

Development of Fetoscopic and Minimally Invasive Ultrasound-guided Surgical Simulator: Part of Global Education

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ABSTRACT

Modern practice in perinatology involves a significant portion of invasive procedures. Training in fetal diagnostic procedures is generally accomplished using *in vitro* model. Fetal therapeutic procedures require a more sophisticated skill. Fetoscopic intervention is most commonly performed for laser dichorionization of the placental in twin-twin transfusion syndrome. A co-ordination between ultrasound guidance and endoscopic surgical skill is required. This article outlines the training schemes in fetal surgery, including surgical simulator (*in vitro*) model, animal model, and observer and hands-on training. We have described our Siriraj Fetoscopic Surgical Simulator™ for the trainee to master his proficiency at his own time and pace.

Keywords: Fetoscopy, Surgical simulator, Twin-twin transfusion syndrome.

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INTRODUCTION

Modern practice in fetal medicine involves a significant portion of minimally invasive fetal procedures. In the past 20 years, there have been a number of invasive procedures being introduced aiming to evaluate or to treat the fetus. Diagnostic procedures such as amniocentesis, chorionic villus sampling, and percutaneous umbilical blood sampling (cordocentesis) can be accomplished under real-time ultrasound guidance. It can take some time for an inexperienced operator to achieve a good co-ordination between the eye and the hand. Most diagnostic procedures are performed by a single operator, with little help from the assistance. Initial training for these diagnostic procedure can be accomplished using *in vitro* model.¹ For therapeutic procedure, the training is more challenging. More sophisticated skill of ultrasound-guided intervention is required. In addition, assistance plays a more important role in this type of procedure. In fetal shunting procedure, for instance, it is required that the operator must use his both hands to deploy the shunting system while co-ordinating with the sonographer.

Fetoscopy was originally used to guide fetal blood sampling from chorionic vessels.² It was soon replaced by

ultrasound-guided cordocentesis. Twin-twin transfusion syndrome (TTTS) has renewed the interest of fetoscopic intervention in the past decade.³ Fetoscopy-guided laser ablation of intertwin anastomosing vessels has been the most effective treatment for severe mid-trimester TTTS.⁴ Not only the patient care has been significantly improved; fetoscopy has also open new research opportunities. There is a learning curve for all new invasive procedures, in terms of success and complication rates, which improves with experience. The demand for surgeons who are able to adequately perform the procedure is increasing. Attempts have been made to steepen this learning curve. Training strategy, including surgical simulator (*in vitro*) model and animal model, is discussed in this article.

Surgical Simulator (*in vitro*) Model

Fetoscopy intervention requires a combination of two surgical skills; ultrasound guidance and laparoscopy. Being able to practice and get accustomed to the fetoscopic surgical instruments can reduce unnecessary maternal and fetal morbidity. The complication is generally higher in the initial phase of learning curve. It is imperative that the trainee need to acquire some hands on experience before they go on performing the procedure under rigid supervision. Our team at Division of Maternal Fetal Medicine, Department of Obstetrics and Gynecology, Faculty of Medicine, Siriraj Hospital, has created an in-house *in vitro* model to aid in our training system of invasive fetal diagnostic and therapeutic procedures. This model is designed to simulate the intrauterine environment so that the trainee can master their proficiency with convenience. In the center where procedure is not practiced regularly, having the surgical simulator can help the surgeon maintaining his skill.

At our initial phase of training in fetoscopy, we modified the pre-existing model that was designed for training in cordocentesis.⁵ This traditional box model is a plastic container, measured 35 × 18 × 15 cm in diameters. A rubber latex sheet is mounted at the bottom to prevent sonographic reverberation. The fresh placenta from seronegative individuals is obtained anonymously. To keep blood in the chorionic angioarchitecture, the umbilical cord is tied and all chorionic vessels are stitched at their tail end. The placenta is then rinsed clean. To simulate the posterior

placenta, the placenta is fixed to the rubber sheet at the bottom of the model with few stitches to prevent it from floating. To simulate the anterior placental, the placenta is fixed to the rubber sheet cover with a plastic net.

This model is simple and easy to assemble. Trainee can practice their coagulation skill by trying on real laser on the real blood vessels. However, it has some limitations. The fresh placenta is at risk of contamination and biohazard. Blood contamination can also obscure the endoscopic view. Placenta from single is being used most of the time; therefore chorionic angioarchitecture is not the same as those in monochorionic conception. Plastic net used in simulation of anterior placenta can get in the way during the coagulation practice.

To overcome these limitations, we have designed an intrauterine endoscopic training model; Siriraj Fetoscopic Surgical Simulator™. It can be described as a soft rubber spherical model measured 35 cm in diameter, as shown in Figure 1. It was mounted on the inside with a rubber replica of monochorionic twin placenta. The model represents a mid-trimester uterus complicated with polyhydramnios resulting from severe TTTS. It is stationed on an arched plaster foundation. Three one-way valve ports are strategically carved on the surface of this model accordingly with the placenta model on the inside. Tap water can be infused or withdrawn from one of these ports. The rubber material used is durable, yet transparent to ultrasound.

Under continuous ultrasound guidance, the trainee can master his technique of systematically examination of chorionic angioarchitecture and intertwin anastomoses, as shown in Figure 2. There is co-ordination between the laparoscopic and sonographic findings, simultaneously. The trainee can get used to the fibrescopes and video-endoscopic images. Using this close-system rubber model, infusion and

deflation of fluid to improve visibility and optimize sufficient work medium can be practiced. This surgical simulator is easy to assemble. The trainee can master his proficiency at his own time and his own pace. Placental location can be designated by choosing an appropriate port of entry. Cloudy amniotic fluid can be created, and the trainee can learn how to clear up the vision in close simulator system (unlike the 'box model' as shown in Fig. 3).

Even with detailed imitation of the TTTS condition, this surgical simulator is not perfect. Real laser coagulation cannot be practiced on this rubber model. Dynamic parameters, such as fetal movement and active bleeding, cannot totally be created in *in vitro* environment. To the best of our knowledge, there has been no report of surgical simulators for open fetal surgery.

Animal Model

Specific intrauterine conditions may be simulated in the animal model. *In vivo* training has several strengths over the synthetic surgical simulator. Pregnant sheep is most commonly used for training and developing new surgical



Fig. 1: Training unit using Siriraj Fetoscopic Surgical Simulator™



Fig. 2: Views from the inside of Siriraj Fetoscopic Surgical Simulator™ showing a simulation of anterior and posterior placenta. Note the chorionic angioarchitecture and intertwin anastomoses



Fig. 3: Traditional box model

techniques because of their adequate uterine volume and fetal size. Surgical trainees can learn how to maneuver the instruments and to solve obstructive operative environment, such as intra-amniotic bleeding, collapsed amniotic sac, fetus blocking. Trainees can also learn how to detect postoperative complications, such as amniotic fluid leakage, bleeding from the myometrium, miscarriage, or death. 'Maternal' morbidity can serve as an objective surrogate for their performance.

Manipulations with an undetermined safety (i.e. intrauterine CO₂ insufflation) can be practiced provided that the animals are taken care of in accordance to the animal welfare guidelines. Investigational regimens (amniopatch, for example) can also be attempted. Certain fetal malformations can be created on purpose in order to treat them later. Gastroschisis has been created in fetal lambs through laparoscopic approach.⁶ Fetal meningomyelocele is another example of iatrogenic malformation created for research purposes.⁷ More advanced surgical procedures, such as dissection of the abdominal wall, ligation of the male urethra in the male fetus, and endoscopy of the fetal esophagus and trachea can also be accomplished.⁸

Animal model has certain limitations. Sheep has a bicornuate uterus with a 145-day of gestational period.⁹ Fetal intervention procedures are performed between days 70 and 80. General anesthesia is usually required. Perioperative care for this large animal can be costly. Smaller animal model, such as pregnant rabbit, has been studied. Rabbit model is less expensive, more readily available, and not requiring special facility for lodging or anesthesia.¹⁰ Recently, baboon has also been used as a model for fetoscopic surgery.¹¹ This primate model has an advantage over other animal that it can simulate intrauterine repair of fetal cleft lip. Also, it has a unique potential for a practice in open fetal surgery.

Observer and Hands-on Training

Surgical skill proficiency may not be equally developed for all individuals with a fixed number of training specimens.

Some centers allow for trainees to perform invasive procedures on the fetus destined to be terminated. This strategy may not be applicable in fetal surgery, since the aim of treatment is to make the pregnancy ongoing. Observation and hands-on training with senior surgeons is common at the beginning. The trainee then gradually acquire enough skill to assist, and finally to perform the procedure as primary surgeon. Only a few centers offer formal training program for fetoscopic interventions. Systematic evaluation of the trainee in fetoscopic laser ablation has been proposed.¹²

CONCLUSION

Fetoscopic laser coagulation of placental anastomosis is now a standard of care for TTTS. Fetal outcomes rely heavily on the operator's experience. *In vitro* training of fetal surgery, using TTTS as a model, may allow for a steeper learning curve. Fetal surgery has no real limit of growth in a lot of directions. An important problem is that there are a limited number of centers that perform enough interventions for the trainee to learn, and master their skill. The momentum of expansion of new center enthusiastic to perform the procedure raises the demand for formal training and evaluation. Knowledge in fetal surgery is dynamic with continuous better understanding of the disease's physiology, in addition to instrumental evolution.

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