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Review Article

Nano-enabled Approaches for Pregnancy Care: Early Detection, Monitoring, and Risk Prediction

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Abstract

Pregnancy, a complex developmental process, begins with the fertilization of an egg by a sperm and culminates in childbirth. Throughout the gestational period, the maternal organism experiences significant hormonal, metabolic, and anatomical alterations. Consequently, the well-being of both the mother and the developing fetus depends upon the early diagnosis and precise monitoring of the pregnancy. Nanotechnology has improved the early, accurate, and safe detection of pregnancy, in addition to current diagnostic methods. This review explores the use of gold nanoparticles to create highly sensitive tests for human chorionic gonadotropin (hCG) in home pregnancy tests. This paper highlights the use of wearable nanosystems for monitoring the health of mothers and babies. It also covers early risk assessments utilizing biosensors made with nanomaterials and blood tests designed with nanoengineering. Furthermore, it explores the potential and practical uses of new, portable technologies during pregnancy. These advancements underscore the transformative capacity of nano-assisted methodologies in continuous monitoring, early detection, and the assessment of pregnancy-related risks. The incorporation of nanotechnology into wearable devices presents significant prospects for enhancing the protection of maternal and fetal well-being in the future.

Keywords: prenatal care, nano-enabled diagnostics, maternal-fetal monitoring, wearable technologies, nano-enabled biosensors

1. Introduction

The complex biological process of pregnancy begins with the fertilization of an egg cell by a sperm cell and ends with the formation of a zygote. The zygote proceeds through rapid mitotic divisions after fertilization in the ampulla of the fallopian tube, starting with the 2-cell stage and moving on to the 4-cell stage and finally the 8-cell stage. After around 72 hours of fertilization, it develops into a morula. This embryonic stage develops into a blastocyst on the fourth or fifth day, at which point it starts to travel via the fallopian tube. About six to ten days following ovulation, it implants into the uterine endometrial lining (Figure 1) [1], [2]. Implantation, the initial phase of gestation, triggers the production of human chorionic gonadotropin (hCG), a hormone crucial for the early development of both the embryo and the placenta [3]. Gestational age, a key metric in clinical obstetrics, is calculated from the first day of the last menstrual period (LMP) [4]. Accurate monitoring of fetal development, the identification of critical periods of vulnerability, and the provision of appropriate obstetric care all necessitate a standard duration of approximately 40 weeks, or 280 days.

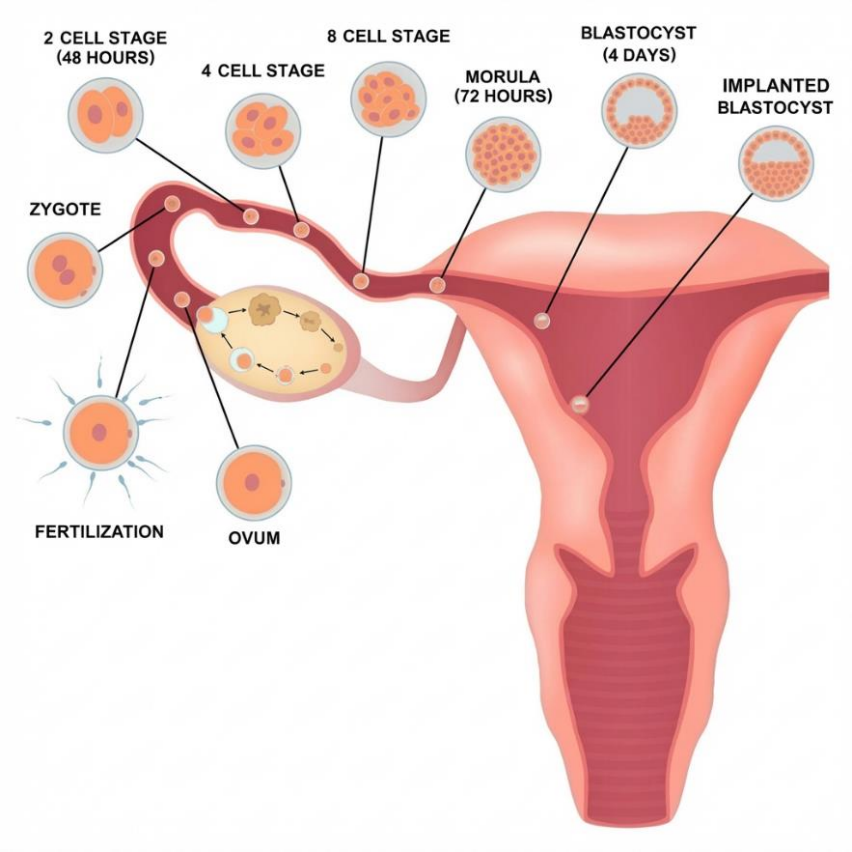


Figure 1. Description of the fertilization process.

Fetal development proceeds across three trimesters, each characterized by specific developmental phases and maternal adaptations. The initial trimester, spanning from the first week to the twelfth week, experiences substantial developmental transformations. Organogenesis, the process of organ formation, is particularly noticeable during this period, leading to the formation of crucial structures like the brainstem and the early development of the heart. Excessive fatigue, mood swings, morning sickness, migraines, swollen or sore breasts, frequent urination, and constipation are among the hormonal problems women frequently experience during this period of pregnancy.

The fetus continues to grow quickly during the second trimester (weeks 13-28), at which time its organ systems mature, its limbs begin to move, and its skeleton clearly begins to ossify. Many of the initial symptoms, like nausea, may disappear on the maternal side, but additional changes can appear. These include discomfort in the back, belly, groin, and thighs; stretch marks; darkening of the skin; swelling in the cheeks, ankles, and fingers; tingling in the hands; and itching in the palms or abdomen.

The fetus shows rapid weight gain during the third trimester (weeks 29-40), and the brain and lungs continue to develop. During this time, the fetus usually shifts into a head-down position. In addition, the mother may develop varicose veins, heartburn, back and pelvic pain, edema, increased weariness, sleep disruptions (due to the baby's movements, leg cramps, or frequent urination), and other discomforts from the growing uterus (Figure 2) [5], [6].

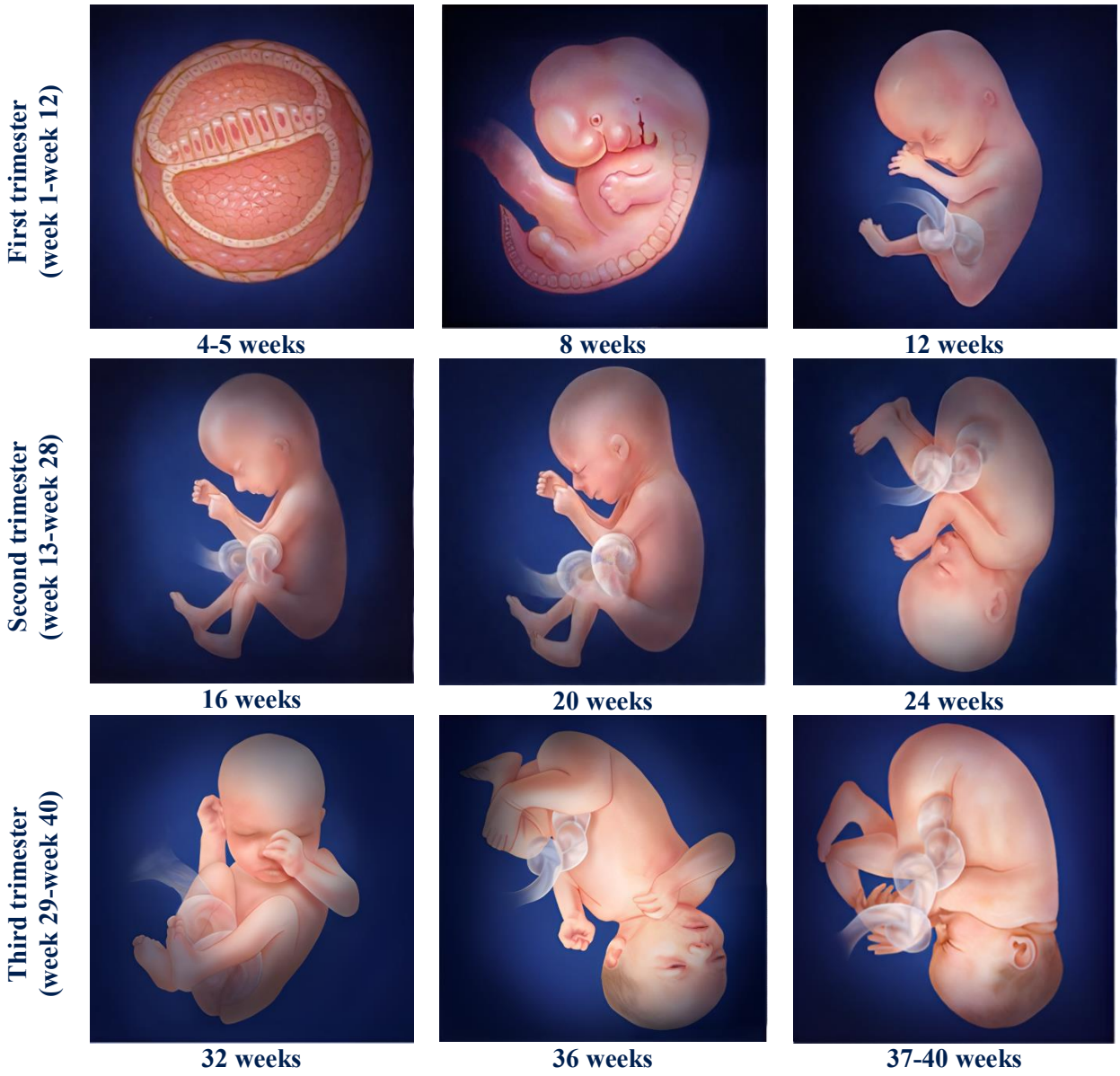


Figure 2. Demonstration of gestational age with trimesters [5].

The term "pregnancy term" refers to the time frame within which labor is expected to occur, with the optimum health outcomes for both mother and child. Significant developmental changes continue during the last weeks of pregnancy, according to recent research. Consequently, medical organizations such as the NICHD and ACOG have developed a more precise system for categorizing the gestational age [7]. Specifically, early term is characterized by a gestational age of 37 weeks, full term by 39 weeks, late term by 41 weeks, and post-term by 42 weeks or later [8]. These variations are very crucial in a clinical setting because the liver, brain, and lungs, which are all developing organs, expand quickly between 37 and 39 weeks of pregnancy. Therefore, babies born prematurely are less likely to face breathing problems, temperature imbalances, feeding difficulties, and other health issues. To make the best decisions concerning labor induction, monitoring, and the timing of delivery, a full comprehension of term classifications is necessary. This is crucial for achieving the best possible outcomes for both mothers and their newborns (Table 1) [9].

Table 1. Categorizing the terminology of gestation.

Term Category	Gestational Age Range	Brief Meanings
Preterm	20 weeks 0 days – 36 weeks 6 days	Immaturity of organ systems
Early Term	37 weeks 0 days – 38 weeks 6 days	Still maturing
Full Term	39 weeks 0 days – 40 weeks 6 days	Best outcomes
Late Term	41 weeks 0 days – 41 weeks 6 days	Increased monitoring
Post-Term	≥ 42 weeks 0 days	Higher risks

To support the developing fetus and prepare the mother's body for childbirth, the hormonal environment experiences significant and intentional changes. During the first trimester, from week one to week twelve, human chorionic gonadotropin (hCG), which is necessary for maintaining pregnancy, increases rapidly, reaching its highest level between weeks eight and twelve. Later, the level lowers dramatically. Progesterone and estrogen, often known as estradiol, are steroid hormones that increase throughout pregnancy. The levels of these hormones rise sharply, particularly in the second and third trimesters, and generally reaches its highest concentration at about the 40th week, shortly before labor begins (Figure 3). Both the development of the fetus and the maintenance of the uterine lining depend on these hormones. Other hormones, such as prolactin, hPL (human placental lactogen), and relaxin, also gradually increase and perform specific functions such as relaxing the pelvic cavity and preparing the mammary glands for milk production. Finally, the hormone oxytocin, which is necessary for the initiation of uterine contractions for labor and delivery, increases just before the last stage of pregnancy. The transition to the postpartum period is characterized by a rapid decrease in progesterone and estrogen levels and an increase in oxytocin immediately after birth [10], [11].

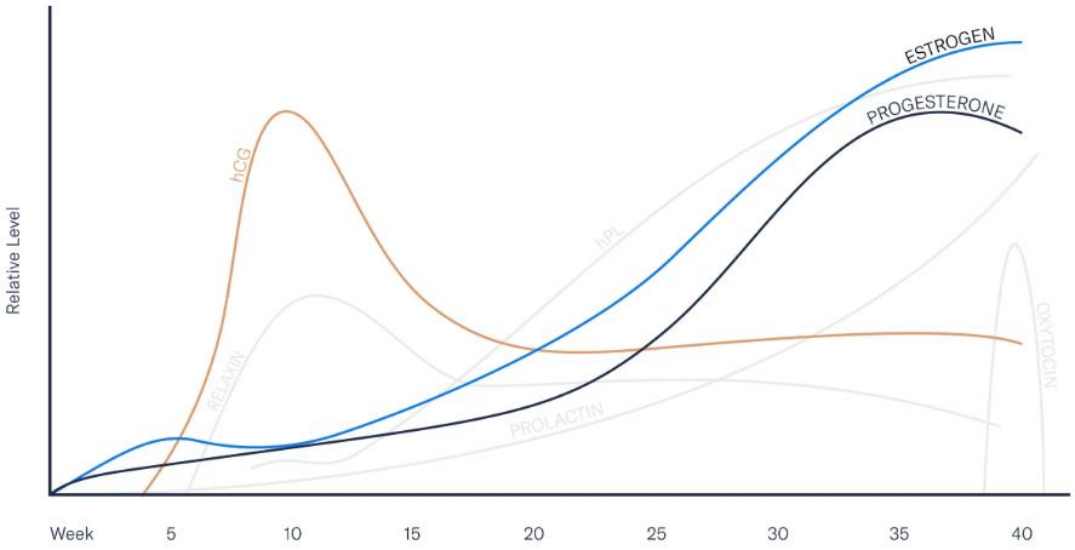


Figure 3. Graphical illustration of hormonal changes during pregnancy [12].

A variety of biochemical and imaging methods can be used to confirm pregnancy, including ultrasound examinations, blood tests, and urinalysis are the main methods. Urine pregnancy tests, widely used in both clinical and home settings, can detect human chorionic gonadotropin (hCG) [11]. Usually, these tests get accuracy when menstruation is late. Blood tests with higher sensitivity in measuring human chorionic gonadotropin (hCG) can detect pregnancy sooner, about seven to ten days later [13]. Blood tests are generally divided into two types: quantitative tests, which measure specific hormone levels to monitor early development, and qualitative tests, which confirm pregnancy. In addition, ultrasound, a non-invasive imaging technique, is often used to determine gestational age [14]. The gestational sac, which reveals where the fertilized egg implants, can be seen on an ultrasound between the fourth and fifth weeks of pregnancy. The fetal heartbeat is then detectable between the fifth and sixth weeks of gestation, providing important information about the timing and health of the pregnancy.

This research seeks to provide a thorough analysis of nanotechnology's role in prenatal care, specifically concentrating on early diagnosis, ongoing monitoring, and the evaluation of potential risks to both mother and fetus. To clarify recent developments, clinical relevance, and future possibilities within nanotechnology-supported prenatal healthcare, this article will integrate perspectives from prenatal biology, established diagnostic techniques, and novel biosensor technologies enhanced by nanotechnology.

2. Nano-enabled Early Pregnancy Detection: Label-based Biosensor

Home pregnancy tests provide a rapid, straightforward, and reliable early pregnancy detection, thereby illustrating the widespread application of nanotechnology within reproductive healthcare. These tests utilize a gold nanoparticle (AuNP)-assisted lateral flow immunoassay (LFA) design (Figure 4) in which a urine sample is passively drawn via capillary action, generating a diagnostic response on a nitrocellulose membrane [15], [16]. The application of the urine sample to the sample pad initiates the dissolution of the dehydrated antibody-gold nanoparticle complex, thereby enabling the migration of the gold-labeled antibodies along the test strip. Home pregnancy tests serve as a prominent illustration of nanotechnology's extensive utilization within reproductive healthcare, offering a quick, easy, and precise method for the early detection of pregnancy.

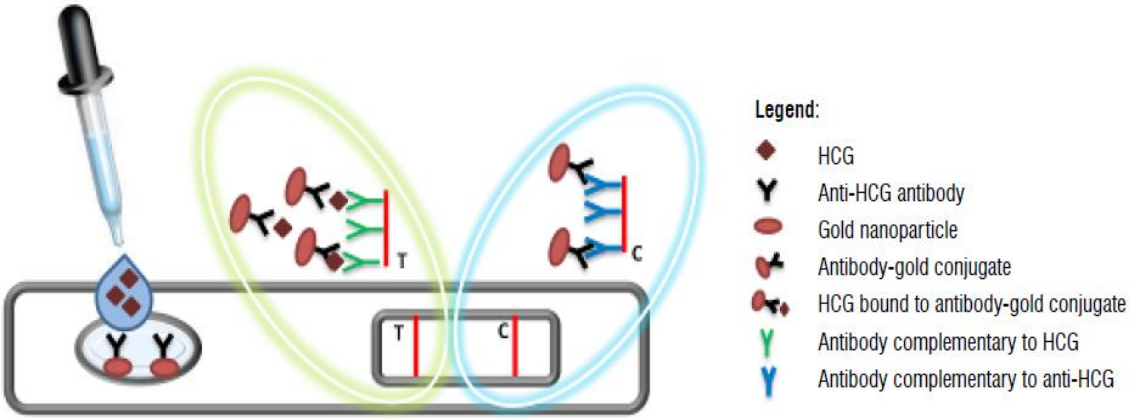


Figure 4. Operational mechanism of hCG detection in a gold nanoparticle-based lateral-flow pregnancy test [17].

Gold nanoparticles are essential to this technology due to their special optical, chemical, and physical characteristics [18]. Localized surface plasmon resonance [19], [20] allows for quick, equipment free diagnosis at home by producing a strong, consistent red coloration [21] that is visible to the naked eye. AuNPs are perfect labels for antibody-based detection because of their strong and controlled binding to biomolecules, high biocompatibility, and exceptional durability. Thanks to their nanoscale size, they have a large surface area for antibody conjugation, which increases sensitivity and makes it possible to detect pregnancy at extremely early stages, often even before a missed period. Traditional LFAs are distinguished from µPADs [22] or LOC systems by the lack of regulated flow mechanisms, constructed fluidic channels, and the incapacity to carry out sequential or multi-step processes. Rather, label-based biosensing [23] and point-of-care testing (POCT) [24] are present in a more primitive but highly effective form. Despite this, gold nanoparticle-enabled LFAs continue to be an excellent example of nanotechnology utilized in routine healthcare, and they are the technology behind the billions of home pregnancy tests that are used worldwide each year.

3. Nano-enabled Early Pregnancy Detection: Paper-Based Microfluidic (µPADs)

Recently, there has been increased interest in the use of microfluidic paper-based analytical devices (PADs) as cutting-edge research-level platforms for pregnancy detection, offering a versatile and affordable alternative to commercial LFAs. These µPAD devices are laboratory-developed prototypes made from patterned cellulose [25] or nitrocellulose channels using wax printing or hydrophobic barriers, rather than lateral flow assays that use standardized nitrocellulose strips and are mass-produced for consumer markets. Instead of using these

devices in standard clinical settings, researchers can position them to perform best in experimental detection formats by customizing the flow pathways, reaction sites, and multi-step amplification.

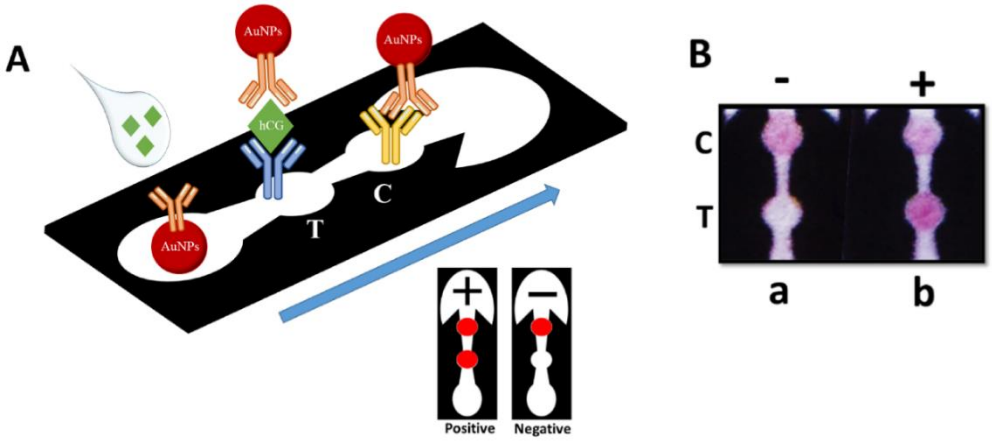


Figure 5. Operational mechanism of hCG detection in a gold nanoparticle-based paper-based microfluidic pregnancy test [26].

Figure 5 illustrates the working mechanism of a pregnant µPAD, employing gold nanoparticle (AuNP)-labeled antibodies. As depicted in panel A, a urine sample is introduced to the device, where hCG in the sample binds to AuNP-conjugated detecting antibodies. As the combination progresses, immobilized anti-hCG antibodies hold complexes in the test (T) region, creating a visible red dot due to the bright plasmonic color of the AuNPs. The test's efficacy is demonstrated by the presence of excess AuNP-antibodies within the control (C) region. Panel B presents the µPAD results, which differentiate between a positive sample (illustrated in image B, displaying both T and C regions and generating distinct red signals) and a negative sample (depicted in image A, where only the C region is visible) [26]. This observation confirms the hypothesis that AuNPs generate a bright, clearly visible color without requiring supplementary instruments, thereby emphasizing their essential role in visual outputs for both lateral flow assays (LFAs) and paper-based diagnostic (PAD) pregnancy tests.

4. Physiology of Normal Birth: Cervical Ripening and Dilation

Cervical ripening is a crucial beginning to vaginal delivery, reliant upon the cervix undergoing a timely transformation. This essential physiological process involves the cervix's transformation from a firm, collagen-rich structure that sustains pregnancy into a flexible, elastic canal, thereby facilitating fetal passage [27]. This transformation, distinguished by a complex interplay of hormonal and inflammatory signals that induce extracellular matrix imbalance, results in collagen fiber degradation and heightened tissue hydration [28], [29]. Consequently, this maturation is critical for the efficient advancement of labor.

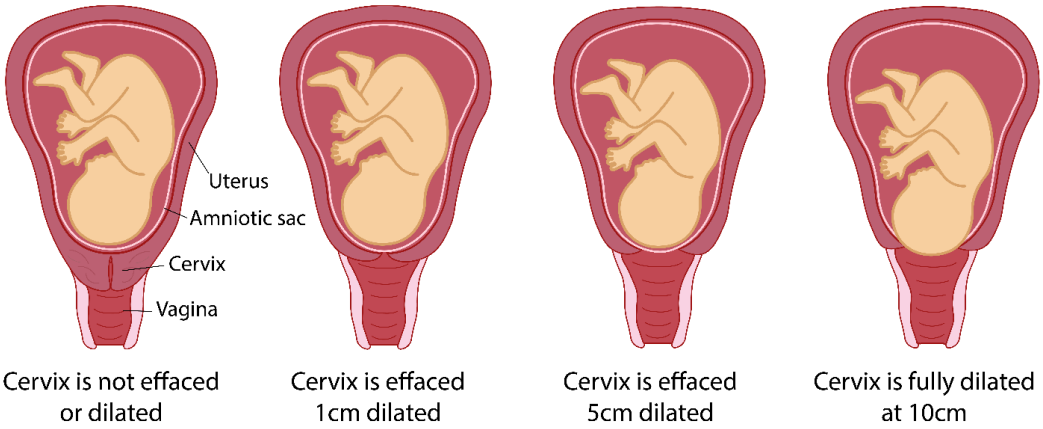


Figure 6. The progression of cervical dilation [31].

Effacement and dilation are two key mechanical changes that happen during labor. Effacement involves the cervix thinning and shortening, while dilation is the gradual opening of the cervical os. This process is described in Figure 6, which illustrates the changes that occur during labor. The cervix goes through a transformation, moving from a closed, undeveloped state to a fully thinned and dilated state, with an opening of 10 cm [30], [31]. The cervix's dilation is significant for the fetal head to pass through the birth canal. This observable physical change reveals the cervix's ability to stretch. Given that aberrations in this maturation process can result in cervical rigidity, as observed in post-term pregnancies, the condition of the cervix is a crucial clinical factor influencing successful delivery and overall obstetric outcomes. Consequently, the capacity to monitor these mechanical indicators with precision and without invasive procedures is essential for both the prevention and management of these complications.

Without this period of maturation, when the cervix is firm, long, and closed, vaginal delivery is not possible. This is because uterine contractions cannot create enough mechanical openings. Therefore, cervical ripening significantly influences the course of labor, the results of childbirth, and the method of delivery.

5. Physiology of Abnormal Birth: Post-term Pregnancy and Risks

Aberrant birth physiology is linked to maternal-fetal incompatibility and increased perinatal risk when gestational age exceeds 42 weeks. Placental aging [32], which is characterized by reduced oxygen and nutrition supply, impaired endocrine function, and placental perfusion (blood flow) [33], is the main source of the underlying pathophysiology. Consequently, fetal homeostasis is disturbed. In addition to the miscalculated pregnancy date, several physiologic variables contribute to this extended time. Adipose tissue releases pro-inflammatory cytokines, including TNF-α, which can reduce the myometrium's sensitivity to labor cues, making maternal obesity a major risk factor [34]. Furthermore, male fetal sex is an independent risk factor since male fetuses are statistically linked to longer pregnancies and exhibit increased vulnerability to oxidative stress and nutritional scarcity brought on by an aging placenta [35]. The risk of adverse outcomes increases significantly with gestational age due to umbilical cord compression (UCC), oligohydramnios (low levels of amniotic fluid) [36], and chronic fetal hypoxia (lack of adequate oxygen). The risk of stillbirth increases exponentially between weeks 41 and 43. Prolonged pregnancy is an independent risk factor for stillbirth, as shown in Figure 7 [32]. The risk is steady and relatively modest until the end of the pregnancy, but it rises quickly after 40 weeks [37]. Additionally, pregnancies in which the placenta is still functioning have a much-increased risk of fetal macrosomia (birth weight >4,500 g) [38]. The risk of shoulder dystocia, brachial plexus damage, and postpartum hemorrhage in mothers is significantly increased by this aberrant growth, which is frequently "asymmetrical" with disproportionately big fetal shoulders and trunks [39]. Vaginal birth becomes physiologically impossible in the absence of this maturational phase, which is characterized by a lengthy, dense, and closed cervix. This condition is because uterine contractions are unable to produce sufficient mechanical openings. Cervical ripening, therefore, significantly influences the course of labor, the obstetric results, and the final delivery method.

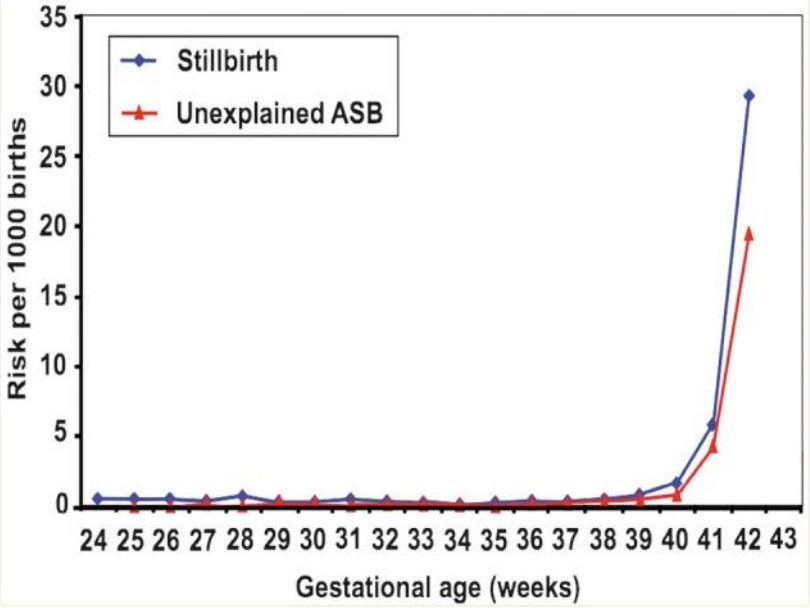


Figure 7. Risk of stillbirth and unexplained antepartum stillbirth per 1,000 ongoing pregnancies according to gestational age [32].

Clinical treatment usually begins while the cervix is still "immature," and rapid intervention is important to reduce these risks. Cervical maturation is the first stage of this process and can be achieved with pharmacological drugs such as prostaglandins like Dinoproston or Misoprostol to chemically soften cervical collagen, or with mechanical techniques such as Foley catheters to physically dilate the cervix [40].

Once the cervix is ready, regular uterine contractions are induced, and active labor is initiated by amniotomy (artificial membrane rupture or AROM) and administration of titrated synthetic oxytocin [40]. Since the late-term fetus has limited physiological reserves to withstand the stresses of labor, continuous fetal heart rate monitoring is necessary to detect late decelerations during this process. The clinical approach shifts to cesarean delivery [41] when the fetal heart rate is concerning (often due to depleted placental reserves) or when cephalopelvic disproportion occurs due to macrosomia (excessively large baby). The physiological difficulties of post-term gestation led to a far greater rate of surgical intervention to prevent avoidable perinatal morbidity and mortality, even though the aim is a safe vaginal birth.

6. Monitoring and Prevention of Pregnancy Complications: Clinical Management

Continuous and multi-parameter monitoring of physiological well-being is crucial to prevent maternal and fetal complications arising from post-term pregnancies and other high-risk obstetric conditions. To detect hypertensive diseases, metabolic abnormalities, and infectious processes [42] at an early stage, maternal monitoring includes routine monitoring of blood pressure, urinary protein excretion [43], blood glucose levels, body temperature, heart rate, and oxygen saturation, while fetal monitoring, to detect early signs of placental insufficiency and impaired fetal perfusion, includes daily fetal movement assessment, serial ultrasonographic biometry [44], assessment of amniotic fluid volume, and Doppler flow studies of the umbilical and middle cerebral arteries [45], [46]. Cardiotocography (CTG) [47], which allows for simultaneous assessment of fetal heart rate (FHR) patterns and uterine activity and early detection of fetal hypoxia or distress, remains a vital component of fetal monitoring [48]. A necessary part of maternal fetal monitoring is the use of internal and external electronic technology for fetal heart rate (FHR) monitoring [49], [50]. The real-time data on fetal circulation, oxygenation patterns, and acid-based balance provided by these methods can indicate potential problems. Internal monitoring with fetal scalp electrodes produces more accurate and consistent data, even though external FHR monitoring with Doppler is a non-invasive technique frequently used in prenatal care and delivery, where external signals are inconsistent. These techniques help doctors identify problematic patterns that may indicate fetal distress in high-risk pregnancies, enabling early clinical assessment and intervention (Figure 8) [51].

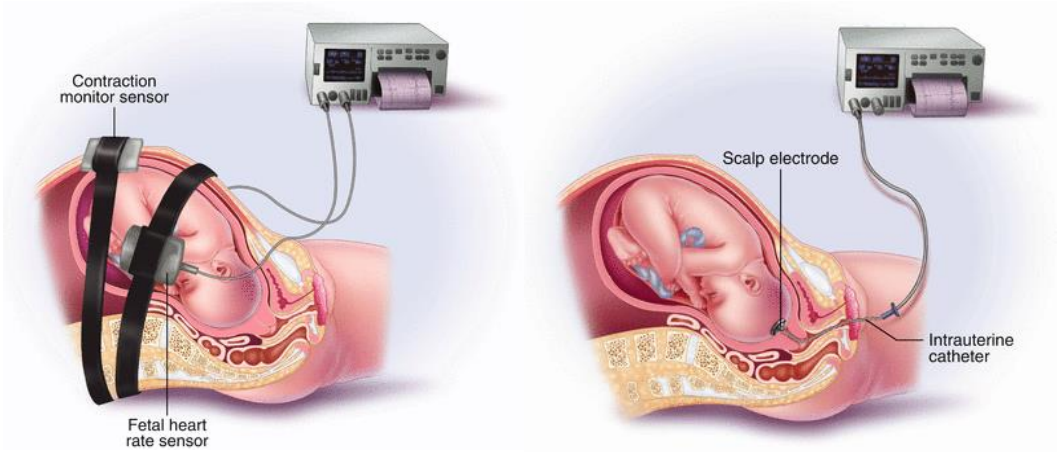
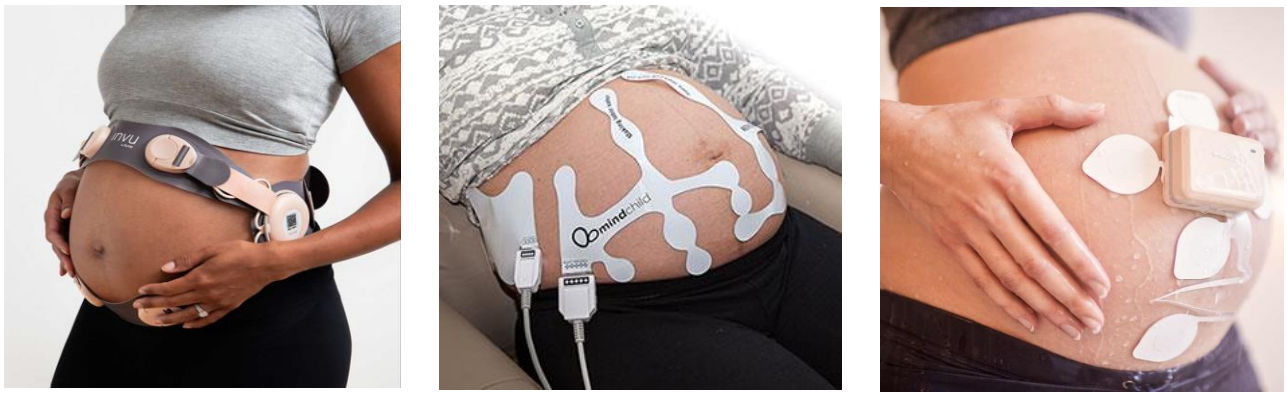


Figure 8. External and internal fetal heart rate monitoring techniques [51].

Two highly useful structured testing methods are contraction stress testing (CST) and biophysical profiling (BPP), which allow for the early diagnosis of fetal reserve declines, such as fetal oxygenation and neurological integrity, before a significant clinical decline [52]. These tests are performed more frequently (twice a week) in terms of high-risk pregnancies to detect even the slightest changes in fetal condition early on. These coordinated monitoring technologies operate as early warning systems, helping to prevent complications throughout labor and delivery. They also provide vital information about the changing risks for both the mother and the developing fetus.

7. Monitoring and Prevention of Pregnancy Complications: Wearable Technologies

Beyond traditional, hospital-based assessments, maternal-fetal monitoring has been greatly enhanced by recent advances in wearable technologies. Wearable electrocardiography (ECG) [53] and photoplethysmography (PPG) [54], [55] sensors, smart patches, wearable ultrasound belts, smart abdominal belts, and textile-integrated biosensors [56], [57] are examples of contemporary wearable systems that enable continuous, non-invasive monitoring of maternal and fetal physiological parameters in both home and outpatient settings. In addition to monitoring maternal heart rate, blood pressure, oxygen saturation [58], glucose levels, body temperature, physical activity, sleep patterns [59], and uterine contraction dynamics [60], these platforms can also record fetal heart rate (FHR) [61] and fetal movement data [62], [63] through increasingly advanced abdominal wearables (Figure 9) [64]. Wearable technology supports proactive surveillance by producing longitudinal physiological data outside of clinical settings [65], especially in high-risk and late-term pregnancies where intermittent clinician-based monitoring may not be sufficient.



(a) **(b)** **(c)**

Figure 9. Commercial wearable devices: (a) Philips remote fetal monitoring (Model: 989803219951) [66], (b) MERIDIAN M110 disposable electrode patch [67], (c) Avalon beltless fetal monitoring (Avalon CL) [68].

Although cardiotocography (CTG) is still the conventional clinical standard for evaluating fetal heart rate and uterine activity, many advanced wearable monitoring systems are made to use small, portable, non-invasive sensor technologies that are appropriate for long-term or at-home monitoring to record CTG equivalent physiological signals, such as fetal heart rate variability, uterine contraction patterns, and maternal ECG [69]. Wearable fetal ECG and Doppler-based technologies serve as outpatient options that allow long-term evaluation of fetal well-being, in contrast to traditional CTG, which is frequently not wearable and is limited to short-term, in-hospital recordings. Fetal hypoxia, uteroplacental insufficiency, abnormal uterine activity, and impaired fetal autonomic regulation are examples of obvious complications that may be identified by subtle abnormalities in baseline heart rate, variability, accelerations, and decelerations.

8. Nanotechnology-enabled Biosensing and Diagnostic Innovations in Pregnancy Care

Nanotechnology has revolutionized prenatal diagnosis by enabling the highly sensitive, rapid, and low-invasive diagnosis of pregnancy-related disorders. Detection of even the smallest molecular changes associated with placental dysfunction, fetal risk, and adverse pregnancy outcomes is possible thanks to the extraordinary electrical, optical, and biochemical sensitivity of nanofeature biosensors made from materials such as graphene [70], carbon nanotubes [71], gold nanoparticles [72], and polymer nanocomposites. Recent progress includes blood tests employing nanotechnology that can identify serious pregnancy abnormalities before they exhibit any obvious symptoms. These tests use nanostructured platforms, like the NanoVelcro Chip, to collect rare trophoblast cells from the placenta found in the mother's blood [73], [74]. This approach provides a more precise initial diagnosis of placenta accreta spectrum disorders than traditional ultrasound examinations [75]. Furthermore, newly engineered rapid nanosensors can detect symptoms of preeclampsia, gestational diabetes, fetal growth restriction, and preterm labor during the first trimester, thereby facilitating early risk evaluation and the implementation of preventive strategies [76], [77]. Through enhanced diagnostic sensitivity and ongoing assessment, nanotechnology is improving maternal-fetal monitoring and prenatal imaging.

The application of functionalized nanoprobes and nanoparticle-based contrast agents in MRI and ultrasonography can refine fetal and placental imaging, thereby facilitating earlier and more accurate detection of structural and developmental anomalies [78]. Moreover, innovative wearable and wireless nanosensor technologies are emerging [79]. These are designed to track the well-being of mothers and babies in real-time, eliminating the need for invasive methods. This advancement allows for constant monitoring of pregnancy health, extending beyond the limits of traditional medical settings. These advancements collectively underscore the increasing significance of nanotechnology within prenatal care, particularly concerning early detection and diagnosis. Furthermore, they emphasize the necessity for further evaluations of safety, placental interactions, and clinical applicability prior to its widespread implementation.

9. Portable and Handheld Technologies Enhancing Maternal and Fetal Health

Recent advancements in diagnostic methods using nanotechnology have led to the quick manufacturing of portable and handheld devices. These devices are designed to promote maternal and fetal health during pregnancy. Portable fetal Doppler technologies and compact fetal heart rate monitors have made it possible to monitor a baby's heartbeat without direct contact [80]. Portable ultrasound systems [81] (Figure 10) enable imaging of the fetus, facilitating both home-based and remote applications. These devices, which do not utilize nanotechnology, are gaining significance in decentralized prenatal care due to their capacity to enhance accessibility, offer early confirmation of fetal well-being, and permit more frequent monitoring beyond conventional clinical environments. In the future, integrating wearable nanomaterials, advanced data analysis, and biosensors with nanoscale features into these portable devices could greatly improve real-time monitoring, diagnostic accuracy, and individualized prenatal care.

(a) (b)

Figure 10. Commercial handheld devices: (a) FetalPlus fetal doppler [80] and (b) Pulsenmore ultrasound [81].

10. Conclusion and Future Directions

Nanotechnology is revolutionizing prenatal care by facilitating ultra-sensitive detection, improved monitoring, and the early prediction of maternal and fetal complications. Nano-enabled biosensors, microfluidic platforms, and diagnostic tools incorporating nanomaterials have demonstrated considerable promise in addressing the shortcomings of conventional pregnancy tests and monitoring methods, particularly during the initial phases of gestation. Furthermore, advancements like wearable nanosystems and nano-engineered blood tests are providing novel opportunities for minimally invasive, real-time, and personalized prenatal care. The growing demand for decentralized, home-based prenatal care is further evidenced by the rapid advancement of portable and handheld technologies designed for fetal and maternal monitoring. Although these devices may not directly incorporate nanoscale elements, their functionality can be enhanced through integration with wireless platforms, sophisticated data analytics, and nanotechnology-driven sensors, thereby improving the precision of continuous monitoring and diagnostic capabilities. Further research should focus on improving biocompatibility, safety, and clinical validation, along with creating regulatory guidelines for using nanomaterials during pregnancy. Wearable technology, nanotechnology, and portable testing methods offer the potential to make prenatal care more personalized, preventive, and predictable.

Author Contributions

Both authors contributed equally to the conceptualization, data collection, and writing of this manuscript.

Conflict of Interest

The authors declare no conflicts of interest.

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Data Availability Statement

All data analyzed during this study are included in this published article.

Abbreviations

Human Chorionic Gonadotropin (hCG), Last Menstrual Period (LMP), American College of Obstetricians and Gynecologists (ACOG), National Institute of Child Health and Human Development (NICHD), Human Placental Lactogen (hPL), Gold Nanoparticle (AuNP), Lateral-flow Immunoassay (LFA), Paper-based Microfluidic Devices (μPADs), Point-of-Care Testing (POCT), Lab-on-a-Chip (LOC), Tumor Necrosis Factor-alpha (TNF-α), Umbilical Cord Compression (UCC), Artificial Rupture of Membranes (AROM), Cardiotocography (CTG), Fetal Heart Rate (FHR), Contraction Stress Testing (CST), Biophysical Profiling (BPP), Electrocardiography (ECG), Photoplethysmography (PPG).

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