.

Endoscopic cannulas

Two types of balloon cannulas were used. In group I, custom-made ports were used, consisting of a shortened, 5 mm diameter laparoscopic cannula (Endopath, Ethicon Endo-Surgery, Dilbeek, Belgium or Surgiport, AutoSuture, Mechelen, Belgium) inside a 6.5 endotracheal tube (Portex, Hythe, Kent, U.K.) (12). In group II and primates, commercially available balloon cannulas were used (LaparoSAC, Marlow, Willoughby, Ohio).

Discussion

The widespread application of open fetal surgery has been hampered by its extreme morbidity and mortality to the fetus, often because of uterine and amniotic factors (8). Hysterotomy to gain access to the fetus causes premature contractions in the primate (1, 14), and produces hemodynamic changes even in the

ovine model (13). The emergence of videoendoscopic surgery has given new hopes for the future of fetal surgery (5, 11). Maintaining the fetus inside the uterine cavity, thus protecting it from dehydration and hypothermia, should lessen fetal trauma. Several models of in-utero procedures have been developed in the sheep (2, 3, 6), and limited human experience has already been reported (4, 15).

While many of the claimed or proven advantages of minimal access surgery may benefit endoscopic fetal surgery as well, certain differences exist between common laparoscopy and the endoscopic approach to the gravid uterus. Laparoscopic access through the strong abdominal wall is usually straightforward. If anchoring of the cannula is necessary, threaded grips or other anchoring devices can be used and, when it occasionally occurs, pneumodissection of the peritoneum has no far-reaching consequences beyond subcutaneous emphysema. In contrast, the uterine wall is composed of multiple, delicate layers. Hemostasis, minimal myometrial trauma and membrane protection are keys to avoiding uterine irritation. The chorionic and amniotic membranes, in particular, should not be allowed to separate, leak or rupture, as these are strong stimuli to uterine contractions and premature labor (1), and can lead to oligohydramnios and even pulmonary hypoplasia (4).

We have already demonstrated the benefits of balloon cannulas to stabilize the membranes and keep all layers of the uterine wall together during endoscopic manipulation of the fetus (3, 12). Initially, we used purse-stringed hysterotomies to introduce the cannulas in the ewe's uterus. This proved a safe, but cumbersome and somewhat traumatic method. Hysterotomies, and direct manipulation of the membranes, may not be as harmless in a primate model. We, and others (7), have therefore utilized a Seldinger guidewire technique. While access to the amniotic cavity was reproducibly achieved with the method, pressure during dilatation from a puncture to a 5–6 mm diameter hole caused tenting and forward dissection of the membranes. Use of a radially expanding outer sheath eliminated forward dissection, as seen both in the ovine and nonhuman primate model and in human. While a commercially available system can be (and was) used, the same effect could be achieved with a soft plastic outer sleeve introduced separately over the guidewire. In a small nonhuman primate model (the adult size Rhesus monkey weighs 3–5 kg), endoscopic placement, manipulation and removal of relatively large cannulas (three 5 mm inner diameter ports in a 10 cm high gravid uterus) did not cause membrane dissection, amniotic leaks or premature contractions. Thus, axial shearing forces during dilatation by the cannula occurred between the cannula and the outer sheath, while the force on the uterine wall was only radial in nature.

Whether such precautions are necessary for human endoscopic fetal surgery, is not yet established. Certainly, the high incidence of amniotic leaks after endoscopic umbilical cord ligation (4, and Quintero RA, personal communication) would suggest that minimal access surgery needs to be minimally invasive to the gravid uterus before it becomes a better alternative to open fetal surgery.

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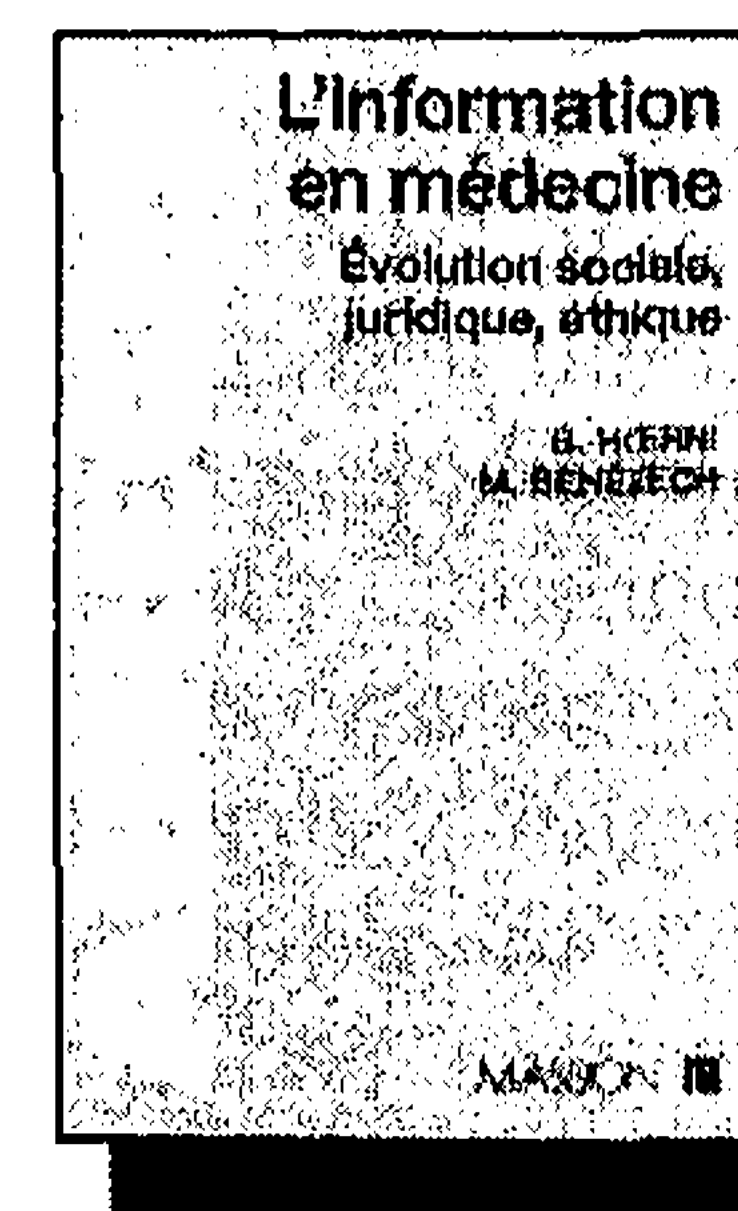
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