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Review Article

Basal Body Temperature in Reproductive Medicine: A Comprehensive Review and Contemporary Applications

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Abstract

Basal body temperature (BBT) is a convenient, continuous, non-invasive, and cost-effective method with irreplaceable advantages in the field of gynecological reproductive endocrinology. This review provides a comprehensive overview of the development history of BBT, analyzes its physiological regulatory mechanisms and interpretation, and examines the current state of research on its clinical applications in reproductive medicine. While many aspects of BBT's clinical use and underlying mechanisms remain to be fully understood by modern medicine, the advancement of artificial intelligence (AI) technologies and their integration into BBT research are paving the way for a new phase in its development and application.

Keywords: Basal Body Temperature (BBT), Reproductive Medicine, Reproductive Endocrinology, Gynecology, Infertility

Introduction

Basal body temperature (BBT) is a valuable tool in reproductive medicine for diagnosing endocrine disorders—such as infertility, ovulatory dysfunction, and luteal phase deficiency—and for evaluating treatment efficacy. Despite its advantages, attention to BBT has waned with the rise of modern diagnostic technologies, and many aspects of its clinical application and regulatory mechanisms remain unclear. This paper systematically reviews literature on BBT's development, regulation, and clinical utility, aiming to renew interest and foster further advancements in this field.

1. Development of BBT Measurement

Basal body temperature (BBT) monitoring has played a significant role in understanding female reproductive physiology. The invention of the thermometer by Galileo Galilei in 1593 laid the foundation for temperature-based observation. In 1868, William S. Squire first identified the biphasic pattern of BBT during menstrual cycle [1-4]. In 1905, Dutch gynecologist Theodoor Hendrik Van de Veld linked BBT shifts associated with ovulation and later, in 1926, attributed the temperature rise to luteal function, noting its association with increased vaginal secretions and mid-cycle abdominal pain [5]. With advancements in ultrasound and hormone assays, BBT's clinical use declined, and its reliability was questioned [6]. However, recent studies highlight its correlation with hormonal fluctuations [7]. Modern technology, including smartphone apps and different kinds of wearable sensors, has improved BBT tracking by enabling continuous, dynamic monitoring [8-15]. Despite advancements, current clinical data are insufficient to fully assess the accuracy and consistency of these methods, which are crucial for objectively understanding BBT's physiological mechanisms and hormonal correlations.

2. Physiological Mechanisms Regulating BBT

Core body temperature, which reflects the temperature of deep tissues, is regulated at around 37°C in most placental mammals and follows a 24-hour circadian rhythm [16-19]. Core temperature varies with the menstrual cycle and is measured as basal body temperature (BBT) during the morning rest period. Although central arterial or mixed venous blood temperature ideally represents core body temperature, its inaccessibility makes commonly used sites—such as the mouth, axilla, ear canal, or tympanic membrane—provide less accurate indicators of core temperature, skin temperature is usually not a good indicator of core body temperature [20-21].

Estrogen, progesterone, and testosterone influence temperature-sensitive neurons in the hypothalamus, which plays a key role in regulating body temperature and homeostasis. These hormones may have synergistic or antagonistic effects on temperature regulation [22-26].

During the follicular phase, BBT is low due to estrogen [27]. Estrogen likely regulates body temperature by acting on temperature-sensitive neurons in the preoptic area of the hypothalamus via nuclear steroid receptors, alternating the excitatory firing rate and integrating thermal signals in key brain regions controlling thermoregulation [22]. Additionally, estrogen promotes lower body temperature by enhancing heat dissipation responses, such as increased vasodilation of skin blood vessels [28,29]. Studies show that follicular phase temperatures do not significantly change with age and have weak correlations with daylight duration and cycle length [30].

In the late follicular phase, just before ovulation, estradiol levels rise, causing core body temperature to reach its lowest point [29,31]. Correspondingly, studies show that average vaginal temperature decrease compared to the early follicular phase as estradiol increases before ovulation [29,31,32].

Many studies suggest that the rise in BBT during ovulation and the sustained high-temperature phase in the luteal phase are linked to progesterone's effects on temperature-sensitive neurons in the preoptic area of the brain [24,27]. However, this increase in BBT occurs 24-48 hours after plasma progesterone and 17-hydroxyprogesterone levels rise, coinciding with the LH surge [33,34]. Furthermore, a linear increase between pregnanediol-3α-glucuronide (PDG) levels and BBT is observed during ovulation, but once PDG levels exceed 10 mcg/mg Cr, BBT no longer rises [7]. This suggests that there is a limit to how much BBT can increase, even with higher PDG levels. Moreover, a study using smartphone applications found that luteal phase temperature shows age-related changes, with a gradual increase until it peaks at age 29, stabilizing after age 42, and then declining [30].

BBT starts to decrease after the fourth month of pregnancy and returns to pre-ovulation levels by the fifth month. Although progesterone levels continue to rise during mid-pregnancy, the decrease in BBT suggests that progesterone is not the sole cause of the elevated temperature [35,36]. This implies an indirect relationship between progesterone and BBT [37]. Additionally, there is no significant change in norepinephrine levels before and after ovulation, suggesting that the rise in BBT after ovulation is mainly driven by norepinephrine release from the hypothalamus, influenced by estrogen during the follicular phase [38].

The relationship between progesterone and estrogen and its impact on BBT is intricate and not yet fully understood. Forman et al. observed BBT in 87 patients undergoing in vitro fertilization and found no correlation between BBT increase and progesterone levels or hormone stimulation type, suggesting that progesterone does not directly control temperature. Instead, it may interact synergistically with estrogen [39]. Additionally, the amplitude of the daily temperature rhythm decreases during the luteal phase, highlighting the critical role of the balance between progesterone and estrogen in regulating body temperature [20,40]. However, the specific dynamics of how those hormones interact remain unclear and warrant future investigation.

In summary, progesterone and estrogen regulate body temperature through complex interactions and dynamic balances in both central and peripheral mechanisms. Their effects on vasodilation and vasoconstriction likely influence the hypothalamus, further modulating core body temperature. However, the exact physiological mechanisms behind BBT regulation remain unclear. Exploring these dynamics will offer a more comprehensive understanding of how hormones control thermoregulation across different phases of the menstrual cycle and pregnancy.

3. Interpretation of BBT

Basal body temperature (BBT), measured at rest upon waking, is 0.3°C to 0.7°C higher during the luteal phase than the follicular phase [41]. The World Health Organization (WHO) defines the transition from low to high temperatures during ovulation as a rise of at least 0.2°C within 48 hours or less and sustained over three consecutive days, known as the "3/6 rule" [42-44]. A "cover line" can be drawn on BBT charts at the highest temperature from the six days before the rise. A sustained increase above this line confirms ovulation with a biphasic pattern [45]. BBT fluctuations can be influenced by numerous factors, including colds, inflammation, alcohol consumption, recording methods, sleep schedules, education level, and thermometer quality [42,52,53].

Studies suggest that in conception cycles, early luteal progesterone levels rise more significantly, and both estrogen and progesterone are elevated during the mid-luteal phase compared to non-conception cycles. These hormonal patterns may indicate high-quality cycles favorable for conception [46].

The temperature changes during ovulation can vary in pattern across individuals. The fertile window spans six days, ending on the day of ovulation [47]. Within this window, pre-ovulatory temperature dips occur in 33%-75% of cycles [48]. The temperature rise during ovulation can follow different patterns: sharp and rapid (74%-82%), gradual (15%), stepwise (2%), or sawtooth. All show clear biphasic patterns [49,50]. However, other studies report 84% of BBT charts displaying a biphasic pattern, with 26% showing a rapid rise and 58% a gradual rise [51].

Small-scaled studies found no significant correlation between BBT and prolactin levels, or differences in BBT between groups with thyroid-stimulating hormone (TSH) levels above or below 2.5 mU/L [54].

Though BBT patterns are useful for tracking ovulation and conception cycles, the reproductive medicine community has yet to establish a universally accepted standard for interpreting BBT, leading to variability in clinical practice [55].

4. Clinical Applications of BBT

Current literature suggests that observing BBT in clinical practice can offer insights into various physiological and pathological aspects:

1) Observing Ovulation

BBT-based ovulation predictions have an accuracy of 74-98%, as confirmed by studies using serum and urinary hormone levels and ultrasound examinations. Luteinizing hormone (LH) test kits have a significant margin of error when used alone, though widely used for ovulation detection. Combining basal body temperature (BBT) monitoring and reproductive apps can improve detection accuracy and shorten detection times [56-60].

BBT is considered unreliable for accurately identifying luteinized unruptured follicles (LUFs). A study of 71 infertile women with normal menstrual cycles and biphasic BBT patterns found 15 cases (21.1%) of LUFs, confirmed through ultrasound, laparoscopy, hormone measurements, and endometrial histology [61]. Another study of 50 similar patients identified 3 cases (6%) of LUFs [62-63].

BBT alone is imprecise for predicting ovulation timing due to significant variability. In ovulatory cycles, 0-20% of BBT charts may show monophasic patterns, and 12-20% of monophasic BBT charts may still correspond to ovulation [57,64]. Even advanced application technologies have limited ability to accurately pinpointing ovulation days. Studies also report that follicular rupture may occur before or after the BBT rise, further complicating ovulation prediction [65-67]. For example, Buxton et al. found that in one-third of cases, ovulation had occurred over 24 hours before the first BBT rise during laparoscopic exams [68]. Similarly, Newill et al. observed no conceptions when insemination occurred before day 11 of the cycle or more than 48 hours after the BBT rise. Most conceptions occurred the evening before the rise [50].

Using BBT alone limits the accuracy of determining the ovulation window, but extending the prediction window can improve it. The concordance between the BBT nadir and LH peak on the same day is 20-30%. However, extending the prediction window by one day before and after the LH peak increases accuracy to 57-70%, and by two days improves accuracy rises to 83-98% [69]. Wilcox et al. found peak fertility occurs within the two days before ovulation [70].

Polycystic ovary syndrome (PCOS) is the most common endocrine disorder in women, accounting for about 85% of ovulatory dysfunction cases. Using vaginal biosensors, researchers have generated reproductive cycle temperature curves that reveal significant differences in BBT among PCOS patients compared to healthy controls. PCOS patients display delayed temperature rises and greater daily fluctuations, despite a prolonged follicular phase and a generally normal luteal phase [54]. Liu et al. analyzed BBT patterns in 148 PCOS patients and found that the most common pattern was monophasic, followed by atypical biphasic, with no typical biphasic patterns observed [89].

Although the exact optimal date for conception may vary, most studies agree that the three days before ovulation represents the ideal fertile window. Combining BBT with cervical mucus observations and urinary ovulation tests enhances accuracy in identifying the fertile window. Overall, majority of studies conclude that BBT is a relatively accurate method for both retrospective and dynamic analysis of ovulation.

2) Understanding Luteal Function:

The American Society for Reproductive Medicine recommends BBT as a non-invasive diagnostic tool for luteal phase deficiency (LPD), though establishing diagnostic criteria for LPD is challenging due to the fluctuating nature of progesterone levels [72]. The average luteal phase lasts 12.4–13.7 days [56,71]. Many experts suggest considering LPD when the luteal phase is ≤10 days [72]. A slow post-ovulatory rise in BBT and luteal phase length are proposed diagnostic criteria for LPD. Studies suggest that a slow rise in BBT during ovulation may indicate poor ovulation or early luteal phase dysfunction, increasing the risk of miscarriage [73]. Women with LPD also show significant differences in temperature curves, including higher amplitude during the luteal phase compared to those with normal luteal function [54].

Some studies suggest BBT can only detect severe LPD, while most mild to moderate cases show normal luteal phase lengths. A normal luteal phase length doesn't rule out significant dysfunction [75]. Schliep et al. divided LPD patients with progesterone ≤10 ng/mL into two groups: clinical LPD (short luteal phase <10 days) and biochemical LPD (progesterone ≤5 ng/mL), suggesting different underlying mechanisms [76]. Matsumoto classified BBT curves into seven types, while Kunimoto combined BBT, urinary progesterone, and endometrial images for seven LPD types. Building on Matsumoto's system, Taneda introduced the High-Temperature Phase Scoring (HPS), Igarashi proposed the High-Temperature Phase Area Index (PLI), and Iizuka developed the Implantation Phase Area Index (PNI) to predict pregnancy outcomes [77].

BBT can be helpful in predicting pregnancy outcomes, but it has its limitations. Women who conceive easily typically have stable BBT patterns during the luteal phase, while those with fertility issues or emotional instability often show irregular fluctuations. No significant differences are found in early BBT charts between women who experience early miscarriages and those who have normal deliveries [50]. BBT curves do not reflect the severity of threatened miscarriage or indicate unruptured ectopic pregnancies [36]. BBT is a convenient tool for early pregnancy diagnosis. A luteal-phase high-temperature period exceeding 16 days suggests pregnancy with 97% accuracy [88]. However, immunoassays for urinary HCG offer greater sensitivity and convenience. For patients with irregular cycles, combining BBT with HCG measurements allows for more timely and accurate early pregnancy and biochemical pregnancy diagnoses [79].

3) Assessing Ovarian Reserve Function

Shorter menstrual cycles are linked to reduced ovarian reserve due to hormonal dysfunction in the early follicular phase, leading to LPD [78]. After age 36, the high-temperature phase on BBT chart begins to shorten, with a more significant decrease in high-temperature phases by age 46. The BBT pattern shows a shortened follicular low-temperature phase (8–10 days), earlier ovulation, and a slower rise and fall during the luteal phase, resulting in a mountain-like shape. For example, in a study of 110 women undergoing artificial insemination on days 8–10 of their menstrual cycles, none with biphasic BBT patterns achieved pregnancy [50,54,79].

Researchers suggest that menstrual cycle length may serve as an indicator of oocyte quality and ovarian reserve function in older women [78,83]. Hormonal dysfunction in the early follicular phase, including lower LH peaks and reduced oocyte quality, can lead to LPD, along with abnormal progesterone and estradiol secretion during the luteal phase. However, after adjusting for age, isolated ovarian reserve decline has been found unrelated to LPD [80–82].

4) Assisting in the Diagnosis of Endometriosis

A delayed decline in BBT during the three days prior to menstruation could serve as a preliminary screening method for Endometriosis (EM) [87]. EM is a chronic, estrogen-dependent inflammatory gynecological disease. In the 1980s, researchers proposed that pelvic EM is associated with a delayed decline in follicular-phase BBT after menstruation [84]. Studies found that two-thirds of EM patients exhibited this phenomenon, compared to only 1/16 of controls. Additionally, significant temperature differences were observed in the three days before menstruation between EM and non-EM patients. Although the mechanism remains unclear, elevated temperature in endometriosis is thought to indicate an enhanced inflammatory response, characterized by increased activity of pelvic macrophages and higher levels of lymphokines, interleukins, and prostaglandins [85]. Research indicates that EM patients exhibit elevated ovarian vein progesterone levels in the early follicular phase, suggesting inadequate luteolysis and extended luteal function into the next cycle. This delayed BBT drop may reflect progesterone's effect on the hypothalamic thermoregulatory center [86].

5) Diagnosing Ovulatory Dysfunction

Abnormal uterine bleeding is a common issue often linked to ovulatory dysfunction, such as infrequent ovulation, anovulation, or luteal insufficiency. BBT monitoring provides a non-invasive, straightforward method to assess menstrual cycle dynamics and the relationship between bleeding and menstruation. When combined with other diagnostic tools, BBT helps identify the specific type and underlying cause of the bleeding [88].

Conclusion:

In conclusion, BBT monitoring remains a critical tool in gynecological endocrinology for predicting ovulation, supporting conception, and evaluating the efficacy of treatment such as ovulation-inducing drugs and natural therapies. The biphasic nature of BBT provides valuable insights into menstrual cycle patterns and reproductive health. The advent of wearable devices, including bracelets, rings, armbands, ear-based sensors, waist monitors, has revolutionized this process by enabling automatic, continuous temperature tracking during nighttime, showing the most scientific promise in reflecting biphasic BBT and accurately predicting ovulation. These user-friendly devices, integrated with AI, are anticipated to transform BBT monitoring into a simple, accurate, real-time, non-invasive, and cost-effective diagnostic method in reproductive endocrinology.

Author Contribution Statement

Iris Guo led the manuscript revision and finalized the draft. Xiaoxiong Shen developed the original idea and prepared the initial draft. Zhuo Chang provided feedback on the final manuscript. Huikun Su was responsible for verifying the references. All authors have read and approved the final version of the manuscript.

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Disclosure of Interest

The authors declare no conflicts of interest related to this work.

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