INTRODUCTION

The uterus is an organ dedicated to reproduction and can vary its function within a short period of time, based on reproductive requirements. In women of reproductive age, the uterus plays a role in the induction of menstruation each month. Subsequently, the uterus regenerates the endometrium, secretes cervical mucus, and prepares the uterine environment for implantation. The pregnant uterus contributes to fetal growth and development; it also induces labor and contributes to delivery at the appropriate time.

Abstract

Purpose: To evaluate the uterine kinetics in each phase of the menstrual cycle when observed in detail using cine-mode magnetic resonance imaging (MRI) of sagittal and transverse plane images.

Methods: Seven volunteers with a history of multiple natural pregnancies and deliveries were enrolled from January 2017 to May 2017. The kinetic parameters (depth, frequency, and direction) of uterine muscle contractions were evaluated in cine-mode MRI.

Results: Strong contractions from the uterine cornua to cervix were detected during menstruation. In the late follicular phase, the frequency of opposing contractions from the cervix and uterine cornua increased. Immediately before ovulation, contractions from the cervix reached the uterine fundus. After ovulation, opposing contractions returned. These contractions gradually decreased in the mid-luteal phase, while fine contractions from the cervix to the middle of the uterine body were frequently observed until 7 days after ovulation. Few contractions were observed in the implantation phase.

Conclusions: Our data suggest that the uterine kinetics change in each phase of the menstrual cycle in accordance with the purpose of the uterus in each phase. Further, cine-mode MRI studies of each phase are needed to assess the relationships between uterine kinetics and infertility.

KEYWORDS

cine-mode magnetic resonance imaging, embryo transfer, smooth muscle cells, uterine contraction, uterine muscle
Intrauterine pressure measurement using a transducer and transvaginal ultrasound examination has been utilized to study the kinetics of the uterus. Intrauterine pressure is reportedly elevated during menstruation, and the number of uterine contractions increases during the follicular phase. Ultrasound studies have revealed that endometrial wave-like activity originates from the uterine cervix and travels toward the fundus in the follicular phase.

Cine-mode magnetic resonance imaging (MRI) was recently developed and has been used for functional analysis of various organs in many clinical fields. In cine-mode MRI, serial images are taken in the same plane at high speed with short intervals; these are used to produce a moving image resembling a time-lapse video recording.

In the field of gynecology, cine-mode MRI has reportedly been useful for kinetic analysis of uterine function during the past decade. Fujiwara et al reported a change in the frequency and direction of uterine peristalsis during the menstrual cycle as shown by cine-mode MRI. Additionally, they showed a direct correlation between dysmenorrhea and uterine contraction. Yoshino et al reported that frequent endometrial movement in the implantation phase reduced the pregnancy rate in women with uterine fibroids. Furthermore, Shitano et al analyzed uterine kinetics of nonpregnant women using coronal plane images; they found contractions originated from the uterine endometrium and traveled to the outer layer of the myometrium during the follicular phase.

The present study aimed to further characterize uterine kinetics during each phase of the menstrual cycle in nonpregnant women with normal menstrual cycles and a history of multiple pregnancies and deliveries. Notably, our study used cine-mode MRI performed in the sagittal and transverse planes, which has not been previously published. Furthermore, MRI in our study comprised 90 images over 3 minutes, with intervals of 2 seconds between images (ie, 30 frames per second, similar to the characteristics of television); these images were assembled into time-lapse videos to investigate the kinetics of uterine myometrial contractions with higher frame rate than in previous reports.

2 MATERIALS AND METHODS

2.1 Volunteers

We performed the present study in the Soranomori Clinic during the period from January 2017 to May 2017. Informed consent was obtained from all volunteers, and this study was approved by our institutional review board. Seven healthy female volunteers, 30-43 years of age, participated in this study. They had regular menstrual cycles of 26-30 days and a history of ≥2 pregnancies and deliveries after natural conception. None of the seven women had uterine myomas, adenomyosis, or a history of recurrent miscarriages.

2.2 Study design

Cine-mode MRI was performed at 2-4 days after the beginning of menstruation, in the late follicular phase at the beginning of the luteinizing hormone (LH) surge, in the periovulatory period (2-3 days after LH surge), and in the implantation phase (6-10 days after ovulation). LH surge was assessed daily by using a urinary LH kit (Clearview®; Alere Medical) from the 8 day of menstruation. The serum concentrations of follicle-stimulating hormone, LH, estradiol, and progesterone were checked (Access; Beckman Coulter, Inc) at each cine-mode MRI examination. Transvaginal ultrasound examinations were not performed to avoid stimulating the uterus. The growth of dominant follicles was confirmed by T2-weighted MRI.

2.3 Cine-mode MRI

MRI examinations were performed using a 1.5-T magnet unit with a four-channel body coil at our institution (Achieva 1.5T Conversion; Philips Japan). At the beginning of the MRI examination, pelvic images were acquired by three-dimensional plane imaging (sagittal, coronal, and transverse plane images). The sagittal and transverse planes were then adjusted as follows, in accordance with uterine shape: the sagittal plane contained the mid-fundus of the uterus and the uterine cervix, whereas the transverse plane contained the bilateral uterine cornua and cervix in a single image showing the triangular shape of the uterine cavity (Figure 1).

Under quiet respiration, 90 two-dimensional images were acquired using a single-shot turbo spin-echo sequence (repetition time/echo time, 2000/90 ms; field of view, 250 mm; slice thickness, 6 mm; matrix, 256 × 256) every 2 seconds for 3 minutes, and the cine mode was constructed with 30 images per second. In these MRI examinations, gastrointestinal peristalsis was not suppressed with hyoscine butylbromide, as this agent can suppress uterine contractions.

FIGURE 1 Definition of sagittal and transverse magnetic resonance imaging planes. The sagittal plane contains the mid-fundus of the uterus and uterine cervix. The transverse plane contains the bilateral uterine cornua and cervix in a single image showing the triangular shape of the uterine cavity.
Table 2 shows the mean frequencies of uterine contractions from three-fourths of the inner-side myometrium (Figure 1b1,b-2).

Two types of contractions were observed: contractions with gradually increasing frequency were then detected both from the uterine fundus to the cervix and from the cervix to uterine fundus, as well as the depth of the contracting uterine myometrium layer in the sagittal plane. Table 3 shows the mean frequencies of uterine contractions from the bilateral cornua to the cervix and from the cervix to the bilateral cornua, as well as the depth of the contracting uterine myometrium layer in the transverse plane. All of the contractions from the cervix to the bilateral cornua were synchronized. On the other hand, the contractions from the bilateral cornua didn’t synchronize in the transverse plane. In the case showed a difference in the frequency of the contraction between the bilateral cornua, the larger number was defined as the number of the contractions from the fundus (Table 3).

### 2.4 Imaging and statistical analyses

The presence of uterine myometrial contractions, sources and terminals of uterine wave-like contractions, frequency of peristalsis, contracting myometrial layer, and deformity of the uterine cavity were analyzed by three gynecologists and one radiological technologist, and described by their consensus. Differences in number and direction (fundus–cervix) of uterine peristaltic contractions were compared within menstrual phases by the Mann-Whitney U test and between menstrual phases with the Kruskal-Wallis test. Differences in contractile frequency (right–left) within menstrual phases were compared with the Mann-Whitney U test. All statistical comparisons were performed with Ekuseru-Toukei (Ekuseru-Toukei 2012; Social Survey Research Information Co., Ltd.).

### 3 RESULTS

The seven volunteers had a mean age of 40.0 ± 2.0 years. Their mean cycle length was 28.0 ± 1.1 days; mean gravida was 3.29 ± 0.88, and mean parity was 3.29 ± 0.88. Notably, all volunteers had a history of two or more natural pregnancies without undergoing infertility treatment. The serum concentrations of each hormone at each of the five examinations are summarized in Table 1.

### 3.1 Characteristics of contractions in each phase

#### 3.1.1 Menstruation phase

The contractions arising from the uterine cornua occurred with similar frequency to those arising from the cervix during the menstruation phase in both sagittal and transverse planes ($P = .3927, P = .2235$). With respect to the depth of myometrial contraction layer, one-half to three-fourths of the inner-side myometrial layer contracted strongly in five of the seven volunteers; in the remaining two volunteers, the entire myometrial layer contracted strongly.

#### 3.1.2 Late follicular phase

The serum estrogen concentration rose acutely as the follicle grew in the late follicular phase (Table 1). During this phase, uterine myometrial contractions occurred only in the inner-side myometrial layer immediately below the junctional zone. Contractions with gradually increasing frequency were then detected both from the uterine cornua and cervix. The contractions arising from the uterine cornua occurred with similar frequency to those arising from the cervix during the late follicular phase in both sagittal and transverse planes ($P = .6612, P = .1391$; Tables 2 and 3). Contractions arising from the uterine cornua ipsilateral to the leading follicle did not show a significant difference in frequency relative to those arising from the contralateral side ($P = .1081$; Table 4). Wave-like contractions from the uterine fundus to the cervix and from the cervix to uterine fundus, as well as the depth of the contracting uterine myometrium layer in the sagittal plane. Table 3 shows the mean frequencies of uterine contractions from the bilateral cornua to the cervix and from the cervix to the bilateral cornua, as well as the depth of the contracting uterine myometrium layer in the transverse plane. All of the contractions from the cervix to the bilateral cornua were synchronized. On the other hand, the contractions from the bilateral cornua didn’t synchronize in the transverse plane. In the case showed a difference in the frequency of the contraction between the bilateral cornua, the larger number was defined as the number of the contractions from the fundus (Table 3).

| TABLE 1 Volunteers’ serum hormone concentrations |
|-----------------------------------------------|
|                                             |
| Follicle-stimulating hormone (mIU/mL)        |
| Luteinizing hormone (mIU/mL)                 |
| Estradiol (pg/mL)                            |
| Progesterone (ng/mL)                         |
| Menstruation (n = 7), mean ± SD              |
| Late follicular phase (n = 4), mean ± SD     |
| LH surge (n = 2), mean ± SD                  |
| Postovulatory period (n = 3), mean ± SD      |
| Implantation phase (n = 4), mean ± SD        |
| 10.05 ± 4.48                                 |
| 5.07 ± 2.81                                  |
| 33.57 ± 14.28                                |
| 0.40 ± 0.18                                  |
| 372 ± 14.28                                  |
| 5.07 ± 2.81                                  |
| 10.80 ± 3.21                                 |
| 297.00 ± 95.77                               |
| 0.45 ± 0.15                                  |
| 356.0 ± 24.0                                 |
| 0.86 ± 0.13                                  |
| 62.33 ± 15.46                                |
| 11.30 ± 4.46                                 |
| 10.80 ± 3.21                                 |
| 40.54 ± 10.97                                |
| 3.74 ± 0.97                                  |
| 181.00 ± 103.04                              |
| Abbreviations: LH, luteinizing hormone; SD, standard deviation. |
| *Dash indicates measurement was not performed.* |
both the cervix and cornua seemed to counteract each other and disappear around the middle region of the uterine body when an opposing contraction was encountered.

3.1.3 | LH surge phase

In the LH surge phase, the frequency of wave-like contractions from the cervix peaked and reached the uterine fundus in both the sagittal plane and the transverse plane ($P = .1025$, $P = .1213$; Tables 2 and 3). In contrast, the contractions from the bilateral uterine cornua were nearly undetectable.

3.1.4 | Postovulatory period

After ovulation, the LH surge ended, the serum estradiol concentration decreased, and the progesterone concentration began to rise. In this phase, wave-like contractions from the uterine cornua appeared again. The frequency of contractions from the uterine cervix decreased after the LH surge. The contractions arising from the uterine cornua occurred with similar frequency to those arising from the cervix during the late follicular phase in both sagittal and transverse planes ($P = .5002$, $P = .8166$; Tables 2 and 3). Contractions arising from the uterine cornua ipsilateral to the ovulated ovary did not show a significant difference in frequency relative to those arising from the contralateral side ($P = .2612$; Table 4).

3.1.5 | Implantation phase

A gradually increasing frequency of wave-like contractions from the uterine cervix to the middle of the uterine body was observed.
around the implantation period. These contractions appeared as fine movements immediately below the junctional zone, and occasionally reached the uterine fundus. Few contractions from the uterine cornua were observed. At approximately 8-9 days after ovulation, no contractions were detected from the cervix or uterine cornua. As the progesterone concentration began to decrease, slight contractions from the uterine cornua began to appear in one volunteer.

### 3.1.6 Overall frequencies of contraction among the five phases

The frequencies of contractions from the uterine fundus to the cervix and from the cervix to the uterine fundus significantly differed among the five phases in the sagittal plane ($P = .0044, P = .0051$) and in the transverse plane ($P = .0087, P = .0258$).

### 4 DISCUSSION

The derivation, strength, frequency, and myometrial layer of uterine contractions might change for various reasons during the menstrual cycle. The present study revealed potential variations in contractions during the menstrual cycle, although the differences were not statistically significant. Uterine movements can be vaguely detected using transvaginal ultrasound tomography, whereas cine-mode MRI enables detailed visualization of uterine contractions.\(^{10,11,14}\) Cine-mode MRI may thus be more beneficial than ultrasound imaging for precise detection and confirmation of the direction of uterine contractions.\(^{18}\)

Cine-mode MRI is preferable to elucidate the derivation, frequency, and direction of uterine myometrial movement. In a cine-mode MRI study using the coronal plane, Shitano et al\(^{17}\) captured a total of 60 images at 3-second intervals and used these to assemble

| TABLE 2 | Characteristics of wave-like contractions in each phase in the sagittal plane |
| --- | --- | --- | --- | --- |
| | $F \rightarrow C$, mean ± SD\(^a\) | $C \rightarrow F$, mean ± SD | $P$ (direction)\(^b\) | Thickness\(^d\) |
| Menstruation (n = 7) | 1.29 ± 0.88 | 0.86 ± 0.64 | .3927 | 3/4,1/4,3/4,2/4,3/4,4/4,4/4 |
| Late follicular phase (n = 4) | 5.00 ± 1.22 | 4.00 ± 2.74 | .6612 | JCZ (all) |
| LH surge (n = 2) | 0.00 | 6.50 ± 0.50 | .1025 | JCZ (all) |
| Postovulatory period (n = 3) | 4.33 ± 2.62 | 6.00 ± 2.16 | .5002 | JCZ (all) |
| Implantation phase (n = 3) | 0.25 ± 0.43 | 0.00 | .3173 | JCZ/Isthmus6, Isthmus4\(^e\) |
| $P$ (phase)\(^f\) | .0044 | .0051 |

Abbreviations: LH, luteinizing hormone; JCZ, junctional zone; SD, standard deviation.

\(^a\)F → C, number of wave-like contractions from uterine fundus (cornu) to cervix; C → F, number of wave-like contractions from uterine cervix to fundus.

\(^b\)Mann-Whitney $U$ test.

\(^c\)Kruskal-Wallis test.

\(^d\)Thickness, ratio of myometrial layer showing contraction; Isthmus, fine contractions around cervical isthmus (number indicates contractions per 3 min).

\(^e\)Only two thickness measurements were performed among the three volunteers.

| TABLE 3 | Characteristics of wave-like contractions in each phase in the transverse plane |
| --- | --- | --- | --- |
| | $F \rightarrow C$, mean ± SD\(^a\) | $C \rightarrow F$, mean ± SD | $P$ (direction)\(^b\) | Thickness\(^d\) |
| Menstruation (n = 7) | 1.29 ± 0.45 | 1.00 ± 1.41 | .2235 | 2/4,1/4,4/4,2/4 \(^e\) |
| Late follicular phase (n = 4) | 5.75 ± 1.79 | 2.75 ± 1.92 | .1391 | JCZ (all) |
| LH Surge (n = 2) | 0.50 ± 0.50 | 7.50 ± 0.50 | .1213 | JCZ (all) |
| Postovulatory period (n = 3) | 4.00 ± 2.83 | 4.00 ± 2.16 | .8166 | JCZ (all) |
| Implantation phase (n = 3) | 1.00 ± 0.71 | 0.25 ± 0.43 | .1547 | JCZ, JCZ/Isthmus7\(^d\), JCZ/Isthmus5 |
| $P$ (phase)\(^f\) | .0087 | .0258 |

Abbreviations: LH, luteinizing hormone; JCZ, junctional zone; SD, standard deviation.

\(^a\)F → C, number of wave-like contractions from uterine fundus (cornu) to cervix; C → F, number of wave-like contractions from uterine cervix to fundus.

\(^b\)Mann-Whitney $U$ test.

\(^c\)Kruskal-Wallis test.

\(^d\)Thickness, ratio of myometrial layer showing contraction; Isthmus, fine contractions around cervical isthmus (number indicates contractions per 3 min).

\(^e\)Only four thickness measurements were performed among the seven volunteers.
TABLE 4 Differences of wave-like contractions in late follicular phase and during ovulation in the transverse plane

| Derivation of contraction | Late follicular phase (n = 4) | Postovulatory period (n = 3) |
|---------------------------|------------------------------|----------------------------|
| R → L, mean ± SD<sup>a</sup> | 3.75 ± 2.49 | 2.67 ± 0.94 |
| L → R, mean ± SD<sup>a</sup> | 4.50 ± 3.04 | 2.67 ± 3.77 |
| Ipsilateral, mean ± SD<sup>b</sup> | 5.75 ± 1.79 | 4.00 ± 2.83 |
| Contralateral, mean ± SD<sup>b</sup> | 2.50 ± 2.69 | 1.33 ± 1.89 |
| P (derivation)<sup>c</sup> | .1081 | .2612 |

Abbreviation: SD, standard deviation
<sup>a</sup>R → L, the number of wave-like contraction from the right cornu to left cornu; L → R, the number of wave-like contraction from left cornu to the right cornu.
<sup>b</sup>Ipsilateral, frequency of wave-like contractions from the uterine cornu of the dominant follicle; Contralateral, frequency of wave-like contractions from the uterine cornu of the nondominant follicle.
<sup>c</sup>Mann-Whitney U test.

Shortly after the LH surge ended in this study, the frequency of movements from the cervix decreased and movements from the uterine cornua became detectable again. In the transverse plane, the frequency of the contraction from the ovulation side cornu tended to be higher than that from the contralateral side, as observed before ovulation; however, this was not statistically significant.

The frequency of wave-like movements from the uterine cervix to the uterine fundus gradually decreased after ovulation. However, fine movements from the cervix frequently occurred around the cervical isthmus only during this period. Orisaka et al reported peristaltic movement of the cervical isthmus during the implantation phase in nonpregnant women. Our study found this peristalsis of the cervical isthmus, which disappeared in two of four volunteers in the middle of the luteal phase. In the same period, the frequency of the wave-like movements from the uterine cornua also decreased. The decreased frequency of movements from the uterine cornua is consistent with previous studies involving intrauterine pressure measurements, transvaginal ultrasound, and cine-mode MRI.

Based on reduction in sex steroid hormone concentrations, the uterine myometrium in nonpregnant women gradually begins to contract from the uterine cervix or cornua 10 days after ovulation. Prior to the beginning of menstruation, all layers of the uterine myometrium begin to sporadically contract.

These phenomena suggest that sex steroid hormones may have important roles in nonpregnant uterine contractions. Estrogen reportedly promotes the formation of gap junctions between uterine smooth muscle cells to enhance the transmission of muscle contractions, while progesterone suppresses the formation of gap junctions and plays a role in quiescing the uterine muscle. Estrogen might lead to contractions of the uterine muscle layer along with follicle development, and the frequency of uterine contractions gradually decreases after ovulation. When the serum concentration of progesterone decreases, the smooth muscle tissues begin to gradually react to the electric stimulus again, and menstruation might begin. Notably, the administration of an anti-progesterone drug (RU486) has been reported to promote the

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reaction of uterine muscle to prostaglandin, thereby inducing uterine contraction.\textsuperscript{22} Furthermore, recent reports indicate that telocytes were found in the uterine myometrium and endometrium; these cells might regulate uterine contractions in various stages of the menstruation cycle, pregnancy, labor, and postpartum uterine involution.\textsuperscript{21,24} Sex steroid hormones are presumed to influence smooth muscle cells and telocytes, and the kinetics of the uterus may change during the menstrual cycle. Further physiological research is required in this field.

It was difficult to fully clarify the trends of uterine kinetics in this study because of the small number of volunteers. Although the ethics committee approved a larger study, we were unable to recruit additional volunteers. In addition, the examinations were not performed every point during the menstrual cycle in all volunteers. Because this was a small study, we did not exclude those participants from the analysis because of missing data. However, this study has shown several new aspects of the uterine kinetics in the menstrual cycle of nonpregnant women. Further studies should involve a larger sample size and examinations at multiple points in the menstrual cycle.

The frequency, intensity, and direction of uterine myometrial contractions change throughout the menstrual cycle. Variations in these movements are essential for reproduction. It is necessary to investigate the mechanisms of these variations in detail and to apply cine-mode MRI to elucidate the causes of gynecologic disease, infertility, and obstetric complications.

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DISCLOSURES

Conflict of interest: The authors declare no conflict of interest. Human rights statements and informed consent: All the procedures were followed in accordance with the ethical standards of the responsible committees on human experimentation (institutional and national) and with the principles of the Helsinki Declaration of 1964 and its later amendments. The protocol of this research project was approved by the institutional review board of Soranomori Clinic. Informed consent was obtained from all volunteers for the examinations and in this study. Additional informed consent was obtained from all volunteers for which identifying information is included in this article. Animal studies: This article does not contain any studies with animal subjects performed by the any of the authors.

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REFERENCES

1. Hendricks CH. A new technique for the study of motility in the non-pregnancy human uterus. J Obstet Gynaecol Br Commonwealth. 1964;71:712-715.
2. Cibils LA. Contractility of the nonpregnant human uterus. Obstet Gynecol. 1967;30:441-461.
3. van Gestel I, Ijland MM, Hoogland HJ, Evers JL. Endometrial wave-like activity in the non-pregnant uterus. Hum Reprod Update. 2003;9:131-138.
4. Birnholtz JC. Ultrasonic visualization of endometrial movements. Fertil Steril. 1984;41:157-158.
5. Kunz G, Beil D, Deininger H, Wildt L, Leyendecker G. The dynamics of rapid sperm transport through the female genital tract: evidence from vaginal sonography of uterine peristalsis and hysterosalpingoscintigraphy. Hum Reprod. 1996;11:627-632.
6. Bulletti C, de Ziegler D, Polli V, Diotallevi L, Del Ferro E, Flamigni C. Uterine contractility during the menstrual cycle. Hum Reprod. 2000;15(Suppl 1):81-89.
7. Sechtem U, Pfliugfelder PW, White RD, et al. Cine MR imaging: potential for the evaluation of cardiovascular function. AJR Am J Roentgenol. 1987;148:239-246.
8. Wakamiya M, Furukawa A, Kanasaki S, Murata K. Assessment of small bowel motility function with cine-MRI using balanced steady-state free precession sequence. J Magn Reson Imaging. 2011;33:1235-1240.
9. Morotomi T, Iuchi T, Hashimoto T, Sueyoshi Y, Nagasao T, Isogai N. Image analysis of the inferior rectus muscle in orbital floor fracture using cinemode magnetic resonance imaging. J Craniofac Surg. 2015;43:2066-2070.
10. Nakai A, Tagoshi K, Yamaoka T, et al. Uterine peristalsis shown on cine MR imaging using ultrafast sequence. J Magn Reson Imaging. 2003;18:726-733.
11. Fujiwara T, Tagoshi K, Yamaoka T, et al. Kinematics of the uterus: cine mode MR imaging. Radiographics. 2004;24:e19.
12. Nishino M, Tagoshi K, Nakai A, et al. Uterine contractions evaluated on cine MR imaging in patients with uterine leiomyomas. Eur J Radiol. 2005;53:142-146.
13. Orisaka M, Kurokawa T, Shukanami K-I, et al. A comparison of uterine peristalsis in women with normal uterus and uterine leiomyoma by cine magnetic resonance imaging. Eur J Obstet Gynecol Reprod Biol. 2007;135:111-115.
14. Tagoshi K. Uterine contractility evaluated on cine magnetic resonance imaging. Ann N Y Acad Sci. 2007;1101:62-71.
15. Yoshino O, Hayashi T, Osuga Y, et al. Decreased pregnancy rate is linked to abnormal uterine peristalsis caused by intramural fibroids. Hum Reprod. 2010;25:2475-2479.
16. Kido A, Tagoshi K. Uterine anatomy and function on cine magnetic resonance imaging. Reprod Med Biol. 2016;15:191-199.
17. Nakai A, Tagoshi K, Kosaka K, et al. Uterine peristalsis: comparison of transvaginal ultrasound and two different sequences of cine MR imaging. J Magn Reson Imaging. 2004;20:463-469.
18. Shitano F, Kido A, Kataoka M, et al. Evaluation of uterine peristalsis using cine MRI on the coronal plane in comparison with the sagittal plane. Acta Radiol. 2016;57:122-127.
19. Hendrix EM, Myatt L, Sellers S, Russell PT, Larsen WJ. Steroid hormone regulation of rat myometrial gap junction formation: effects on cx43 levels and trafficking. Biol Reprod. 1995;52:547-560.
20. Di WL, Lachelin GC, McGarrigle HH, Thomas NS, Becker DL. Oestriol and oestradiol increase cell to cell communication and connexin43 protein expression in human myometrium. Mol Hum Reprod. 2001;7:671-679.
21. Kilarski WM, Hongpaisan J, Semlik D, Roomans GM. Effect of progesterone and oestradiol on expression of connexin43 in cultured human myometrium cells. Folia Histochem Cytobiol. 2000;38:3-9.
22. Bygdeman M, Gemzell K, Gottlieb C, Swahn M‐L. Uterine contractility and interaction between prostaglandins and antiprogestins. Clinical implications. Ann N Y Acad Sci. 1991;626:561‐567.
23. Roatesi I, Radu BM, Cretoiu D, Cretoiu SM. Uterine telocytes: a review of current knowledge. Biol Reprod. 2015;93:10.
24. Janas P, Kucyba I, Radoń‐Pokracka M, Huras H. Telocytes in the female reproductive system: an overview of up‐to‐date knowledge. Adv Clin Exp Med. 2018;27:559‐565.

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