Original Article

Development of a silicone-based goat uterine model for artificial insemination training

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Abstract

A goat uterine model for artificial insemination (AI) training has not been created previously. The eight goat uteri were collected from the slaughterhouse and measured to serve as a prototype size for the model. A goat uterine model was developed based on silicone material. This study compared the suitability of silicone between 20,000 and 30,000 centipoise viscosity and the cervical opening between the circular and linear types for this model. These were made up of four models with alternating differences between viscosity and cervical openings. Twenty AI officers evaluated the satisfaction score of the internal and external appearance of the model and compared silicone viscosities and types of cervical opening by questionnaire. After the officer's evaluation, the high-satisfaction type was chosen to use for participant-farmer training. In the course of AI training, the thirty participants practiced with a goat uterine model before doing so with live goats. After training, participants assessed the satisfaction of the internal and external appearance of the model and the usefulness of the AI training. The result showed that the silicone viscosity of 30,000 centipoises was more satisfying to officers than that of 20,000 centipoises. The type of cervical opening was not clearly different. Both the officers and participants satisfied both the internal and external appearance of the overall models. The participant was satisfied with the usefulness of this model for AI training. The goat uterine model in this study is suitable for AI training. However, this model needs further development for advanced AI training.

Keywords: Goat uterine model, Artificial insemination, Goat uterus, Silicone

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Introduction

The training for artificial insemination (AI) in goats uses the uterus from a slaughterhouse and a live female goat. The participant in training has no experience using the equipment or procedure. The AI procedure in goat used the vaginal speculum to expand the vulva for seek out the cranial cervix, and use an insemination gun inserted through the cervix to release the semen into the uterine body (Nuti, 2007; Cseh *et al*., 2012). Both devices take time to practice, including the technique for inserting the insemination gun through the cervix. The procedure of AI in each step must be done carefully. Also, AI training in a participant with live goats takes more time, which may cause stress and trauma in the goats. In the present, many medical operation trainings have been practiced with a model. These models could reduce the time spent with live animals, reduce stress, and decrease trauma (Sandmann *et al*., 2019; Alser *et al*., 2020). In addition, the model can reduce the cost and increase the success of AI. The goat uterine model for artificial insemination training could be used to train the participant in vaginal speculum and insemination gun practice before being done on live goats.

The model for AI training was created for many species, such as cattle (patent number KR20110120721A) and swine (patent number CZ30463U1). The model was developed with different structures due to the fact that each species has a different uterine structure and uses different techniques for AI. In cattle, the cervix is deep in the abdominal cavity, which requires palpation per rectum to locate. The cattle cervix has several folds, and the cervical gap is a crooked canal (Diskin, 2018). The model in cattle for AI training was designed with an anus and devious cervical opening. In swine, the cervix is an interdigitating prominence that accommodates the corkscrew glans penis of boars (Geisert *et al*., 2020). The model in swine for AI training was designed to fit the spiral insemination gun (Mellagi *et al*., 2022). In goats, the technique to insert the insemination gun was different from that in cattle and swine. The goat uterine model must be created in a different design.

The goat uterine model can be developed from many materials. Silicone is a popular material for model creation, especially in animal anatomical models (Gibbons *et al*., 2022; Nuber *et al*., 2022). The silicone comes in a variety of viscosities, each of which is appropriate for a specific task. In Thailand, the favorite silicone viscosity for creating models was 20,000 and 30,000 centipoise. The silicone viscosity of 30,000 centipoise has more elasticity than 20,000 centipoise (Lorenz and Kandelbauer, 2014). However, these viscosities have not previously been compared for suitability for goat uterine production.

This study will create a goat uterine model for AI training. The different silicone viscosities for the developed goat uterine model could be compared to find the suitable viscosity for the model.

Materials and Methods

This protocol was approved by the Animal Usage and Ethics Committee of Veterinary Science Faculty, Mahidol University (Protocol number MUVS-2020 -10-48) for goat uterine collection from slaughterhouses and the Mahidol University Central Institutional Review Board, Mahidol University (Protocol number. MU-CIRB 2022/167.1306) for a questionnaire-based satisfaction survey among AI staff and farmers.

Goat uterine collection and measurement: Eight goat uteri were collected from the slaughterhouse in Nong Chok District, Bangkok Province, Thailand. All uteri were measured and recorded in centimeters. Uterine length and circumference were measured from the vulva to the uterine body, i.e., the vulva, vagina, cervix, and uterine body (Figure 1). The labia line opening was measured vertically, and the labia width was measured horizontally. Each uterine segment was measured using a digital caliper, ruler, and thread. Only the cervix was counted for the number of folds and measured for width, thickness, and length between folds. The length and width of the goat uterus were calculated as the mean for the goat uterine model.

Goat uterine model development: In this study, the different viscosities of silicone and types of cervical opening were compared to find the most suitable for developing a goat uterine model (Table 1). The goat uterine model was only developed from the vulva to the uterine body. The size of the model was based on the mean goat uterus in the previous experiment (Table 2). However, this size was adapted to be suitable for AI training, especially the size of the cervix, which was adapted to facilitate training.

A prototype of the model was created and sculpted from plasticine. The outside model's diameter widens at the vulva, suddenly narrows at the vagina, and then gradually widens to the uterine body, as shown in Table 4. The total length of the model was 23.3 centimeters. The model did not separate the parts of the vulva and vagina. This model was divided into two main parts, as shown in Figure 2A and 2C. The first parts were the outer wall of the uterus, with two pieces to be joined together (Figure 2A). The thickness of the silicone was 0.3 centimeters. The second part was a sheet of varying thickness for creating a four-piece cervical folds and one piece of barrier between the cervix and uterine body (Figure 2C). The cervical opening was designed into two types, e.g., hole and straight line, to find which one felt most similar to inserting an insemination gun through a female goat cervix. The first type was center-drilled into a 3.5-millimeter round hole under a 1-millimeter-thick flap (Figures 3A and 3C). This type was designed to fit the diameter of an insemination gun. This hole opening was commonly used for insemination training models in cattle, such as the Bovine Breeder™ artificial insemination simulator from Realityworks, Inc., USA. The second type was cut to 9.5 millimeters in the median line under a 1-millimeter-thick flap (Figures 3B and 3D). This straight line was developed to resemble the space between cervical folds. The size of the cervical model is shown in Table 5.

The silicone was used to make a mold from plasticine. The silicone used in this study was purchased from Infinite Crafts Co., Ltd. in Thailand. Two viscosities of silicone were chosen, i.e., 20,000 and 30,000 centipoise. All pieces of the model were

assembled and joined together with silicone. Two different silicone viscosities and two types of cervical opening were matched to form four different goat uterine models for testing, as shown in Table 1. All models were housed in a box that could be lifted up for easy insertion of the vaginal speculum (Figure 4). The different cervical openings and viscosities of silicone in the models were not detailed to officers.

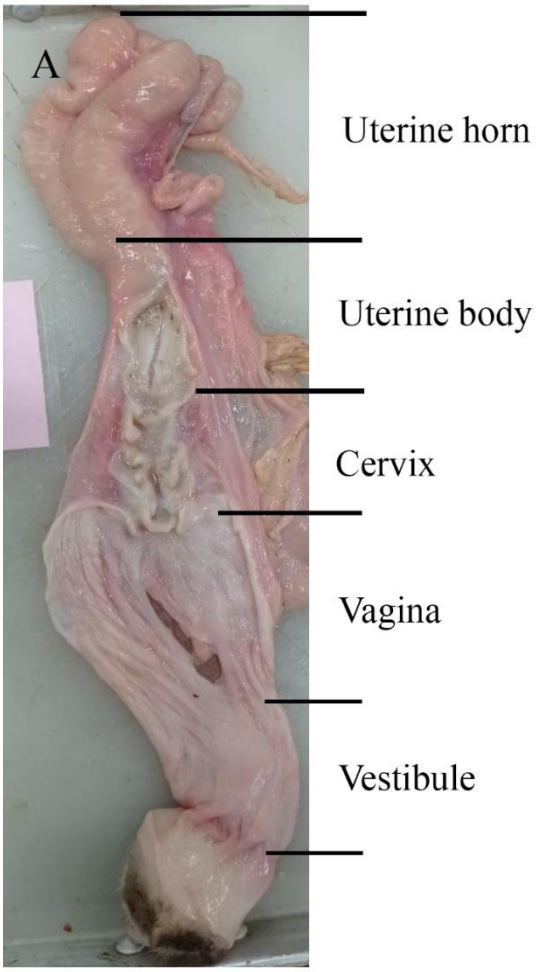

Figure 1 Goat uterine regions.

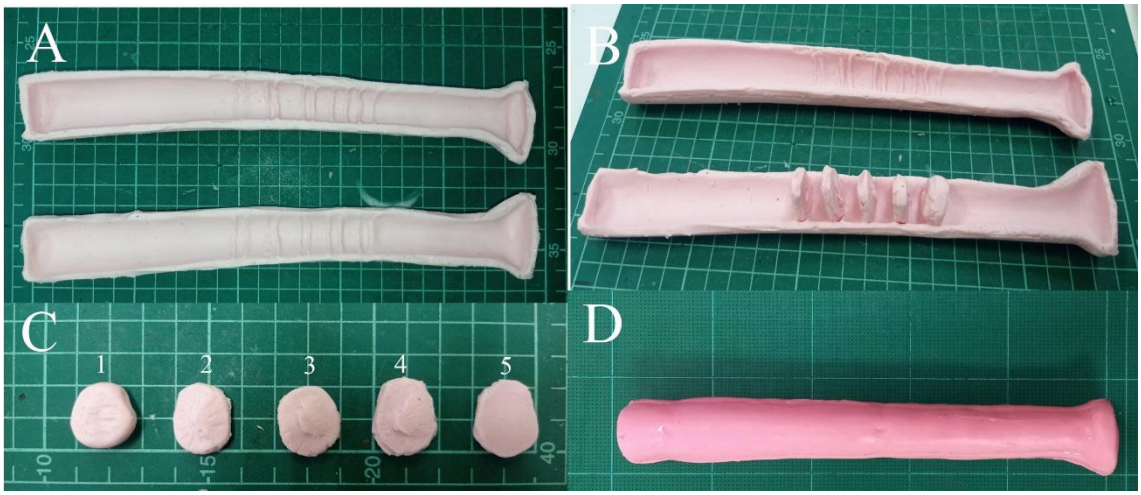

Figure 2 Goat uterine model development, outer wall of uterus model (A), outer wall of uterus model and position of cervix (B), cervix model from near the vagina (1)to uterine body (5)(C), and outside of outer wall.

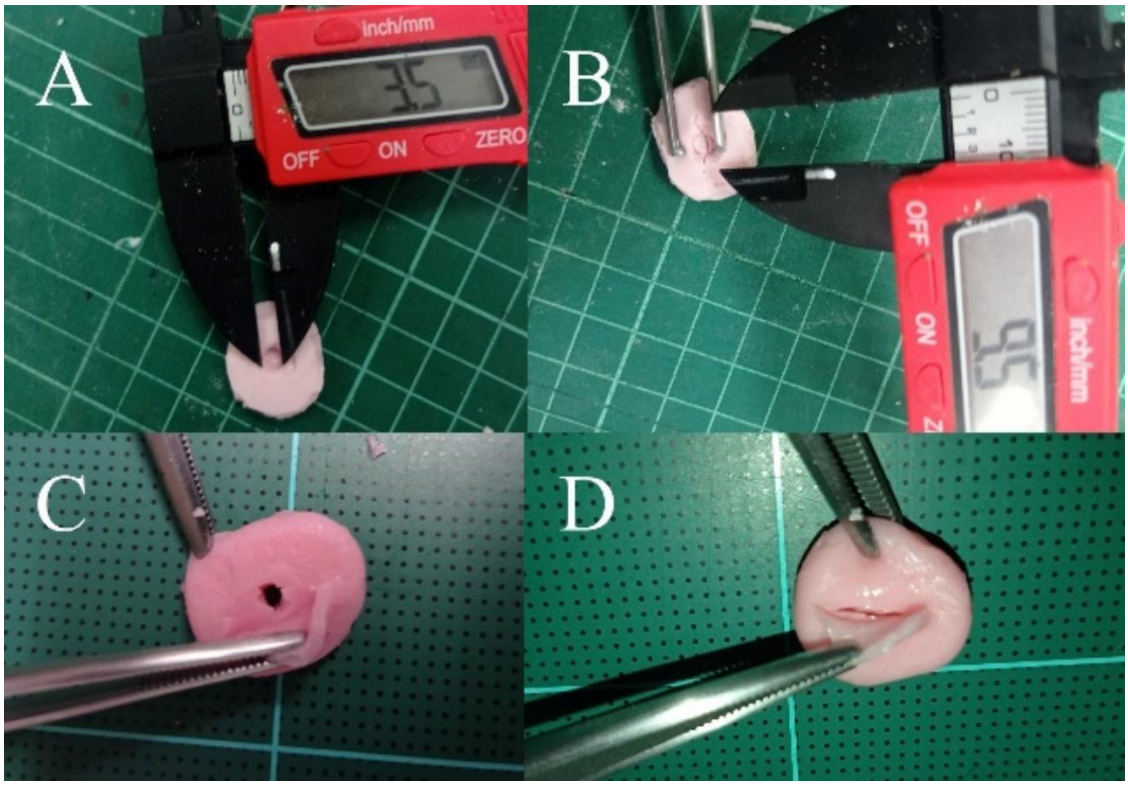

Figure 3 Model of goat cervix, diameter of cervix hole (A), length of cervix straight line (B), flap cover the hole (C) and flap cover the straight line (D).

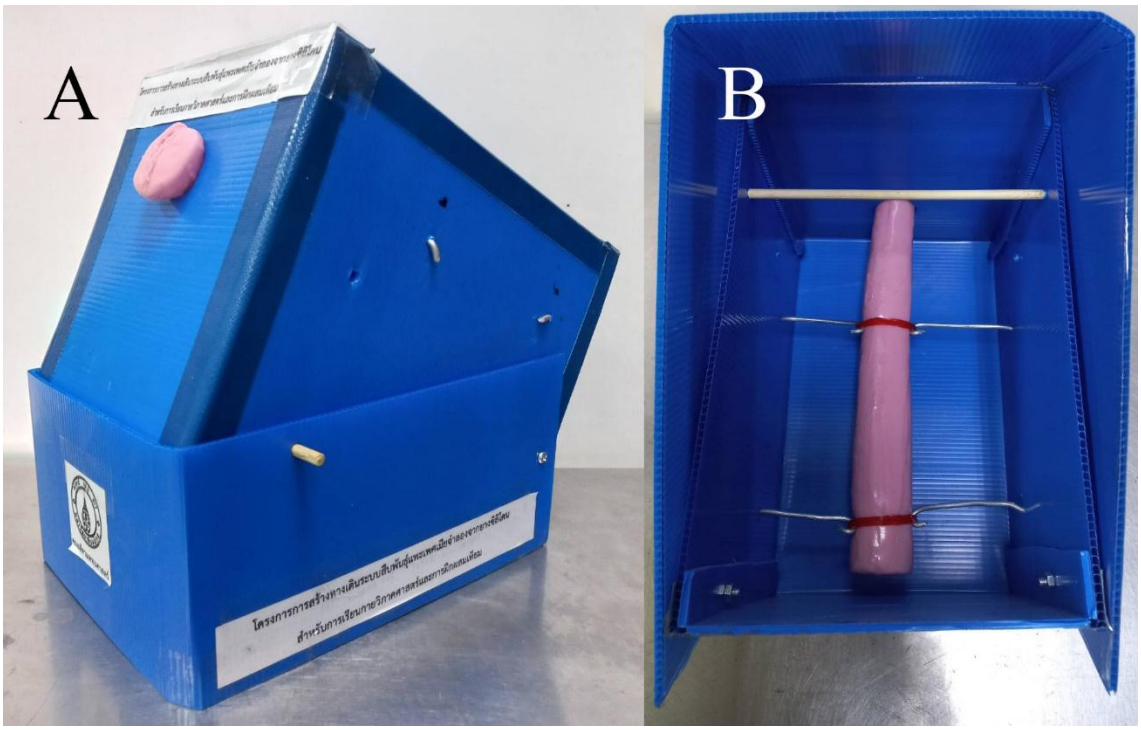

Figure 4 Goat uterine model in box, outside of model in box during elevate (A) and inside of model in box (B).

Table 1 Types of uterine model

Model	Cervical type	Silicone type	Viscosity (centipoise)
Type 1	Round hole 3.5 mm	RA-210	30,000
Type 2	Straight cut 9.5 mm	RA-210	30,000
Type 3	Round hole 3.5 mm	RA-320	20,000
Type 4	Straight cut 9.5 mm	RA-320	20,000

Table 2 Goat uterine measurement

Region of uterus	Length (cm)	Circumference (cm)
Vulva length	3.82±0.2	6..01±0.84
Vagina length	7.88± 0.38	5.39±0.64
Cervical length	4.2±0.54	6.01±0.56
Uterine body	4.55±0.46	6.89±0.74

Table 3 Goat cervical measurement

Cervical folds	n	Cervical folds width (cm)	Space after fold width (cm)	Fold high (cm)
1st fold near vagina	5	0.91±0.11	0.44±0.08	1.13±0.14
2nd fold	5	0.64±0.08	0.38±0.06	0.69±0.12
3rd fold	5	0.58±0.08	0.26±0.04	0.5±0.08
4th fold	5	0.58±0.07	0.27±0.03	0.34±0.11
5th fold	4	0.44±0.15		0.11±0.01

Table 4 Size of goat uterine model

Uterine model region	Length (cm)	Circumference (cm)	Outside diameter (cm)
Vulva	1.6	11.5	3.6
Vagina	5.5	9.0	2.5
Cervix	4.0	9.5	2.6
Uterine body	12.4	10.0	3.3
Total	23.5		

Table 5 Size of cervical folds in the goat uterine model

Cervical folds	Long (cm)	Width (cm)	Thick (cm)	Space (cm)
1st fold	1.9	1.5	0.8	0.5
2nd fold	2	1.5	0.5	0.6
3rd fold	2.2	1.9	0.4	0.9
4th fold	2.4	1.9	0.3	

Questionnaire-based satisfaction survey: The questionnaire was used to evaluate the goat uterine model for AI. The questionnaire was divided into two sets. An AI officer who had experience with goat AI at least 10 times was recruited for this study and answered the first set of questionnaires. These officers were on duty in the three stations of the Biotechnology and Artificial Insemination Research Center (i.e., Ratchaburi, Chonburi, and Saraburi) and the Embryo Transfer Biotechnology and Germplasm Research Center, Nakhon Ratchasima, Department of Livestock Development, Thailand. Twenty officers answered the questionnaire after testing and evaluating the model. This questionnaire was divided into two parts. The first part asked the officers to compare the similarity of the external and internal appearance models to a live goat uterus and determine whether they were suitable for AI teaching. The external appearance was evaluated based on the shape and vulva appearance of the model. The internal appearance was evaluated after using a vaginal speculum to find the cranial cervix. The second part compared the four types of models to find the one that had the most similarity to the live goat uterus for inserting insemination through the cervix.

Only the best type of model from the officer's selection was used to teach the participant farmer during the goat AI learning course at the Embryo Transfer Biotechnology and Germplasm Research Center, Nakhon Ratchasima, Department of Livestock Development, Thailand. Before AI in a female goat, the thirty participants were taught with a goat uterine model. After that, the questionnaire was used to estimate the suitability of using this model for training. The questionnaire asked participants about their satisfaction with the similarity and benefit of insemination training using a goat uterine model. The first part of the question concerned the similarity of the external appearance of the vulva and cervical model to that of a female goat. The second part of the question concerned the benefits of using the model in training prior to real AI, i.e., vaginal speculum and insemination gun insertion training, and their usefulness in AI training.

All questions in the questionnaire were on a score ranging from 5 (high satisfied), 4 (satisfied), 3 (neutral), 2 (low satisfied), and 1 (unsatisfied). The respondent could choose only one option. The satisfied scores in each question of all respondents were summarized and calculated to mean ± SE. These means of satisfaction results from the respondents were converted into scores according to their level of satisfaction. The high satisfied score had a mean of 4-5 points, the satisfied score had a mean of 4–3 points, the neutral score had a mean of 3-2 points, the low satisfied score had a mean of 2-1 points, and the unsatisfied score had a mean of less than 1 point. The scores obtained for each topic were averaged and show satisfaction according to the average score obtained (Prathep *et al.*, 2021).

Statistical analysis: The data of goat uterine measurement were reported in mean ± SE. This study was limited in both the number of goat AI officers and farmer partici
in each AI cer
course did not open regularly, the number of participants in each course was uncertain. Due to these limitations, the sample size of participants in both parts were calculated using the Cochran formula. The answers to the questionnaire were calculated in mean ± SE, analyzed based on descriptive analysis, and reported as mode statistics.

Results

The goat uterine measurement is shown in Table 2. The average length of the uterus from vulva to uterine horn was 26.19±1.59 centimeters, which ranged from 21 to 32.5 centimeters. The average length of the cervix was 4.2±0.54 centimeters, which ranged from 3.9 to 6.3 centimeters. In this study, the number of cervical folds was different in each goat and was between 4 and 5 folds. The first cervix to close the vaginal fold was the thickest, followed by the thinnest. The average labia opening length was 3.36±0.19 centimeters and labia width was 3.18±0.52 centimeters.

The goat uterine model was created and adapted from goat uterine measurements. The goat uterine model size is shown in Table 3. The length of the model from the vulva to the uterine body was 23.5 centimeters. The labia length and width of the model were 3.65 and 3.2 centimeters, respectively. The labia opening length of the model were wider than the vulva diameter, similar to those of a female goat. The vulva was the narrowest part of the model and gradually became wider, reaching its widest at the end. This model contains only four cervical folds. The cranial part of the cervical model was designed in the shape of a fold, similar to that of a female goat (Figures 3C and 3D).

The officers were satisfied with the goat uterine model, as shown in Table 5. The mean scores for external and internal appearance were 3.65±0.15, and 3.9±0.1, respectively, which showed satisfaction. The suitable for AI teaching score was a high satisfied score of 4.2±0.16. The comparison between model types is shown in Table 6. The satisfaction of each model was neutral, but model type 1 had a satisfaction score of 3.85±0.21, which was higher than the other types. This model was chosen for training participants in a goat AI course.

The participant farmer was satisfied with the goat uterine model, as shown in Table 6. The mean scores for external and internal appearance were 3.93±0.14, and 3.93±0.12, respectively, which showed satisfaction. The benefit of training with a goat uterine model before AI in female goats was high satisfied. The satisfied scores for the benefit of vaginal speculum and insemination gun training were 4.13±0.1, and 4.07±0.11, respectively. The satisfaction score that was useful in this model for AI training was 4.13±0.1.

Table 6 The satisfaction score for the goat uterine model in mean±SE from the artificial insemination officers

Questions	Mean	SE	Result
Similarity to female goat			
External appearance	3.65	0.15	Satisfied
Internal appearance	3.9	0.1	Satisfied
Suitable for training	4.2	0.16	High satisfied
Model types comparable			
Type 1	3.85	0.21	Satisfied
Type 2	3.8	0.2	Satisfied
Type 3	3.65	0.2	Satisfied
Type 4	3.45	0.15	Satisfied

Table 7 The satisfaction score for the goat uterine model in mean±SE from the artificial insemination training participant

Questions	Mean	SE	Result
Similarity to female goat			
External appearance	3.93	0.14	Satisfied
Internal appearance	3.93	0.12	Satisfied
Benefits of training			
Vaginal speculum	4.13	0.1	High satisfied
Insemination gun	4.07	0.11	High satisfied
Usefulness to artificial insemination training	4.13	0.1	High satisfied

Figure 5 Goat uterine model trial by artificial insemination officers (A) and artificial insemination training participants (B).

Discussion

The goat uteri from the slaughterhouse were different in size. In the slaughterhouse, age, weight, breed, and number of offspring could not be determined. In this study, goat uterine modeling was attempted to make it similar to the most typical size. This study measures only the size of the vulva relative to the uterine body because it is an important site to create a goat uterine model for goat AI training. In this study, the average length of the vulva and vagina was about 11.7 centimeters, which is similar to the study in Norway (about 11 centimeters) (Lyngset, 1968), while slightly different from the study in Bangladesh (about 13.2 centimeters) (Gupta *et al*., 2011). The average length of the cervix in this study was about 4.2 centimeters, which is shorter than the study in Norway (about 5.7 centimeters) (Lyngset, 1968) but longer than the study in Bangladesh (about 3.35 centimeters) (Gupta *et al*., 2011). These data showed that the average length of the goat uterus in this study was not quite different from measurements in other studies. Also, the uterine measurements in this study can be used to create a goat uterine model for AI training.

Successful goat artificial insemination involves inserting an insemination gun through the cervix. The number of cervical folds in the goat uterus in this study was 4 to 5 folds, which is close to the number of cervical folds from the study in Norway (5 to 7 folds) (Lyngset, 1968). The goat uterine models in this study were created for basic training. The number of cervixes in the model was designed to be only four folds, which makes it easier to insert the insemination gun. The cervical folds in the female goat had thickened at the cranial and gradually thinned. The cranial cervix of the model was designed to be thickest and gradually thinner in consecutive folds (Table 5), similar to that found in the female. The cervical opening in a female goat is the gap between folds. The cervical model designed the cervical flap to cover the entire cervical opening. This cervical flap was used to practice the insemination gun finding the cervical opening and inserting (Figures 3C and 3D).

The goat uterine model for AI training in goats was not previously created. However, the uterus model for AI training had been developed in many species, such as cattle (Artificial insemination practice instruments, patent number KR20110120721A) and swine (A simulator for insemination of sows, patent number CZ30463U1). The goat uterine model in this study developed differently from these two species due to the differences in artificial insemination techniques. The key to successful AI was inserting the insemination gun through the cervix. In the AI technique in cattle, the cervix was palpated and caught through the rectum before inserting the insemination gun (Diskin, 2018). In the swine technique, the insemination gun is inserted and rotated through the cervix without catching the cervix (Mellagi *et al*., 2022). In goats technique, a vaginal speculum was used to widen the vagina and reveal the cranial cervix, which can be used to guide insemination gun insertion, but the remaining part of the cervix is done with experience to reach deep into the uterine body (Nuti, 2007; Cseh *et al*., 2012). The goat uterine model for AI training in this study was designed for goat AI techniques and for no-skill farmers. This model was designed with attention to the size and shape of the vulva for using the vaginal speculum as well as the position and shape of the cervix for inserting the insemination gun. The shape of the vulva was designed as an oval, with the top slightly wider than the bottom. The length of the vulva opening and the length of the vulva and vagina of the model were similar to the average in the uterine measurements in order to closely match the actual use of the vaginal speculum.

The cervical opening model was created in two types. The first type had a round hole that fits the insemination gun, which feels like it was inserted through a round hole that fits the insemination gun. The second type had a straight cut that fits the insemination gun, which feels like pushing through the gaps of the cervix. The model of a goat uterus in this study was developed from silicone for give it elasticity. The silicone had several viscosities, and the high viscosity of silicone rubber indicates high tensile strength or high elasticity (Lorenz and Kandelbauer, 2014). The silicone viscosity in this study was only chosen at two levels, i.e., 20,000 and 30,000 centipoise. These two viscosities were the general viscosities used in Thailand. Both the type of cervical opening model and the silicone viscosity were evaluated by goat AI officers. The officers were most satisfied with model type 1, which was followed by model type 2. These two types had a silicone viscosity of 30,000 centipoise, which is higher than types 3 and 4. This result shows that high silicone viscosity or high elasticity is more suitable for the goat uterine model. However, the different viscosities of silicone for AI model training development were not reported in previous studies.

Interesting, the high viscosity of silicone than in this study may be tested for the improvement of the AI training model.

The cervical opening types between round hole and straight line were not clearly different. The satisfaction of a straight line opening in type 2 seems lower than a round hole opening in type 1, but higher than type 3. Therefore, based on these data, it cannot be clearly confirmed that both types of cervical opening are different. The officers were satisfied with the type of model based more on the viscosity of the silicone than the cervical opening. However, this cervical model can develop to make it more difficult for higher-skill training.

The majority of AI officers and the participating farmer groups rate their satisfaction with both the internal and external appearance of the goat uterine model on a satisfied score. This satisfaction demonstrated that the external and internal appearances of the goat uterine model are adequate for use. However, these results showed that this model must be further developed to have an internal and external appearance more similar to the goat's female uterus. Both groups agreed that this model was useful for goat AI training.

In conclusion, the model of a goat uterus used in this study can be used for training AI. The silicone is suitable for creating the model. The viscosity of silicone makes a difference in the feel of the model. The high viscosity of silicone makes the model resemble a female goat's uterus more than a low-viscosity model. The round hole and straight line of the cervical opening in model of this study are not different. The cervical opening of the model can be created in various shapes to more closely resemble the cervical gap of a female goat. Further development of this model could enhance the internal and external similarity and increase the model's effectiveness as a training tool.

Conflict of interest: This manuscript is no conflict of interest with any financial, personal, or other relationships with other people or organization related to the material discussed.

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