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The Significance and Limitations of Monitoring Sleep during Pregnancy

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Abstract— **Sleep patterns often change during pregnancy and postpartum. However, if severe and persistent, these changes can depict a risk factor for significant health complications. It is thus essential to identify and understand changes in women's sleeping pattern over the course of pregnancy and postpartum, to offer an appropriate and timely intervention if necessary. In this paper, we discuss sleep disturbances during pregnancy and their association with pregnancy complications. We also review the state-of-the-art digital devices for real-time sleep assessment, and highlight their strengths and limitations.**

Clinical Relevance—**This review highlights an importance of an individualized holistic pregnancy care program which engages both the healthcare professionals and the obstetric population, together with an educational module to increase the user awareness on the importance of sleep disturbances and their consequences during and after pregnancy.**

I. Introduction

Pregnancy can introduce a number of health risks and complications to an otherwise healthy population, which can greatly affect the outcome of pregnancy (health of mother, fetus, or both). In some cases, pregnancy leads to loss of fetus by miscarriage (before 20-24 weeks) in less than 10% cases or stillbirth (after 20-24 weeks) in less than 1% cases [1]. Chromosomal abnormality are main reasons for miscarriages and a variety of reasons can lead to stillbirth, where the causes are often not well known. On the other hand, preterm birth (5 to 18% pregnancies) is premature childbirth before 37 weeks of pregnancy, caused by a variety of reasons [2]. Iron deficiency (especial anemia) is one risk factor for preterm delivery and responsible for other complications, such as low birth weight and inferior infant health [3], and in some cases maternal mortality [4]. Iron deficiency (low serum ferritin) and iron deficiency anemia (low serum ferritin and hemoglobin) are considered to be the most prevalent nutritional deficiency in pregnancy. The prevalence is mainly in developing countries (56% and 43% anemia) with lower cases in developed countries (18% and 12% anemia) [5]. In general, there is uncertainty around iron deficiency in pregnancy, with risks of too little as well as too much, that can lead to complications either way [6].

Besides fetus complications, some of the well-known conditions during pregnancy include nausea, hyperemesis gravidarum, gestational diabetes mellitus (GDM), hypertension, preeclampsia and postnatal depression. Regular health monitoring, early detection of risks, and strong communication with healthcare providers can help diagnosis, treat and manage (e.g. lifestyle adaptations) some of these complications before becoming serious [7, 8]. Table 1 presents summary of pregnancy conditions, their time of occurrence, and the prevalence.

Changes to sleep patterns are prevalent during pregnancy. They happen due to hormonal changes (as early as 11-12 weeks of gestation), and are intensified in the last trimester due to fetus enlargement. However, the greatest levels of sleep disruption are reported during the first 4 weeks of postpartum as a result of random sleep cycles of the newborn. Sociodemographic variables, and physical and mental health factors are known to contribute to these changes which might lead to severe sleep disturbances and sleep disorders [9-11].

Previous research has shown a bidirectional relationship between sleep disorders and increased risk of complications during pregnancy, including GDM, hypertension, preeclampsia, and postpartum depression [10, 12]. These complications can result in adverse pregnancy outcomes, including preterm birth, abnormal duration of labor, and mode of delivery [13]; which in turn pose significant economic implications worldwide.

Continuous, non-intrusive monitoring of sleep quality and physiological changes (e.g., heart rate and respiration rate) during sleep have the potential to be embedded into pregnancy care programs in order to identify sleep abnormalities for timely interventions. This could not only prevent adverse pregnancy outcomes, but also significantly reduce economic implications of pregnancy complications. Currently, there are no consistent approaches to monitor pregnant women during sleep. One of the limiting factors is that the existing clinically-validated assessment devices are expensive, obtrusive, and unsuitable for continuous monitoring of sleep patterns.

This review presents the ongoing research in monitoring sleep changes during pregnancy, their association with pregnancy complications and outcomes, available sleep assessment tools, and their limitations in continuous monitoring of sleep in an obstetric population. A literature search in Medline, PubMed, Scopus, and Web of Science was conducted to identify papers published in English. Articles on pregnancy complications, care and management, and also sleep monitoring tools and the association of sleep disorders and disturbances with pregnancy complications were selected for this review.

II. Sleep During Pregnancy

Around 45.7% of women experience significant reduction

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TABLE I. SUMMARY OF PREGNANCY CONDITIONS, TIME OF OCCURRENCE, AND THE PREVALENCE.

Condition	Occurrence	Prevalence
Stillbirth	> week 20	<1%
Hyperemesis Gravidarum	< childbirth	0.3-2%
Gestational Diabetes Mellitus	> week 24 & < week 28	1-14%
Preeclampsia	> week 20	2-8%
Preterm Birth	< week 37	5-18%
Postpartum Depression	> childbirth (4 weeks)	8-26%
Miscarriage	< week 20	10%
Hypertension	> week 20	10-22%
Iron Deficiency Anaemia	<= week 28	12-43%
Nausea and Vomiting	< week 12	70-90%

in their sleep quality during pregnancy, with higher gestational age being associated to poor sleep quality [14].

Sleep alterations are evident early in pregnancy (Fig. 1). Generally, an increase in total sleep time (TST) by 11-12 weeks of gestation is observed due to an increase in stage one of sleep (light sleep) [11]. At the same time, women experience an increased difficulty in falling asleep (sleep onset latency) and increased and longer periods of awakening after sleep onset (WASO) [12, 15]. Slow-wave sleep (SWS) or deep sleep starts to decrease early in pregnancy, followed by an increase in the second trimester (23-24 weeks of gestation) [11, 15], and then continues to decrease in the third trimester. A marked reduction in rapid eye movement (REM) is also reported later in pregnancy [9, 11].

Sleep becomes poor and more fragmented as pregnancy progresses. Total sleep time reduces, with day-time napping increasing during the last months of pregnancy to compensate for the poor night-time sleep. Women experience the greatest level of sleep disturbances and the lowest amount of sleep during the first four weeks postpartum. Sleep characteristics however improve by week 12 postpartum [11].

III. SLEEP DISORDERS AND PREGNANCY COMPLICATIONS

The most common sleep disturbances during pregnancy are insomnia, sleep-disordered breathing (SDB), and restless legs syndrome (RLS) [12]. These disturbances have been found to increase the risk of pregnancy complications (Fig. 2) and consequently, pregnancy outcomes [16]. Many studies found that sleep disturbances increase the risk of mental disorders during pregnancy and postpartum, including depression, anxiety and stress [10, 13, 17].

Hormonal and physiological changes in early pregnancy, physical discomfort, nocturia, and difficulty in finding a comfortable sleep position are common reasons for presenting insomnia symptoms. Mid-pregnancy insomnia has been identified as a marker for concurrent anxiety and a predictor of postpartum anxiety [18]. Insomnia and RLS also increase the risk of sleep-wake disturbances, which could lead to poor sleep quality and consequently increase the risk of mental disorders [19]. Research shows that poor sleep quality in later pregnancy doubles the risk of emergency caesarean delivery [20].

One of the widely-studied sleep disturbances is sleep-disordered breathing, such as sleep apnea and snoring. Obesity, high gestational and maternal age, and changes in the respiratory physiology during a normal pregnancy can contribute to the development of sleep-disordered breathing [21]. Sleep-disordered breathing has been found to be associated with hypertension, preeclampsia, and GDM [22]. In this vein, research suggested that pregnant women snore more than non-pregnant women (14% vs 4%) [23] and, snoring can be predictive of pregnancy-induced hypertension (14% vs 6%) and preeclampsia (10% vs 4%) [24]. Furthermore, pregnant women with obstructive sleep apnea are at increased risk of pregnancy hypertension and preeclampsia, and adverse pregnancy outcomes such as low birth weight, preterm delivery, and small gestation age [25, 26].

IV. SLEEP ASSESSMENT TOOLS AND THEIR LIMITATIONS

Sleep can be assessed subjectively and objectively.

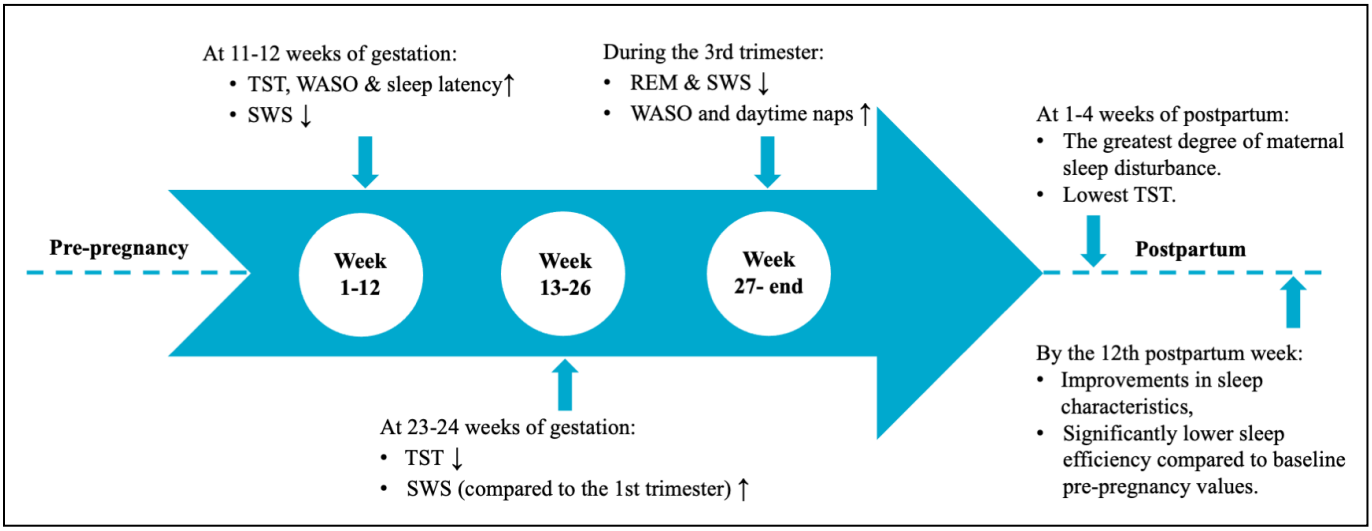

Figure 1. Noticeable changes in sleep structure in a normal pregnancy.

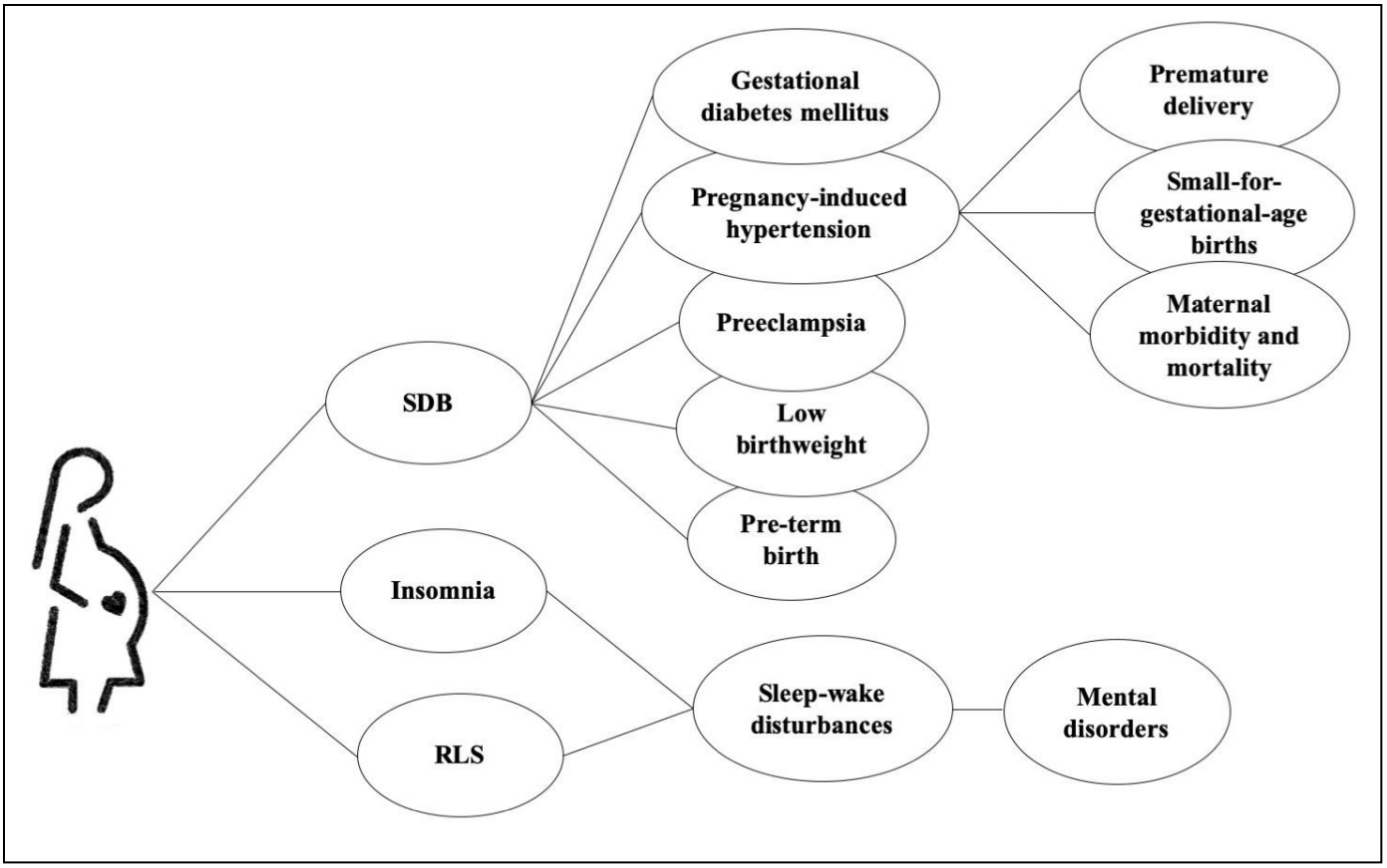

Figure 2. Sleep disturbances associated with pregnancy complications.

Subjective assessment tools are in the form of questionnaires, developed to capture different aspects of sleep, such as quality of sleep. These tools may induce biased responses from participants, as they rely on their opinion about their own sleep. Another limitation of subjective assessment tools is the impossibility of monitoring sleep in a continuous fashion. Table 2 summarizes relevant subjective sleep assessment tools that have been used in pregnancy-related studies.

Objective assessment tools, on the other hand, have been developed to capture physiological measurements (e.g., heart rate and respiration rate) and different features of sleep architecture (e.g., sleep stages, sleep duration, sleep onset latency, awakenings during sleep, etc.) in real-time through wearable and non-wearable technologies.

The gold standard for objective sleep monitoring is Polysomnography (PSG) [27], a multi-parametric test that monitors many body functions, including brain activity, eye movement, muscle activity, and heart rhythm during sleep. While PSG has been widely used in the pregnancy studies, it is invasive, costly, and laborious. Additionally, it is not possible to continuously monitor sleep using PSG, so normally only a few nights of PSG are collected at different time points/trimesters of pregnancy (in the best-case scenario). Another clinically-validated device for objective sleep monitoring is the Actigraph, a wearable device to monitor gross motor activity. This device is also expensive, and needs battery recharging and to be worn continuously. Other available wearable and non-wearable consumer-grade devices have not been validated against PSG. This highlights a need for non-invasive easy-to-use devices for continuous and objective assessment of sleep.

A number of studies used both objective and subjective tools to capture sleep characteristics, and investigated their correlation with pregnancy complications. While some studies showed inconsistent results across different methods of sleep assessment [28], others found a positive correlation between their findings using subjective and objective measurements [29]. This inconsistency might be partially due to the nature of subjective methods, highlighting the strength of objective methods to monitor sleep disturbances during pregnancy.

V. E-Health in Sleep and Pregnancy Care

With digital solutions, women seek trustworthy tools that deliver short answers to everyday concerns, information on local support services, and personalized tools to assess nutrition, fitness, and weight [30]. Lifestyle support tools should be practical, tailored and delivered in the right stage of pregnancy. Healthcare providers also seek engaging and interactive practical information that are evidence-based [30]. E-Health tools with unnecessary content can pose stress during pregnancy [31]. The outcomes for assessing e-Health tools in pregnancy lifestyle relate to usability, feasibility, acceptability, and effectiveness [31].

A recent study in the use of wearables in pregnancy health demonstrated that fetal heat rate and blood pressure being top preferences of health monitoring among pregnant women, while clinicians ranked blood pressure and blood glucose as priority [32].

TABLE II. SUBJECTIVE SLEEP ASSESSMENT TOOLS.

Subjective assessment tools	Description
Pittsburgh Sleep Quality Index [36]	To assesses sleep quality and disturbances over a 1-month time interval
Berlin Questionnaire [37]	To determine the risk of having sleep-disordered breathing (i.e., sleep apnea)
Epworth Sleepiness Scale [38]	To determine the level of daytime sleepiness
National Institutes of Health/International Restless Legs Syndrome Question Set [39]	To provide a diagnosis of restless legs syndrome and assess symptom frequency
Women's Health Initiative Insomnia Rating Scale [40]	To assess perceived insomnia symptoms
Basic Nordic Sleep Questionnaire [41]	To assess different sleep disturbances and complaints
The General Sleep Disturbance Scale (GSDS) [42]	To determine poor sleep quality and poor daytime function
Insomnia Severity Index (ISI) [43]	To assess the severity of both night-time and daytime components of insomnia

To date, however, continuous sleep monitoring has been challenging, costly, and intrusive. While continuous, unbiased monitoring of sleep is not possible through subjective and self-report methods, objective tools are either invasive with limited potential for continuous monitoring of sleep across the course of pregnancy, or are unreliable and not clinically validated.

Another important aspect in monitoring sleep during pregnancy is to effectively engage the obstetric population in the sleep research. A qualitative study with pregnant and postpartum women showed that interaction with a patient-centered technology can promote behavior change toward healthy lifestyle during and after pregnancy [33]. Behavioral-educational sleep interventions have potential to not only enhance the nocturnal sleep of mothers, but also increase their confidence in managing their infant's sleep [34]. A personal health monitoring device has been shown to be effective in engaging pregnant women in behavioral sleep research [35]. While encouraging, more in-depth research is still needed to determine the feasibility of such devices in engaging a larger population, along with their efficacy, in longitudinal studies.

VI. CONCLUSION

Due to physiological, hormonal and anatomical changes, the risk of developing sleep disturbances and sleep disorders for women are higher during pregnancy [44, 45]. Existing physiological and psychological issues can exacerbate sleep disruption during and after pregnancy, with early emergence and enduring adverse outcomes.

Considering the mixed and limited findings available in the literature, more longitudinal studies are required to unravel the factors contributing to, and the consequences of, sleep disturbances during pregnancy. To do so, it is essential to consider women's baselines, pre-pregnancy sleep patterns, and sleep history in addition to continuous and objective monitoring of sleep during pregnancy. Ideally, sleep should be continuously and reliably monitored in normal living environments with little (or no) burden on the individuals (e.g., setting up and charging a device, self-reporting requirements, etc.).

An individualized holistic pregnancy care program is required to reduce the risk of maternal and infant health complications, and any consequent economic implications. Healthcare providers have a key role in engaging the obstetric population in such programs. Sleep monitoring, together with an educational module should be a part of those programs to increase the user awareness on the importance of sleep disturbances and their consequences during and after pregnancy.

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