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Endometrial development in association with ovarian follicular waves during the menstrual cycle

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Abstract

Objectives—Waves of ovarian follicular development during the menstrual cycle have recently been documented in our laboratory. The objective of this study was to test the hypothesis that ultrasonographically detectable changes in the endometrium during the menstrual cycle would differ between women with two vs. three waves of ovarian follicular development and among women with different major and minor wave patterns of follicle growth.

Methods—Fifty women of reproductive age (mean *age* ± SD, 28.0 ± 6.9 years) underwent daily transvaginal ultrasonography for one interovulatory interval (IOI). Ultrasonographic images of the endometrium were obtained each day, and measurements of endometrial area and perimeter (based on the shape of an ellipse, in the transverse plane) and thickness and pattern (in the sagittal plane) were recorded. Endometrial area, perimeter, thickness and pattern were compared between women with two and three waves of follicle development and among women with different minor and major wave patterns of follicular growth during the IOI.

Results—Endometrial area, perimeter, thickness and pattern increased earlier during the follicular phase in women with two vs. three waves of follicular development. In women with two follicle waves, endometrial area and perimeter increased earlier in those with major major vs. minor major follicle wave patterns.

Conclusions—Ultrasonographically detectable changes in the endometrium occurred in association with follicle wave dynamics in women. Earlier development of the endometrium during the follicular phase in women with two vs. three follicle waves was attributed to an earlier increase in dominant follicle estradiol production.

Keywords

endometrium; follicular waves; menstrual cycle; ovary

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INTRODUCTION

Endometrial development during the human menstrual cycle is closely associated with changes in ovarian function. Granulosa cells of developing ovarian follicles in the follicular phase of the cycle produce estradiol, which stimulates the development of the endometrial lining[1–3]. In the few days before ovulation, progesterone levels begin to rise[2]. The source of the preovulatory rise in progesterone levels is not fully known, but is believed to be the theca, granulosa or interstitial cells[2,4–6]. After ovulation, progesterone produced by the corpus luteum is believed to maintain the estrogen-primed endometrium and stimulate endometrial glandular development to provide an environment conducive to implantation[1–3]. Several growth factors have also been shown to regulate endometrial development (e.g. prostaglandins, interleukins, insulin-like growth factors); however, their precise roles are not fully elucidated[7–11]. Communication between the ovaries and uterus is required for reproductive success. It is therefore plausible that abnormal signaling mechanisms between the ovary and uterus are associated with abnormal endometrial development, infertility and recurrent embryonic loss.

Transvaginal ultrasonography (TVS) has become an invaluable tool for evaluating the endometrium during natural menstrual cycles and the treatment for infertility[12–16]. Ultrasonographically detectable changes in the endometrium occur throughout the menstrual cycle in association with changes in concentrations of serum estradiol and progesterone[17,18]. The endometrium is comprised of two layers: the stratum basalis, which lies next to the myometrium, and the stratum functionalis, which lines the endometrial cavity[19]. The thickness of the endometrium and relative echotexture (i.e. reflectivity) of the stratum functionalis compared to the myometrium are measurements used to assess the endometrium ultrasonographically. Endometrial thickness is measured as the distance between the anterior stratum basalis and posterior stratum basalis layers in the sagittal plane[20,21]. Endometrial thickness has been reported to increase during the follicular phase of the menstrual cycle, peak prior to ovulation, plateau during the early luteal phase and then decline prior to menstruation[14–18]. The increase in endometrial thickness during the follicular phase is associated with an increase in serum estradiol levels[17,18,22].

The endometrium appears ultrasonographically as a thin, simple hyperechogenic single stripe immediately following menses (A pattern). The statum functionalis and basalis layers can be visually differentiated as the endometrium develops during the mid–late follicular phase (B pattern). A pronounced triple-line echotextural pattern, reflective of the separation of the stratum basalis and functionalis layers, is observed in the periovulatory period in association with rising estradiol levels (C pattern). The triple-line pattern disappears after ovulation. A more homogeneous, hyperechogenic endometrium is observed as endometrial glands branch and expand under the influence of luteal progesterone production in the secretory phase (D pattern). Visualization of active menstrual flow is indicative of menses (M pattern)[14,18,20,22–24].

The use of ultrasonographic assessment of the endometrium to predict success following controlled ovarian hyperstimulation and *in-vitro* fertilization (IVF) has been studied. In many reports, a thick endometrium and/or triple-line echogenic pattern of the endometrium

around the time of follicle aspiration was associated with favorable IVF outcomes[25–35]. By contrast, other researchers reported no associations between the ultrasonographic appearance of the endometrium and success following assisted reproduction[13,36–40], and recommended that further research be performed before any definitive conclusions are made.

Limited research has been performed to evaluate the endometrium ultrasonographically during spontaneous menstrual cycles. The current state of knowledge on endometrial growth during the menstrual cycle has been based on previously held notions that dominant ovarian follicles developed only during the follicular phase, followed by follicular quiescence during the luteal phase[41–48]. However, it is now known that waves of ovarian follicular development occur during the menstrual cycle[49,50]. A total of 34/50 (68%) women exhibited two follicular waves, and the remaining 32% exhibited three waves during an interovulatory interval (IOI)[49]. A follicular wave was defined as the synchronous growth of a group of follicles. Only the final follicular wave was ovulatory, while all preceding waves were anovulatory. Follicular waves were characterized as major or minor waves[50]. Major waves were those in which one follicle was selected to become dominant over other follicles of the wave, while minor waves were those in which selection of a dominant follicle was not detected. Dominant follicles were selected for preferential growth at a diameter of approximately 10 mm[50]. In women with two follicle waves, minor major (−+) and major major (++) patterns of follicle wave dynamics were observed[50]. In women with three follicle waves, minor minor major pattern (−−+), minor major major pattern (−++) and major major major (+++) patterns were observed[50].

It is not known whether ultrasonographically detectable changes in the endometrium differ between women with two vs. three follicle waves and among women with major and minor patterns of follicular wave dynamics. This information would increase our understanding about the cyclic changes in ovarian and endometrial function that occur in women. Studies performed thus for have involved the assessment of small numbers of women using transabdominal ultrasonography sometimes in combination with endometrial biopsy and/or histological assessment[14–18]. Serial evaluations of the endometrium during the menstrual cycle using high-resolution TVS in large samples of women have not yet been performed. The objective of this study was to characterize changes in the endometrium every day during one IOI using high-resolution TVS. The research hypothesis tested was that endometrial development (as determined by measurements of endometrial area, perimeter, thickness and echotextural pattern) would differ between women with two vs. three follicular waves and among women with different follicle wave patterns.

METHODS

Fifty women participated in a study designed to characterize ovarian follicular wave dynamics during the menstrual cycle[49,50]. Data collected from the 50 women were evaluated to elucidate associations between patterns of follicle wave dynamics and endometrial development. Participants were assessed, by history and physical examination, to be healthy women of reproductive age (mean age ± SD, 28.0 ± 6.9 (range, 19–43) years). Women who smoked, had been pregnant or lactating 6 months prior to initiating study procedures, had used hormonal contraception within 3 months of enrolling, had a history of irregular

menstrual cycles, were taking medication(s) known or suspected to interfere with reproductive function, or were planning surgery during the study period were not eligible to participate. Informed consent was obtained from all women prior to initiating study procedures. Study protocol was approved by the Institutional Review Board of the University of Saskatchewan.

Each participant underwent daily TVS evaluation of her ovarian and uterine status for one IOI. Scans were initiated 12 days after menses (i.e. before the first ovulation) and were continued until 3 days after the second ovulation. High-resolution Ultramark 9 and ATL HDI 5000 ultrasound machines (Advanced Technologies Laboratories, Bothell, WA, USA) with 5–9-MHz multifrequency convex array transducers were used to acquire imaging data. Approximately 90% of the examinations were performed by a single sonographer (A.R.B.). A second sonographer (R.A.P.) was available when the primary sonographer was not present.

The area, perimeter and thickness of the endometrium were measured during each ultrasound examination. Endometrial area and perimeter measurements were based on the shape of an ellipse, in the transverse plane (Figure 1). Endometrial thickness was measured as the distance from the anterior stratum basalis–myometrial junction to the posterior stratum basalis–myometrial junction, in the mid-sagittal plane. The transverse and sagittal planes of section that represented the largest dimensions of the fundal aspect of the endometrium were used for all measurements. Endometrial echotexture was assessed each day as either an M, A, B, C or D pattern. The criteria used to determine endometrial pattern are shown in Table 1[20]. Plus and minus values of endometrial pattern were used to further refine endometrial pattern scores and minimize intraobserver variability. A plus symbol indicated that the endometrium exhibited ultrasonographic features of both the letter pattern noted and the pattern above. A minus symbol indicated an endometrium that exhibited ultrasonographic features of both the letter value noted and the value below.

Mean endometrial area, perimeter, thickness and pattern during the IOI were plotted, irrespective of follicle wave status. Endometrial data were then plotted separately for women with two- or three-wave cycles, as previously determined[49]. In women with two follicle waves, endometrial data were further partitioned into −+ and ++ follicle wave patterns, as previously determined[50]. In women with three follicle waves, data were further categorized into −−+, −++ and +++ follicle wave patterns, as previously determined[50]. For graphical purposes, data were normalized to the mean IOI for women with two (27.4 ± 0.4 days) and three (29.4 ± 0.6 days) follicle waves. Repeated measures ANOVA (PROC MIXED, SAS/STAT Software, 2001, SAS Institute Inc., Cary, NC, USA) were used to assess changes in the area, perimeter, thickness and pattern of the endometrium during the IOI to determine if differences could be detected between women with two vs. three follicular waves and among women with different follicle wave patterns.

RESULTS

The mean area, perimeter, thickness and pattern of the endometrium, irrespective of follicle wave dynamics (i.e. before partitioning data into women with two vs. three follicular waves

and major and minor patterns of follicular development), remained constant during the early to mid-luteal phase, decreased approximately 10 days after ovulation (i.e. the late luteal phase) and then increased during the follicular phase. Endometrial area reached peak values of 281.7 ± 11.9 mm^2 on the day of the first ovulation, declined to a nadir of 106.8 mm^2 3 days after menses began and reached a peak level again of 253.0 ± 14.2 mm^2 immediately prior to the second ovulation. Endometrial perimeter reached a peak level of 75.9 ± 2 mm 10 days after ovulation, decreased to 55.3 ± 1.8 mm 1 day after menses began and then increased to 66.6 ± 2.1 mm prior to the second ovulation. Endometrial thickness reached a peak of 10.4 ± 0.3 mm on the day of the first ovulation, decreased to 4.4 ± 0.2 mm 1 day after menses began and then increased to 9.2 ± 0.4 mm in the late follicular phase before the second ovulation. The endometrium was a D pattern 1 day following the first ovulation, an A pattern 2 days after menses began and a C pattern in the late follicular phase prior to the second ovulation. Ultrasonographic characterizations of endometrial pattern in one woman during the IOI are shown in Figure 2.

Changes in the endometrium during the IOI for women with two vs. three follicular waves are illustrated in Figure 3. Endometrial area (Figure 3a) during the follicular phase of the cycle (i.e. days 17–30) increased earlier in women with two vs. three follicular waves (day effect: $P < 0.0001$; wave effect: 0.88; day * wave effect = 0.008). Endometrial perimeter (Figure 3b) during the follicular phase increased earlier in women with two vs. three follicle waves (day effect: $P < 0.0001$; wave effect: $P = 0.28$; day * wave effect: $P = 0.008$). Endometrial thickness (Figure 3c) during the follicular phase increased earlier in women with two vs. three follicle waves (day effect: $P < 0.0001$; wave effect: $P = 0.01$; day * wave effect: $P = 0.08$). Likewise, endometrial pattern (Figure 3d) during the follicular phase increased earlier in women with two vs. three follicular waves (day effect: $P < 0.0001$; wave effect: $P = 0.02$; day * wave effect: $P < 0.0001$). No differences in endometrial development were detected between women with two vs. three waves during the luteal phase ($P > 0.05$).

Changes in the endometrium during the IOI for women with major and minor wave patterns of follicle development are shown in Figure 4. In women with two follicle waves, endometrial area (day effect: $P < 0.0001$; pattern effect: $P = 0.15$; day * pattern effect: $P = 0.002$) and perimeter (day effect: $P < 0.0001$; pattern effect: $P = 0.003$; day * pattern effect: $P = 0.69$) during the follicular phase appeared to increase earlier in those with ++ vs. −+ wave patterns of follicle growth. In women with three follicle waves, no differences in endometrial development were detected among −−+, −++ and +++ follicle wave patterns (day effect: $P < 0.0001$; pattern effect: $P > 0.05$; day * pattern effect: $P > 0.05$).

DISCUSSION

Serial examinations of the endometrium using high-resolution TVS supported the results of previous studies in which changes in endometrial thickness and echotexture during the menstrual cycle were documented[14,18,20,22–24]. Endometrial area, perimeter and thickness reached a plateau after ovulation, declined at the end of the luteal phase before menstruation, and then increased sharply during the follicular phase of the IOI. Endometrial echotexture was represented by a D pattern in the luteal phase, M pattern during menses, A pattern in the early follicular phase and C pattern in the late follicular phase of the IOI.

The results of the present study supported the hypothesis that endometrial development would differ among women in association with differences in ovarian follicular wave dynamics. Ultrasonographically detectable differences in endometrial development during the menstrual cycle were observed in women with two vs. three waves of ovarian follicular development. Endometrial area, perimeter, thickness and pattern measurements increased earlier during the follicular phase in women with two compared with three waves of follicular development. The earlier development of the endometrium during the follicular phase in women with two follicle waves occurred in association with an earlier rise in serum estradiol levels, as previously described in our laboratory[50]. The earlier increase in estradiol levels was believed to occur as a result of the earlier emergence of the dominant ovulatory follicle in women with two vs. three follicle waves[50]. The preovulatory estradiol, follicle-stimulating hormone and luteinizing hormone surges were previously documented to occur 1 day earlier, in association with a shorter IOI, in women with two vs. three follicle waves[50]. We therefore concluded that the earlier emergence of the dominant ovulatory follicle in women with two vs. three follicle waves was associated with earlier dominant follicle estradiol production, endometrial development and preovulatory hormonal surge.

Major and minor waves of follicle development occur during the follicular and luteal phases of the menstrual cycle in healthy women of reproductive age[50]. Differences in endometrial growth, as determined ultrasonographically, were detected in women with minor and major wave patterns of follicle development. In women with two follicle waves, endometrial area and perimeter during the follicular phase appeared to rise earlier in women with ++ vs. −+ wave patterns of follicular growth. In women with three wave patterns of follicle growth (−−+, −++ and +++ patterns) no differences in endometrial growth were observed. Major waves were those in which a dominant follicle was selected for preferential growth, while minor waves were those in which dominance was not manifest[50]. There was no difference in the day of emergence of the second follicle wave (14 days after the first ovulation) in women with both ++ and −+ patterns of follicular growth[50]. Therefore, we believe the earlier development of the endometrium in women with ++ vs. −+ wave patterns to be inconclusive. Categorization of the data into subgroups of women with different patterns of follicular wave dynamics resulted in small sample sizes. Resolution of this conundrum will require further analyses on a larger sample population.

The results of the present study have increased our understanding of the basic physiological mechanisms underlying ovarian and uterine function during the menstrual cycle and provide rationale for the notion that endometrial development is closely related to ovarian follicle wave dynamics. The knowledge that the endometrium develops earlier during the follicular phase in women with two vs. three follicle waves may help to explain the variability in endometrial thickness and echotexture that has been reported in women undergoing assisted reproductive technologies. In addition, we believe that the knowledge about variability in endometrial growth and follicle wave dynamics during the menstrual cycle may provide insight into the elucidation of uterine factors which may be associated with infertility and/or recurrent pregnancy loss.

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References

1. Baulieu, E., Mortel, R., Robel, P. Estrogen and progesterone receptors in normal and pathological human endometrium. In: Kimball, FA., editor. The Endometrium. SP Medical and Scientific Books; New York, NY: 1980. p. 85-105.
2. Chikazawa K, Araki S, Tamada T. Morphological and endocrinological studies on follicular development during the human menstrual cycle. J Clin Endocrinol Metab. 1986; 62:305–313. [PubMed: 3941159]
3. Guidice, L., Ferenczy, A. The endometrial cycle. In: Adashi, EY.Rock, JA., Rosenwaks, Z., editors. Reproductive Endocrinology, Surgery and Technology. Vol. 1. Lipincott–Raven Publishers; Philadelphia, PA: 1996. p. 271-300.
4. Gougeon A. Steroid 3β-ol-dehydrogenase activity in the largest healthy and atretic follicles in the human ovary during the menstrual cycle. Ann Biol Anim Biochim Biophys. 1977; 17:1095–1099.
5. Hillier, SG. Cellular basis of follicular endocrine function. In: Hillier, SG., editor. Ovarian Endocrinology. Blackwell Scientific Publications; London, UK: 1991. p. 73-106.
6. Speroff, L.Glass, RH., Kase, NG., editors. Clinical Gynecologic Endocrinology and Infertility. 6. Lippincott Williams & Wilkins; Philadelphia, PA, USA: 1999. Regulation of the menstrual cycle; p. 201-246.
7. Smith SK. Prostaglandins and growth factors in the endometrium. Baillieres Clin Obstet Gynaecol. 1989; 3:249–270. [PubMed: 2692920]
8. Guidice LC. Growth factors and growth modulators in human uterine endometrium: their potential relevance to reproductive medicine. Fertil Steril. 1994; 61:1–17. [PubMed: 7507444]
9. Smith SK. Growth factors in the human endometrium. Hum Reprod. 1994; 9:936–946. [PubMed: 7929745]
10. Von Wolff M, Thaler C, Strowitzki T, Broome J, Stolz W, Tabibzadeh S. Regulated expression of cytokines in human endometrium throughout the menstrual cycle: dysregulation in habitual abortion. Mol Hum Reprod. 2000; 6:627–634. [PubMed: 10871650]
11. Taylor R, Lebovic D, Hornung D, Muellef M. Endocrine and paracrine regulation of endometrial angiogenesis. Ann N Y Acad Sci. 2001; 943:109–121. [PubMed: 11594532]
12. Brandt T, Levy E, Grant T, Marut E, Leland J. Endometrial echo and its significance in female infertility. Radiology. 1985; 157:225–229. [PubMed: 3929327]
13. Fleischer AC, Herbert CM, Sacks GA, Wentz AC, Entman SS, James AE Jr. Sonography of the endometrium during conception and nonconception cycles of *in vitro* fertilization and embryo transfer. Fertil Steril. 1986; 46:442–447. [PubMed: 3091409]
14. Fleischer AC, Kalemeris GC, Entman SS. Sonographic depiction of the endometrium during normal cycles. Ultrasound Med Biol. 1986; 12:271–277. [PubMed: 3521022]
15. Fleischer AC, Kalemeris GC, Machin JE, Entman SS, James AE Jr. Sonographic depiction of normal and abnormal endometrium with histopathologic correlation. J Ultrasound Med. 1986; 5:445–452. [PubMed: 3528523]
16. Forrest T, Elyaderani M, Muilenburg M, Bewtra C, Kable W, Sullivan P. Cyclic endometrial changes: ultrasound assessment with histologic correlation. Radiology. 1988; 167:233–237. [PubMed: 3279455]
17. Eden JA, Place J, Carter GD, Jones J, Alaghband-Zadeh J, Pawson ME. What are the ultrasound and biochemical features of impending ovulation? Aust N Z J Obstet Gynaecol. 1988; 28:225–227. [PubMed: 3069088]
18. Katayama T. Ultrasonographic changes in the endometrium during ovulatory cycles – correlation to serum estradiol and progesterone concentrations [in Japanese]. Nippon Sanka Fujinka Gakkai Zasshi. 1990; 42:1530–1536. [PubMed: 2273308]

19. Netter, FH. Atlas of Human Anatomy. Summit, NJ: Ciba-Geigy Corporation; 1989.
20. Lindenberg, S. Ultrasonographic assessment of the endometrium during the normal menstrual cycle. In: Jaffe, R.Pierson, R., Abramowicz, J., editors. Imaging in Infertility and Reproductive Endocrinology. J. B. Lipincott Company; Philadelphia, PA: 1994. p. 47-61.
21. Persadie R. Ultrasonographic assessment of the endometrial thickness: a review. J Obstet Gynaecol Can. 2002; 24:131–136. [PubMed: 12196878]
22. Wang ZM. Transvaginal ultrasonographic monitoring on the morphological changes of ovary and endometrium during normal menstrual cycle [in Chinese]. Zhonghua Fu Chan Ke Za Zhi. 1993; 28:18–20. 59. [PubMed: 8504703]
23. Gormaz G, Prado S, Duque G, Gormaz C, Tsunekawa H, Cossio A, Pentz C, Uribe C. The ultrasonographic characteristics of the endometrium during the spontaneous ovulatory menstrual cycle [in Spanish]. Rev Chil Obstet Ginecol. 1992; 57:257–262. [PubMed: 1342451]
24. Goncalves WJ, Dolnikoff M, de Lima GR, Baracat EC, Nicolau SM, Girao MJ, Novo NF, Giusa MG, Borrelli K. Serial ultrasonography of the endometrium and endocervix during the normal menstrual cycle in women [in Portuguese]. Rev Assoc Med Bras. 1995; 41:197–202. [PubMed: 8574229]
25. Gonen Y, Casper RF. Prediction of implantation by the sonographic appearance of the endometrium during controlled ovarian stimulation for *in vitro* fertilization (IVF). J In Vitro Fert Embryo Transf. 1990; 7:146–152.
26. Check JH, Nowroozi K, Choe J, Dietterich C. Influence of endometrial thickness and echo patterns on pregnancy rates during *in vitro* fertilization. Fertil Steril. 1991; 56:1173–1175. [PubMed: 1743341]
27. Dickey RP, Olar TT, Curole DN, Taylor SN, Rye PH. Endometrial pattern and thickness associated with pregnancy outcome after assisted reproduction technologies. Hum Reprod. 1992; 7:418–421. [PubMed: 1587952]
28. Khalifa E, Brzyski RG, Oehninger S, Acosta AA, Muasher SJ. Sonographic appearance of the endometrium: the predictive value for the outcome of *in-vitro* fertilization in stimulated cycles. Hum Reprod. 1992; 7:677–680. [PubMed: 1639988]
29. Abdalla HI, Brooks AA, Johnson MR, Kirkland A, Thomas A, Studd JW. Endometrial thickness: a predictor of implantation in ovum recipients? Hum Reprod. 1994; 9:363–365. [PubMed: 8027298]
30. Coulam CB, Bustillo M, Soenksen DM, Britten S. Ultrasonographic predictors of implantation after assisted reproduction. Fertil Steril. 1994; 62:1004–1010. [PubMed: 7926110]
31. Noyes N, Liu HC, Sultan K, Schattman G, Rosenwaks Z. Endometrial thickness appears to be a significant factor in embryo implantation in *in-vitro* fertilization. Hum Reprod. 1995; 10:919–922. [PubMed: 7650143]
32. Serafini P, Batzofin J, Nelson J, Olive D. Sonographic uterine predictors of pregnancy in women undergoing ovulation induction for assisted reproductive treatments. Fertil Steril. 1994; 62:815–822. [PubMed: 7926093]
33. Weissman A, Gotlieb L, Casper RF. The detrimental effect of increased endometrial thickness on implantation and pregnancy rates and outcome in an *in vitro* fertilization program. Fertil Steril. 1999; 71:147–149. [PubMed: 9935132]
34. Fanchin R, Righini C, Ayoubi JM, Olivennes F, de Ziegler D, Frydman R. New look at endometrial echogenicity: objective computer-assisted measurements predict endometrial receptivity in *in vitro* fertilization-embryo transfer. Fertil Steril. 2000; 74:274–281. [PubMed: 10927044]
35. Basir GS, O WS, So WW, Ng EH, Ho PC. Evaluation of cycle-to-cycle variation of endometrial responsiveness using transvaginal sonography in women undergoing assisted reproduction. Ultrasound Obstet Gynecol. 2002; 19:484–489. [PubMed: 11982983]
36. Mardesic T, Muller P, Zetova L, Mikova M, Stroufova A. Factors affecting the results of *in vitro* fertilization. iii. The effect of the height and properties of the endometrium in the ultrasound image on the probability of implantation [in Czech]. Ceska Gynekol. 1995; 60:3–7. [PubMed: 7719589]
37. Friedler S, Schenker JG, Herman A, Lewin A. The role of ultrasonography in the evaluation of endometrial receptivity following assisted reproductive treatments: a critical review. Hum Reprod Update. 1996; 2:323–335. [PubMed: 9080229]

38. Sterzik K, Grab D, Schneider V, Strehler EJ, Gagsteiger F, Rosenbusch BE. Lack of correlation between ultrasonography and histologic staging of the endometrium in *in vitro* fertilization (IVF) patients. Ultrasound Med Biol. 1997; 23:165–170. [PubMed: 9140174]
39. Sundstrom P. Establishment of a successful pregnancy following *in-vitro* fertilization with an endometrial thickness of no more than 4 mm. Hum Reprod. 1998; 13:1550–1552. [PubMed: 9688390]
40. Csemiczky G, Wramsby H, Johannisson E, Landgren BM. Endometrial evaluation is not predictive for *in vitro* fertilization treatment. J Assist Reprod Genet. 1999; 16:113–116. [PubMed: 10091112]
41. Gougeon A. Qualitative changes in medium and large antral follicles in the human ovary during the menstrual cycle. Ann Biol Anim Biochim Biophys. 1979; 19:1464–1468.
42. Pache T, Wladimiroff J, DeJong F, Hop W, Fauser B. Growth patterns of nondominant ovarian follicles during the normal menstrual cycle. Fertil Steril. 1990; 54:638–642. [PubMed: 2209884]
43. Hodgen G, Kenigsburg D, Collins R, Schenken R. Selection of the dominant ovarian follicle and hormonal enhancement of the natural cycle. Ann N Y Acad Sci. 1985; 442:23–37. [PubMed: 3925837]
44. Tonetta SA, Zerega GSD. Intragonadal regulation of follicular maturation. Endocr Rev. 1989; 10:205–229. [PubMed: 2473895]
45. McNatty KP, Hillier SG, Boogaard AMVD, Trimbos-Kemper TC, Reichert LK, Hall EVV. Follicular development during the luteal phase of the human menstrual cycle. J Clin Endocrinol Metab. 1983; 56:1022–1031. [PubMed: 6403567]
46. Check J, Dietterich C, Houck MA. Ipsilateral versus contralateral ovary selection of dominant follicle in succeeding cycle. Obstet Gynecol. 1991; 77:247–249. [PubMed: 1988887]
47. Baird DT, Baker TG, McNatty KP, Neal P. Relationship between the secretion of the corpus luteum and the length of the follicular phase of the ovarian cycle. J Reprod Fertil. 1975; 45:611–619. [PubMed: 1107537]
48. Zeleznik AJ. Follicle selection in primates: “Many are called but few are chosen”. Biol Reprod. 2001; 65:655–659. [PubMed: 11514325]
49. Baerwald A, Adams G, Pierson R. A new model for ovarian follicular development during the human menstrual cycle. Fertil Steril. 2003; 80:116–122. [PubMed: 12849812]
50. Baerwald A, Adams G, Pierson R. Characteristics of ovarian follicular wave dynamics in women. Biol Reprod. 2003; 69:1023–1031. [PubMed: 12748128]
51. Baird D. A model for follicular selection and ovulation: lessons from superovulation. J Steroid Biochem. 1987; 27:15–23. [PubMed: 3121918]
52. Ginther OJ, Beg MA, Bergfelt DR, Danadeu FX, Kot K. Follicle selection in monovular species. Biol Reprod. 2001; 65:638–647. [PubMed: 11514323]

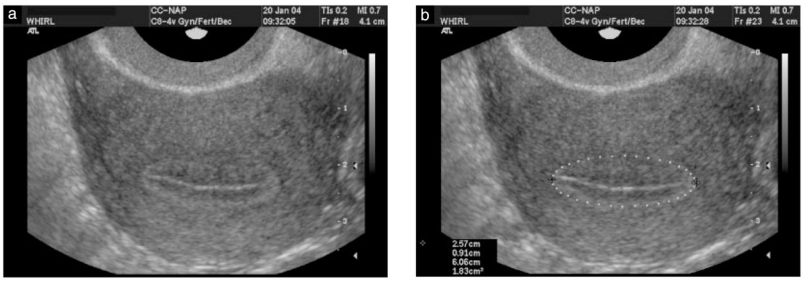

Figure 1.

Ultrasonographic images of the endometrium in maximal transverse plane. The outer stratum basalis layer, inner functionalis layer and uterine lumen are shown (a). Measurements of the long axis, short axis, perimeter and area of the endometrium are shown in the bottom left corner (b). Dotted lines depict the perimeter measurement of the endometrium (b).

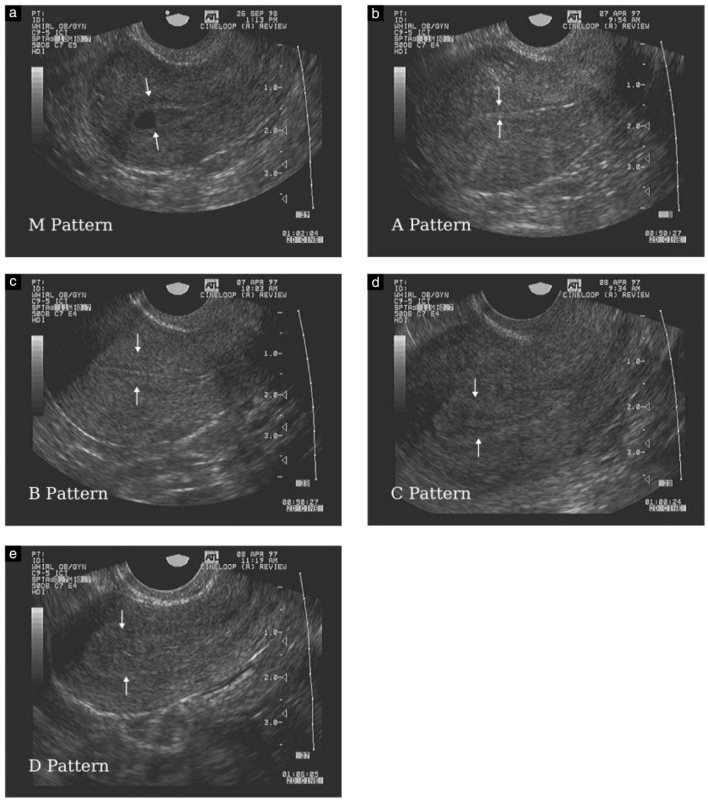

Figure 2.

Ultrasonographic images of the endometrium illustrating the M pattern (a: day 3 of menses; active flow visualized), A pattern (b: early follicular phase), B pattern (c: mid-follicular phase), C pattern (d: periovulatory period) and D pattern (e: mid-luteal phase) of echogenicity. The endometrium is shown in sagittal section. Arrows demarcate the anterior and posterior borders of the endometrium.

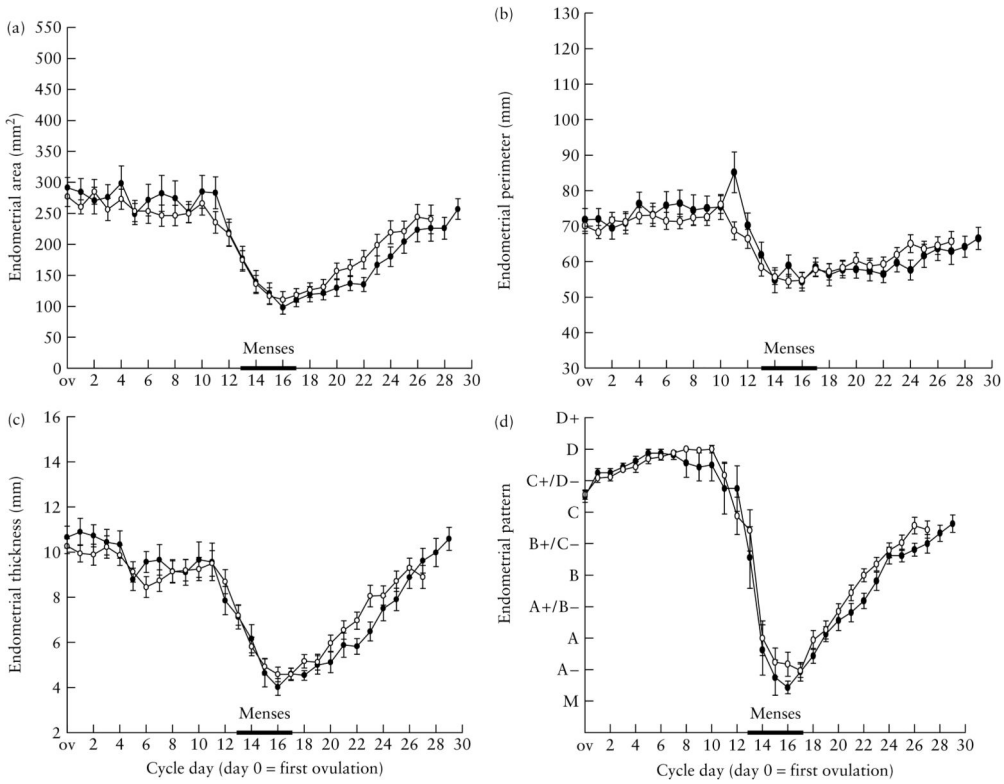

Figure 3.

Endometrial area (a), perimeter (b), thickness (c) and pattern (d) normalized to the mean interovulatory interval for women with two (○; 27.4 ± 0.4 days) and three (●; 29.4 ± 0.6 days) waves of follicle development. Mean ± standard error is shown. ov, ovulation.

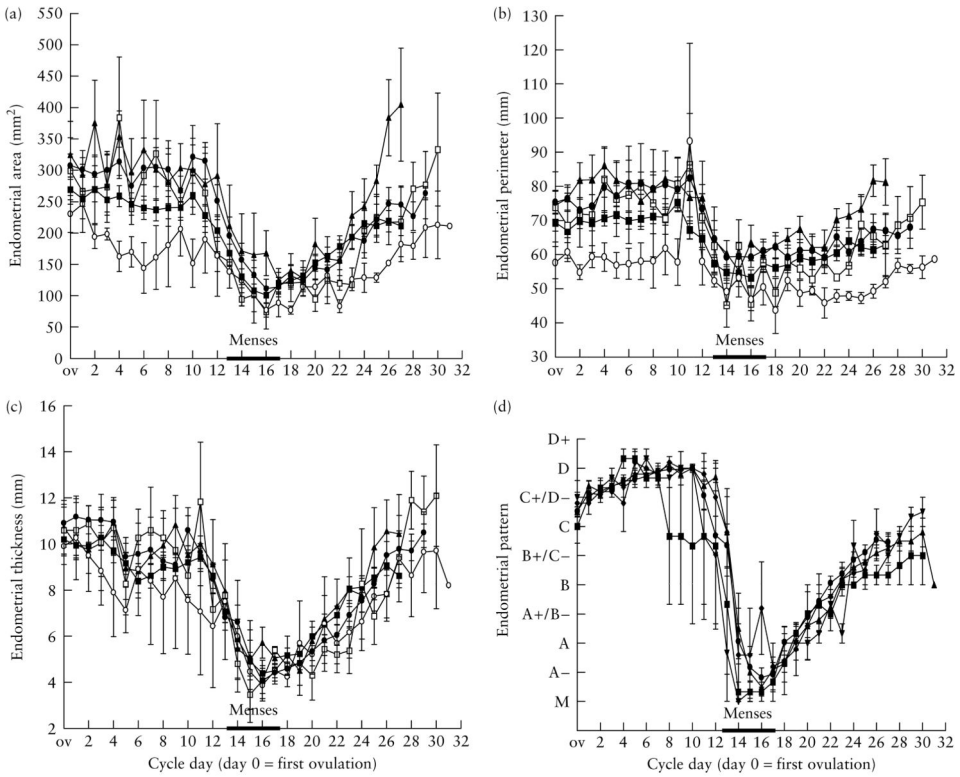

Figure 4.

Endometrial area (a), perimeter (b), thickness (c) and pattern (d) normalized to the mean interovulatory interval for women with −+ (■; 27.4 ± 0.4 days), ++ (▲; 27.2 ± 1.0 days), −−+ (●; 28.8 ± 0.7 days), −++ (○; 30.7 ± 1.0 days) and +++ (□; 30.0 ± 1.0 days) patterns of follicle wave dynamics. Mean ± standard error is shown. ov, ovulation.

Table 1

Characteristics for determining endometrial pattern

Pattern	Criteria
M	Active menstrual flow observed
A	Postmenstrual; thin; single line; no detectable differentiation of stratum functionalis and basalis
B	Early follicular phase; triple line; some differentiation of the stratum functionalis and basalis
C	Periovulatory; thick; pronounced triple line; pronounced differentiation of the stratum functionalis and basalis
D	Luteal phase; thick; homogeneous echogenicity