



Aalborg Universitet

AALBORG UNIVERSITY
DENMARK

Maternal hypothyroidism and adverse outcomes of pregnancy

Knøsgaard, Louise; Andersen, Stig; Hansen, Annebirthe Bo; Vestergaard, Peter; Andersen, Stine Linding

Published in:
Clinical Endocrinology

DOI (link to publication from Publisher):
[10.1111/cen.14853](https://doi.org/10.1111/cen.14853)

Creative Commons License
CC BY-NC-ND 4.0

Publication date:
2023

Document Version
Publisher's PDF, also known as Version of record

[Link to publication from Aalborg University](#)

Citation for published version (APA):
Knøsgaard, L., Andersen, S., Hansen, A. B., Vestergaard, P., & Andersen, S. L. (2023). Maternal hypothyroidism and adverse outcomes of pregnancy. *Clinical Endocrinology*, 98(5), 719-729. <https://doi.org/10.1111/cen.14853>

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal -

Take down policy

If you believe that this document breaches copyright please contact us at vbn@aub.aau.dk providing details, and we will remove access to the work immediately and investigate your claim.

THE ONLY TYPE 2 DIABETES PILL OF ITS KIND¹

RYBELSUS[®]

semaglutide tablets



Superior HbA_{1c} reductions
vs Januvia[®] and Jardiance[®]1-3



Consistent weight reduction
of up to 4.3 kg^{1,2,4,a}



Reduction in cardiometabolic
risk factors¹

HELP YOUR PATIENTS **WAKE UP** TO THE POSSIBILITIES

To learn how RYBELSUS[®] could lead to
better health outcomes for your patients,
visit our RYBELSUS[®] webpages

LEARN MORE

^aWeight reduction results are from PIONEER 4, a 52-week, double-blind, double-dummy trial in 711 adult patients with type 2 diabetes that compared the efficacy and safety of RYBELSUS[®] vs liraglutide and placebo.⁴



References

1. RYBELSUS[®] [summary of product characteristics]. Bagsværd, Denmark: Novo Nordisk A/S; June 2022. 2. Rosenstock J, Allison D, Birkenfeld AL, et al. Effect of additional oral semaglutide vs sitagliptin on glycated hemoglobin in adults with type 2 diabetes uncontrolled with metformin alone or with sulfonylurea: the PIONEER 3 randomized clinical trial. *JAMA*. 2019;321(15):1466-1480. 3. Rodbard HW, Rosenstock J, Canani LH, et al. Oral semaglutide versus empagliflozin in patients with type 2 diabetes uncontrolled on metformin: the PIONEER 2 trial. *Diabetes Care*. 2019;42(12):2272-2281. 4. Pratley R, Amod A, Hoff ST, et al. Oral semaglutide versus subcutaneous liraglutide and placebo in type 2 diabetes (PIONEER 4): a randomised, double-blind, phase 3a trial. *Lancet*. 2019;394(10192):39-50.

RYBELSUS[®] is a registered trademark of Novo Nordisk A/S. All other trademarks, registered or unregistered, are the property of their respective owners. © 2023 Novo Nordisk A/S. Novo Allé, DK-2880, Bagsværd, Denmark June 2023 | HQ23RYB00040



Maternal hypothyroidism and adverse outcomes of pregnancy

Louise Knøsgaard^{1,2}  | Stig Andersen^{2,3} | Annebirthe Bo Hansen¹ |
Peter Vestergaard^{2,4,5} | Stine Linding Andersen^{1,2} 

¹Department of Clinical Biochemistry, Aalborg University Hospital, Aalborg, Denmark

²Department of Clinical Medicine, Aalborg University, Aalborg, Denmark

³Department of Geriatrics, Aalborg University Hospital, Aalborg, Denmark

⁴Department of Endocrinology, Aalborg University Hospital, Aalborg, Denmark

⁵Steno Diabetes Center North Jutland, Aalborg University Hospital, Aalborg, Denmark

Correspondence

Stine Linding Andersen, Department of Clinical Biochemistry, Aalborg University Hospital, Hobrovej 18-22, 9000 Aalborg, Denmark.

Email: stine.a@rn.dk

Funding information

Novo Nordisk Fonden, Grant/Award Numbers: NNF18OC0033520, NNF20OC0059465

Abstract

Objective: Hypothyroidism has been associated with pregnancy complications, but uncertainty prevail regarding the severity and the role of thyroid autoimmunity. This study aimed to evaluate adverse pregnancy outcomes by exposure to maternal hypothyroidism and thyroid autoimmunity.

Design: Retrospective cohort study.

Patients: 14,744 singleton pregnancies from the North Denmark Region Pregnancy Cohort (2011–2015).

Measurements: Maternal thyroid stimulating hormone (TSH), thyroid peroxidase antibodies (TPO-Ab), and thyroglobulin antibodies (Tg-Ab) were retrospectively measured in early pregnancy blood samples (ADVIA Centaur XPT, Siemens Healthineers). Adjusted odds ratio (aOR) with 95% confidence interval (CI) was used to estimate associations between maternal hypothyroidism (TSH cut-offs: 6.0 and 10 mIU/L), thyroid autoimmunity (TPO-Ab cut-off: 60 U/ml, Tg-Ab cut-off: 33 U/ml), and adverse pregnancy outcomes.

Results: Pregnancy outcomes were 93.2% live births, 6.5% spontaneous abortions, and 0.3% stillbirths. The frequency of spontaneous abortion was 6.5% when TSH was below 6.0 mIU/L, 6.5% when above 6.0 mIU/L (aOR: 1.0 [95% CI: 0.5–2.0]), and 12.5% when above 10 mIU/L (aOR: 2.0 [95% CI: 0.8–5.2]). For outcome of preterm birth, the frequency was 5.4% when TSH was below 6.0 mIU/L, 7.8% when above 6.0 mIU/L (aOR: 1.5 [95% CI: 0.7–2.9]), and 11.4% when above 10 mIU/L (aOR: 2.6 [95% CI: 0.9–7.3]). No association was found between thyroid autoantibodies and spontaneous abortion (TPO-Ab: aOR: 1.0 [0.8–1.3], Tg-Ab: 1.0 [0.8–1.2]) or preterm birth (TPO-Ab: aOR: 1.0 [0.8–1.2], Tg-Ab: 0.9 [0.7–1.2]).

Conclusion: A high frequency of adverse pregnancy outcomes was seen among pregnancies exposed to maternal TSH above 10 mIU/L, whereas no association with thyroid autoantibodies was seen.

KEYWORDS

preterm birth, spontaneous abortion, thyroglobulin, thyroid peroxidase, TSH

This is an open access article under the terms of the Creative Commons Attribution-NonCommercial-NoDerivs License, which permits use and distribution in any medium, provided the original work is properly cited, the use is non-commercial and no modifications or adaptations are made.

© 2022 The Authors. *Clinical Endocrinology* published by John Wiley & Sons Ltd.

1 | INTRODUCTION

Hypothyroidism is among the common chronic diseases in pregnant women.¹ During pregnancy, maternal thyroid hormones are vital for foetal growth and brain development² and a hypothesis of foetal programming by maternal hypothyroidism is biologically plausible.^{3,4} Clinical guidelines unanimously state that overt hypothyroidism in pregnant women should be treated to prevent complications.⁵ On the other hand, no universal screening for maternal overt hypothyroidism is implemented, and the current recommendation is limited to selective screening among pregnant women considered at risk for thyroid disease.⁵

The role of maternal thyroid hormones and the adverse effects of maternal hypothyroidism when left untreated is evident from experimental findings and from the historical descriptions of cretinism in children born to mothers with severe hypothyroidism caused by iodine deficiency.⁶ Furthermore, the hallmark study by Haddow et al.⁷ substantiated a risk of adverse child outcomes associated with untreated maternal hypothyroidism, which has been corroborated in other reports.⁸ Large studies have substantiated that the frequency of undetected and untreated overt maternal hypothyroidism is around 0.3%,⁹ which is about 10 times more frequent than congenital hypothyroidism revealed by universal newborn screening.¹⁰ Thus, many criteria for screening¹¹ are met when considering overt hypothyroidism, but a critical determinant is on the definition of actual disease and indication for treatment.

Even if more evidence is needed regarding universal screening for overt hypothyroidism in pregnant women, the scientific focus has moved towards subclinical maternal thyroid function abnormalities, isolated changes in free thyroxine (fT4), and thyroid autoimmunity per se.⁶ However, large randomized controlled trials (RCTs) have not shown any effect of treatment.⁶ We recently showed within the North Denmark Region Pregnancy Cohort (NDRPC), that smaller aberrations in maternal thyroid function in early pregnancy thyroid stimulating hormone (TSH) just above the pregnancy-specific reference range) rarely persisted with repeated blood sampling, whereas markedly increased TSH (above 6.0 mIU/L) was likely to reflect persistent hypothyroidism in a pregnant woman.¹² In our view, a focus on persistent thyroid function abnormalities in pregnant women is needed to inform clinical practice.^{6,12}

In the present study the aim was to identify pregnancies exposed to maternal hypothyroidism in an early pregnancy blood sample and to evaluate the association with adverse outcomes of pregnancy. Furthermore, we aimed to evaluate the role of thyroid autoimmunity per se as reflected by thyroid autoantibodies measured in the early pregnancy blood sample.

2 | MATERIALS AND METHODS

The NDRPC includes a biobank of early pregnancy blood samples drawn from 2011 to 2015 as part of prenatal screening for chromosomal anomalies.¹³ Retrospectively, the blood samples were

used for measurements of thyroid function parameters and auto-antibodies. The blood samples were drawn in median pregnancy week 10 (range 4–20) with 94% of the samples drawn in the first trimester (before the 13th week of pregnancy) and 99% drawn before the 15th week of pregnancy. The biochemical results were linked to data in the Danish nationwide health registers which provided information on all births as well as maternal characteristics and health care contacts before, during, and after the pregnancy (Supporting Information: Table S1). This study included singleton pregnancies with an outcome of live birth, spontaneous abortion, or stillbirth (Figure 1). Exposure was maternal hypothyroidism in the early pregnancy blood sample, and women with biochemical hyperthyroidism defined as TSH below 0.1 mIU/L were not included (Figure 1). The study population included women with no known thyroid disease in pregnancy as well as women with known and treated nonsurgical hypothyroidism, whereas women with other known thyroid diseases were not included (Figure 1). The subgroup of women with surgical hypothyroidism was excluded from the present study, because the group was small, and the focus was on autoimmune hypothyroidism which is predominant in this age group in Denmark.¹⁴

Biochemical analyses of TSH, fT4, thyroid peroxidase antibodies (TPO-Ab) and thyroglobulin antibodies (Tg-Ab) were performed as single measurements using automatic immunoassays (ADVIA Centaur XPT, Siemens Healthineers) as previously described.¹³ Maternal biochemical hypothyroidism was a priori defined as TSH above 6.0 mIU/L, which is the cut-off previously found to define persistent hypothyroidism with repeated early pregnancy blood sampling within the cohort.¹² Furthermore, exposure to TSH above 10 mIU/L was assessed as a marker of overt maternal hypothyroidism with marked TSH elevation.^{5,15} In a sub-analysis, we considered pregnancies exposed to maternal TSH above 4.0 mIU/L in TPO- and/or Tg-Ab positive women. We previously showed within the cohort that such lower TSH cut-off was less likely to reflect persistent hypothyroidism in early pregnancy, however, the combined assessment of TSH and thyroid autoantibodies increased the likelihood of persistent hypothyroidism with repeated blood sampling.¹² Exposure to TPO-Ab was defined by a cut-off value of 60 U/ml given by the manufacturer which corresponded to the cut-off of 59 U/ml established within the cohort.¹⁶ For Tg-Ab, the pregnancy-specific cut-off established within the cohort of 33 U/ml was used,¹⁶ and the cut-off recommended by the manufacturer (60 U/ml) was considered in a sensitivity analysis. In addition to the biochemical assessment of maternal thyroid function, information on maternal thyroid disease known in pregnancy (pre-existing meaning it was diagnosed and treated before the pregnancy) or first diagnosed in the years after pregnancy was obtained from the Danish National Prescription Register (DNPR)¹⁷ and the Danish National Hospital Register (DNHR)¹⁸ (Supporting Information: Table S1). Maternal nonsurgical hypothyroidism was classified among women who had a diagnosis of hypothyroidism or a redeemed prescription of Levothyroxine (LT4) and no registration of thyroid cancer, thyroid surgery, or hyperthyroidism.¹⁹ Exposure to LT4 treatment in pregnancy was defined

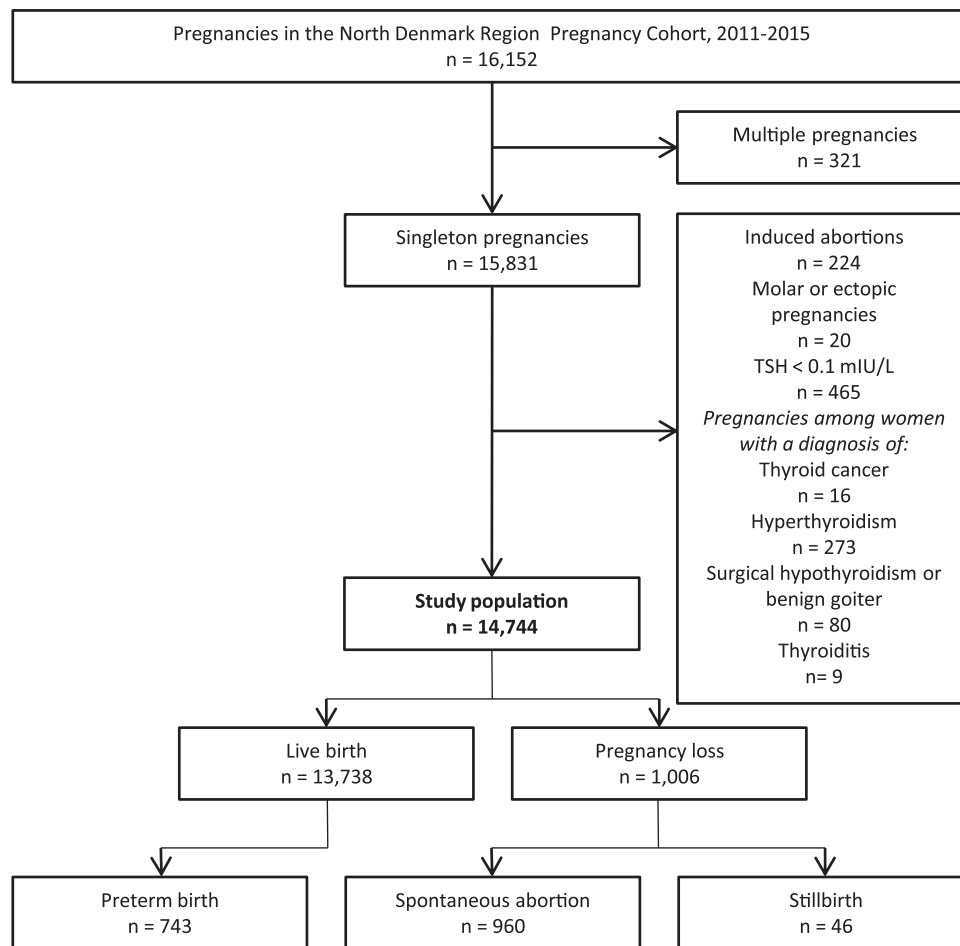


FIGURE 1 Flowchart illustrating the selection of pregnancies from the North Denmark Region Pregnancy Cohort included in the study

by at least one redeemed prescription in the 3-months period before the date of blood sampling in early pregnancy.¹⁹ A total of 6 women with no known thyroid disease at the time of blood sampling in early pregnancy initiated treatment with LT4 later in the pregnancy under study and all terminated the pregnancy with live birth, however, this number was too small to consider any effect of treatment in the analyses.

The outcome of pregnancy was defined from information in the Medical Birth Register (MBR)²⁰ and the DNHR, as previously described¹³ (Supporting Information: Table S1). From the MBR information on all live- and stillbirths was obtained, while information from the DNHR was used to identify pregnancies with a diagnosis of spontaneous abortion, induced abortion, and molar or ectopic pregnancy. The primary outcome was pregnancy loss defined as spontaneous abortion and stillbirth. According to Danish guidelines,²¹ spontaneous abortion was defined as pregnancy loss before the 23rd gestational week (22 completed weeks + 0 days), whereas stillbirth was defined as pregnancy loss from the 23rd gestational week and a registration of stillbirth. The secondary outcome was preterm birth, defined as delivery before the 38th week of gestation (37 completed weeks + 0 days) among all pregnancies carried to a live birth. Furthermore, outcome of caesarean section was evaluated in a

sub-analysis. The primary exposure was maternal hypothyroidism defined by levels of TSH. In a sub-analysis, results were stratified according to maternal levels of fT4 to identify overt and subclinical thyroid abnormalities. Maternal fT4 was evaluated according to the method- and pregnancy-week specific reference ranges previously established within the cohort.¹³ This sub-analysis was only performed among women with TSH above 4.0 mIU/L to ensure enough individuals in the stratified groups.

Categorical variables were described by the number (*n*) and the frequency (%), whereas continuous variables were described by median with a binomial based 95% confidence interval (95% CI). Differences in categorical and continuous variables between groups were assessed by the chi-squared test and Mann-Whitney *U* test, respectively. Logistic regression was used to assess the odds ratio (OR) with 95% CI for spontaneous abortion, preterm birth, and caesarean section in pregnancies exposed to maternal hypothyroidism or elevated levels of thyroid autoantibodies. Results of logistic regression were presented as crude estimates and adjusted for maternal age, parity, origin, and diabetes. Additionally, analyses among pregnancies carried to a live or stillbirth were adjusted for maternal pre-pregnancy BMI and smoking status. Maternal age, BMI, and TSH were included in

the models as continuous variables and all other variables as dichotomous categorical variables. The number of pregnancies with missing data on one or more variables was low (0.5%) and restricted to covariates of maternal origin, BMI, and smoking. Thus, imputation of missing data was not performed. Robust standard errors were added to account for dependency between pregnancies, and analyses were also restricted to the woman's first pregnancy ($n = 13,091$) in the study period in a sensitivity analysis. Statistical analyses were performed using STATA version 17.0 (StataCorp LLC).

The study was approved by the North Denmark Region Committee on Health Research Ethics (N-20150015) and registered according to the General Data Protection Regulation in the North Denmark Region (2015-34). The ethic committee granted an exemption from the requirement of informed consent.

3 | RESULTS

Altogether 14,744 pregnancies were studied, and outcomes were 13,738 (93.2%) live births, 960 (6.5%) spontaneous abortions, and 46 (0.3%) stillbirths (Figure 1). Maternal hypothyroidism (TSH above 6.0 mIU/L corresponding to the 99.16th percentile in the study cohort) was found in 0.8% ($n = 123$) of the pregnancies (Table 1), whereas in 10.5% ($n = 1548$) of the pregnancies the woman was positive for TPO-Ab and in 13.2% ($n = 1948$) for Tg-Ab (Table 2). In exposed pregnancies maternal age, and parity was higher, and known hypothyroidism as well as diabetes were more frequently seen, whereas smoking was less frequent (Tables 1 and 2). Furthermore, maternal hypothyroidism was more frequent among obese women (Table 1), and non-Danish origin was more frequent with exposure to TPO- and Tg-Ab (Table 2).

TABLE 1 Maternal characteristics by thyroid function exposure groups in the main analysis (TSH > 6.0 mIU/L) and in the sub-analysis (TSH > 4.0 mIU/L and thyroid autoantibody positive)

	TSH ≤ 6.0 mIU/L		TSH > 6.0 mIU/L		TSH ≤ 4.0 mIU/L		TSH > 4.0 mIU/L ^a	
	n	Freq (%)	n	Freq (%)	n	Freq (%)	n	Freq (%)
All pregnancies	14,621		123		14,374		287	
Age								
<35 years	12,182	83.3	93	75.6	11,976	83.3	226	78.8
≥35 years	2439	16.7	30	24.4	2398	16.7	61	21.2
Parity								
Nulliparous	6822	46.7	44	35.8	6687	46.5	120	41.8
Multiparous	7799	53.3	79	64.2	7687	53.5	167	58.2
Origin^b								
Born in Denmark	12,974	88.9	110	89.4	12,753	88.9	260	90.9
Not born in Denmark	1617	11.1	13	10.6	1592	11.1	26	9.1
Diabetes in pregnancy								
No	13,326	91.1	101	82.1	13,104	91.2	249	86.8
Yes	1295	8.9	22	17.9	1270	8.8	38	13.2
Known hypothyroidism in pregnancy								
No	14,499	99.2	99	80.5	14,273	99.3	246	85.7
Yes	122	0.8	24	19.5	101	0.7	41	14.3
All births	13,669		115		13,444		269	
Pre-pregnancy BMI^b								
<30 kg/m ²	11,481	83.9	78	68.4	11,236	83.9	203	76.0
≥30 kg/m ²	2192	16.1	36	31.6	2150	16.1	64	24.0
Smoking in pregnancy^b								
No	12,021	88.4	104	91.2	11,811	88.3	250	93.6
Yes	1581	11.6	10	8.8	1567	11.7	17	6.4

Abbreviations: BMI, body mass index; freq, frequency.

^aTSH > 4.0 mIU/L and thyroid autoantibody positive (TPO-Ab > 60 U/ml and/or Tg-Ab > 33 U/ml).

^bMissing values not included: origin ($n = 30$), BMI ($n = 60$), and smoking ($n = 68$).

TABLE 2 Maternal characteristics by thyroid autoantibody exposure groups

	TPO-Ab negative ^a		TPO-Ab positive ^a		Tg-Ab negative ^b		Tg-Ab positive ^b	
	n	Freq (%)	n	Freq (%)	n	Freq (%)	n	Freq (%)
All pregnancies	13,196		1548		12,796		1948	
Age								
<35 years	11,068	83.9	1207	78.0	10,730	83.9	1545	79.3
≥35 years	2128	16.1	341	22.0	2066	16.1	403	20.7
Parity								
Nulliparous	6185	46.9	681	44.0	6027	47.1	839	43.1
Multiparous	7011	53.1	867	56.0	6769	52.9	1109	56.9
Origin^c								
Born in Denmark	11,739	89.1	1345	87.2	11,419	89.4	1665	85.7
Not born in Denmark	1432	10.9	198	12.8	1352	10.6	278	14.3
Diabetes in pregnancy								
No	12,041	91.3	1386	89.5	11,690	91.4	1737	89.2
Yes	1155	8.7	162	10.5	1106	8.6	211	10.8
Known hypothyroidism in pregnancy								
No	13,155	99.7	1443	93.2	12,743	99.6	1855	95.2
Yes	41	0.3	105	6.8	53	0.4	93	4.8
All births	12,344		1440		11,963		1821	
Pre-pregnancy BMI^c								
<30 kg/m ²	10,317	83.9	1179	82.3	9985	83.8	1511	83.4
≥30 kg/m ²	1975	16.1	253	17.7	1927	16.2	301	16.6
Smoking in pregnancy^c								
No	10,832	88.2	1293	90.4	10,428	87.6	1697	93.8
Yes	1453	11.8	138	9.6	1479	12.4	112	6.2

Abbreviations: BMI, body mass index; freq, frequency.

^aCut-off: 60 U/ml.

^bCut-off: 33 U/ml.

^cMissing values not included: origin (n = 30), BMI (n = 60), and smoking (n = 68).

For the primary outcomes of spontaneous abortion or stillbirth, maternal median TSH in early pregnancy was higher and fT4 lower as compared to live births ($p \leq .03$) (Supporting Information: Table S2). When outcome analyses were performed (Table 3), maternal TSH above 6.0 mIU/L was not a risk factor for spontaneous abortion neither in crude nor in adjusted analyses with an OR of 1.0 (Table 3). Considering pregnancies exposed to maternal TSH above 10 mIU/L (n = 40), the frequency of spontaneous abortion was high, and the adjusted OR, although nonsignificant, was 2.0 (Table 3). When restricting to pregnancies with no treated gestational hypothyroidism, the findings were corroborated (Table 3). Notably, maternal hypothyroidism was unidentified and untreated in all pregnancies with an outcome of spontaneous abortion (Table 3). One-third (31.3%) of the women with TSH above 6.0 mIU/L in early pregnancy were diagnosed with hypothyroidism in the years following pregnancy as compared

to 0.8% of the women with TSH below 6.0 mIU/L ($p < 0.001$). In all outcomes of stillbirth, maternal TSH was below 6.0 mIU/L. Thyroid autoimmunity defined by TPO-Ab or Tg-Ab positivity was not a risk factor for spontaneous abortion (Table 3) or stillbirth (TPO-Ab: adjusted OR 0.9 (95% CI: 0.3–2.5); Tg-Ab: adjusted OR 0.9 (95% CI: 0.3–2.3)).

For the secondary outcomes of preterm birth (n = 743), there was no apparent difference in maternal median TSH, fT4, or the presence of thyroid autoantibodies (Supporting Information: Table S3). However, known maternal hypothyroidism, diabetes and smoking was more frequent among preterm births and similar was the frequency of deliveries by caesarean section (Supporting Information: Table S3). When outcome analyses were performed (Table 4), the frequency of preterm birth was higher among pregnancies exposed to maternal hypothyroidism, especially when maternal TSH was above 10 mIU/L,

TABLE 3 Frequency and odds ratio of spontaneous abortion by maternal level of TSH and thyroid autoantibody status in the early pregnancy among all pregnancies ($n = 14,744$) and restricted to pregnancies with no treated gestational hypothyroidism ($n = 14,598$)

Exposure	All pregnancies				Pregnancies with no treated gestational hypothyroidism											
	All		Spontaneous abortion		All		Spontaneous abortion									
	n	n	Freq (%) ^a	95% CI	OR	95% CI	aOR ^b	95% CI	OR	95% CI	aOR ^b	95% CI				
TSH ≤ 6.0 mIU/L	14,621	952	6.5	6.1–6.9	Ref.	-	Ref.	-	14,499	946	6.5	6.1–6.9	Ref.	-	Ref.	-
TSH > 6.0 mIU/L	123	8	6.5	2.8–12.4	1.0	0.5–2.0	1.0	0.5–1.9	99	8	8.1	3.5–15.3	1.3	0.6–2.6	1.2	0.6–2.5
TSH ≤ 10 mIU/L	14,704	955	6.5	6.1–6.9	Ref.	-	Ref.	-	14,566	949	6.5	6.1–6.9	Ref.	-	Ref.	-
TSH > 10 mIU/L	40	5	12.5	4.2–26.8	2.1	0.8–5.1	2.0	0.8–5.1	32	5	15.6	5.3–32.8	2.7	1.1–6.7	2.6	1.0–6.9
TPO-Ab negative ^c	13,196	852	6.5	6.0–6.9	Ref.	-	Ref.	-	13,155	851	6.5	6.1–6.9	Ref.	-	Ref.	-
TPO-Ab positive ^c	1548	108	7.0	5.8–8.4	1.1	0.9–1.3	1.0	0.8–1.3	1443	103	7.1	5.9–8.6	1.1	0.9–1.4	1.1	0.9–1.3
Tg-Ab negative ^d	12,796	833	6.5	6.1–7.0	Ref.	-	Ref.	-	12,743	830	6.5	6.1–7.0	Ref.	-	Ref.	-
Tg-Ab positive ^d	1948	127	6.5	5.5–7.7	1.0	0.8–1.2	1.0	0.8–1.2	1855	124	6.7	5.6–7.9	1.0	0.8–1.3	1.0	0.8–1.2

Abbreviations: aOR, adjusted odds ratio; CI, confidence interval; freq, frequency; OR, odds ratio; Tg-Ab, thyroglobulin antibodies; TPO-Ab, thyroid peroxidase antibodies; TSH, thyroid stimulating hormone.

^aFrequency within the exposure group.

^bAdjusted model included maternal age (continuous variable), and the categorical variables: parity, origin, and diabetes.

^cCut-off: 60 U/ml.

^dCut-off: 33 U/ml.

TABLE 4 Frequency and odds ratio of preterm birth and caesarean section by the maternal level of TSH and thyroid autoantibody status in the early pregnancy among all pregnancies with an outcome of live birth ($n = 13,738$)

	Live births			Preterm birth			Caesarean section										
	All n	n	Freq (%) ^a	n	Freq (%) ^a	95% CI	OR	95% CI	aOR ^b	95% CI	n	Freq (%) ^a	95% CI	OR	95% CI	aOR ^b	95% CI
TSH ≤ 6.0 mIU/L	13,623	734	5.4	734	5.4	5.0–5.8	Ref.	-	Ref.	-	2878	21.1	20.4–21.8	Ref.	-	Ref.	-
TSH > 6.0 mIU/L	115	9	7.8	9	7.8	3.6–14.3	1.5	0.7–3.0	1.5	0.7–2.9	27	23.5	16.1–32.3	1.1	0.7–1.8	0.9	0.6–1.5
TSH ≤ 10 mIU/L	13,703	739	5.4	739	5.4	5.0–5.8	Ref.	-	Ref.	-	2897	21.1	20.5–21.8	Ref.	-	Ref.	-
TSH > 10 mIU/L	35	4	11.4	4	11.4	3.2–26.7	2.3	0.8–6.4	2.7	0.9–7.6	8	22.9	10.4–40.1	1.1	0.5–2.4	1.0	0.5–2.2
TPO-Ab negative ^c	12,302	667	5.4	667	5.4	5.0–5.8	Ref.	-	Ref.	-	2596	21.1	20.4–21.8	Ref.	-	Ref.	-
TPO-Ab positive ^c	1436	76	5.3	76	5.3	4.2–6.6	1.0	0.8–1.2	1.0	0.8–1.3	309	21.5	19.4–23.7	1.0	0.9–1.2	1.0	0.8–1.1
Tg-Ab negative ^d	11,922	652	5.5	652	5.5	5.1–5.9	Ref.	-	Ref.	-	2538	21.3	20.6–22.0	Ref.	-	Ref.	-
Tg-Ab positive ^d	1816	91	5.0	91	5.0	4.1–6.1	0.9	0.7–1.1	0.9	0.7–1.2	367	20.2	18.4–22.1	0.9	0.8–1.1	0.9	0.8–1.0

Abbreviations: aOR, adjusted odds ratio; CI, confidence interval; freq, frequency; OR, odds ratio; Tg-Ab, thyroglobulin antibodies; TPO-Ab, thyroid peroxidase antibodies; TSH, thyroid stimulating hormone.

^aFrequency within the exposure group.

^bAdjusted model included maternal age and pre-pregnancy BMI (continuous variables), and the categorical variables: parity, origin, diabetes, and smoking.

^cCut-off: 60 U/ml.

^dCut-off: 33 U/ml.

but the adjusted estimates did not reach statistical significance. Maternal hypothyroidism was often known and treated among pregnancies with an outcome of preterm birth (55.6%). Considering the sub-analysis of all deliveries by caesarean sections ($n = 2905$), maternal hypothyroidism was not a significant risk factor (Table 4). Among pregnant women with previously diagnosed hypothyroidism, the frequency of caesarean section was 25.7% as compared to 21.1% among women with no known thyroid disease ($p = 0.2$). Thyroid autoimmunity defined by TPO-Ab or Tg-Ab positivity showed no association with either preterm birth or caesarean section (Table 4).

The sub-analysis using a lower cut-off of TSH (4.0 mIU/L) in combination with thyroid antibody positivity showed no association between this exposure and outcomes of spontaneous abortion, preterm birth, or caesarean section (Table 5). Similarly, no significant associations were seen when stratified by overt and subclinical abnormalities according to maternal level of ft4 (Table 5).

Sensitivity analyses showed consistent findings when restricting analyses to the first pregnancy in the study period (Supporting Information: Table S4). Furthermore, the risk estimates were similar when adjusting analyses of maternal thyroid autoimmunity for the level of maternal TSH (Supporting Information: Table S5), and when a cut-off of 60 U/ml for Tg-Ab was used for identification of Tg-Ab positive pregnant women (Supporting Information: Table S6).

4 | DISCUSSION

In a large cohort of nearly 15,000 pregnancies with retrospective biochemical assessment of maternal thyroid function parameters, 0.8% of the women had early pregnancy TSH above 6.0 mIU/L, whereas 0.3% had TSH above 10 mIU/L. Considering maternal hypothyroidism in early pregnancy in relation to outcomes of pregnancy, results of the present study substantiated a high frequency of spontaneous abortion and preterm birth when maternal hypothyroidism was marked with TSH was above 10 mIU/L. On the other hand, maternal hypothyroidism defined by a TSH cut-off of 6.0 mIU/L and the presence of thyroid autoantibodies per se did not increase the risk of adverse pregnancy outcomes.

Hypothyroidism in pregnant women has long been a matter of clinical and scientific concern. Historically, concerns were raised from the description of cretinism in areas with severe iodine deficiency and a causal role of maternal thyroid function was established.⁶ Since then, the clinical recommendations on diagnosis and treatment of maternal overt hypothyroidism are indisputable, however, universal screening for overt hypothyroidism is hitherto not implemented.⁵ In contrast, a substantial focus on subclinical hypothyroidism and isolated low ft4 has emerged.⁶ Considering such smaller abnormalities in maternal thyroid function, results of observational studies are divergent and in contrast to large RCTs.⁶ The discrepancy and the lack of treatment effect in the RCTs is debated, however, with a predominant focus on the timing of intervention (treatment) and on the assessment of outcomes in the child (e.g., age at intelligence testing).^{5,22,23} One may also speculate on the definition of

TABLE 5 Frequency and odds ratio of outcomes of spontaneous abortion, preterm birth, and caesarean section when stratified by maternal TSH as well as overt and subclinical abnormalities in early pregnancy

	All pregnancies				Live births				Caesarean section							
	Spontaneous abortion		Preterm birth		Preterm birth		Preterm birth		Caesarean section		Caesarean section		Caesarean section			
	n	Freq (%) ^a	aOR ^b	95% CI	n	Freq (%) ^a	aOR ^c	95% CI	n	Freq (%) ^a	aOR ^c	95% CI	n	Freq (%) ^a	aOR ^c	95% CI
TSH ≤ 4.0 mIU/L	14,374	930	6.5	6.1–6.9	Ref.	-	-	5.0–5.8	Ref.	-	-	20.4–21.8	Ref.	-	-	-
TSH > 4.0 mIU/L ^d	287	18	6.3	3.8–9.7	0.9	0.6–1.5	0.7–2.9	3.7–9.9	1.2	0.7–2.0	17.5–27.8	1.0	0.7–1.3	60	22.3	17.5–27.8
Overt ^e	89	9	10.1	4.7–18.3	1.4	0.7–2.9	1.4–12.3	1.4–12.3	1.0	0.3–2.7	13.9–33.2	1.0	0.6–1.6	18	22.5	13.9–33.2
Subclinical ^f	198	9	4.5	2.1–8.5	0.7	0.3–1.3	3.7–11.5	3.7–11.5	1.3	0.8–2.4	16.5–28.8	1.0	0.7–1.4	42	22.2	16.5–28.8

Abbreviations: aOR, adjusted odds ratio; CI, confidence interval; freq, frequency; TSH, thyroid stimulating hormone.

^aFrequency within the exposure group.

^bAdjusted model included maternal age (continuous variable), and the categorical variables: parity, origin, and diabetes.

^cAdjusted model included maternal age and pre-pregnancy BMI (continuous variables), and the categorical variables: parity, origin, diabetes and smoking.

^dTSH > 4.0 mIU/L and thyroid autoantibody positive (TPO-Ab > 60 U/ml and/or Tg-Ab > 33 U/ml).

^eAbnormal TSH and free T4 below the pregnancy week and method-specific lower reference limit.

^fAbnormal TSH irrespective of maternal free T4 in early pregnancy.

exposure.^{6,12} Thus, the identification of subclinical hypothyroidism and isolated low fT4 varies considerably between studies regarding the biochemical methods and the definition of abnormal thyroid function.^{24,25} Furthermore, reports in pregnant and nonpregnant populations have raised a concern about the indirect methods for assessment of free thyroid hormone concentrations.^{24,26–28}

We recently highlighted a focus on the persistency of biochemical abnormalities in early pregnant women.¹² In most studies, the definition of exposure to abnormal maternal thyroid function and randomisation to treatment is made from a single blood sample. However, substantial biological variation occurs in thyroid function tests,^{29,30} and in a large cohort of Danish pregnant women, we found that maternal TSH in early pregnancy should be above 6.0 mIU/L to ensure that the classification of hypothyroidism was consistent in a repeated blood sample.¹² These findings led us to speculate whether the inclusion of non-persistent thyroid function abnormalities may have contributed to the divergent literature regarding subclinical hypothyroidism and isolated low fT4 in maternal thyroid function.¹² Following these lines of thought, it was an a priori decision to identify pregnancies exposed to persistent maternal hypothyroidism in the present study using the chosen TSH cut-offs. Our study design with linkage between the biochemical measurements of maternal thyroid function in early pregnancy blood samples and information in nationwide health registers provided unique opportunities to identify pregnancies exposed to unidentified maternal hypothyroidism since the women were followed for later onset of thyroid disease. This follow-up substantiated the cut-off of 6.0 mIU/L to identify persistent hypothyroidism in early pregnancy since the frequency of later diagnosed hypothyroidism was above 30% as compared to less than 1% among pregnancies with TSH below 6.0 mIU/L. Our previous investigation raised a concern about non-persistent thyroid function abnormalities when using a TSH cut-off lower than 6.0 mIU/L, particularly among thyroid autoantibody negative pregnant women.¹² In women of reproductive age, hypothyroidism is predominantly of autoimmune origin,¹⁴ and we speculate on the underlying mechanisms of slightly elevated TSH in thyroid autoantibody negative women and whether this relates to actual thyroid disease.^{6,9} Thus, when considering a lower TSH cut-off of 4.0 mIU/L in the present study we included the criteria of TPO- and/or Tg-Ab positivity to identify persistent abnormalities, and results corroborated the main findings using a TSH cut-off of 6.0 mIU/L. Based on our previous investigations within the cohort and other recent reports,^{24,31} we did not study associations with isolated abnormalities in maternal fT4. Concern has been raised about the validity of free thyroid hormone measurements in pregnancy using automatic immunoassays (indirect methods) and thereby the definition of exposure,⁶ and our focus was on marked and persistent autoimmune hypothyroidism in early pregnant women.

Criteria for the definition of overt hypothyroidism in pregnant women differs across studies.^{9,25} In a large meta-analysis of 43 studies with data on overt hypothyroidism, the prevalence ranged from 0% to 13.1% and the overall pooled prevalence of overt hypothyroidism among studies using population-based trimester-specific reference

ranges was 0.5%.²⁵ Considering unidentified overt maternal hypothyroidism that would be detected by universal screening, the prevalence is estimated to be around 0.3%, but with study differences regarding the definition.⁹ When a TSH cut-off of 10 mIU/L was applied in our cohort of 14,744 pregnancies, we found 32 cases of undetected and untreated maternal hypothyroidism. Haddow et al. similarly identified pregnant women with untreated hypothyroidism and found 48 cases among 25,216 pregnancies.⁷ From these figures it appears that even if the study cohort is large, the expected prevalence of undetected marked maternal hypothyroidism with TSH above 10 mIU/L is less than 0.5% and the number of exposed pregnancies will be small. It was a fact, also in our study, that numbers were small in some of the analyses for example for the rare outcome of stillbirth. However, exposure to persistent and marked hypothyroidism is clinically important and broadening of the exposure definition to increase numbers in the exposed groups may water down the results, thus, it is in our view not an appropriate method. Individual participant-data meta-analyses with combined assessment of different pregnancy cohorts will increase the number of exposed individuals. However, such recent large studies did not report results of overt hypothyroidism and pregnancy outcomes.^{32–34}

Our findings in the present study indicate adverse outcomes of pregnancy when maternal TSH is above 10 mIU/L and either undetected and untreated or known and inadequately treated. Notably, the association observed for spontaneous abortion strengthen when considering only undetected maternal hypothyroidism which may suggest that correction of the hypothyroidism could play a role in modifying the risk. This specific association with marked untreated maternal hypothyroidism is in line with previous investigations on child neurodevelopmental outcomes. Haddow et al. found that untreated maternal hypothyroidism associated with lower intelligence quotient (IQ) in the child, whereas IQ was normal when maternal hypothyroidism had been treated.⁷ Andersen et al. found that undetected maternal TSH above 10 mIU/L in early pregnancy associated with lower IQ in the offspring, whereas child IQ was normal when maternal TSH was in the range from 5 to 10 mIU/L.⁸ Considering outcomes of pregnancy loss, Taylor et al. evaluated the risk of spontaneous abortion among LT4 treated pregnant women, and TSH above 10 mIU/L revealed the highest risk of spontaneous abortion pointing towards a concern of inadequately treated maternal hypothyroidism.³⁵ Stillbirth is a serious, but rare, outcome of pregnancy and large cohorts are needed to study the outcome when the exposure is similarly rare. Allan et al.³⁶ studied 9403 pregnant women in the second trimester and concluded that maternal TSH above 6.0 mIU/L was a risk factor for foetal death, however, their stratified analyses on levels of maternal TSH reveal that the highest frequency of foetal death was seen when maternal TSH was above 10 mIU/L. In addition to pregnancy loss, we studied the risk of preterm birth, and our results for this outcome of pregnancy similarly pointed towards a risk associated with maternal TSH above 10 mIU/L. We additionally evaluated the outcome of caesarean section and found no association between maternal hypothyroidism and outcomes of caesarean section neither when

maternal hypothyroidism was known (pre-existing) nor when it was defined from biochemical measurement in early pregnancy. Previous investigations reported that pre-existing maternal hypothyroidism increased the risk of caesarean section and suggested that this increased risk may be due to associated pregnancy complication.^{37,38} However, indications for caesarean section are heterogeneous and deemed important to extend the findings on this specific outcome in women with hypothyroidism and to investigate the association with other adverse outcomes of pregnancy.

We studied a large and unselected cohort of Danish pregnant women, however, the exposure investigated was relatively rare making the number of exposed cases limited in some of the analyses. Thus, the sample size may have influenced the findings and did not allow for stratified analyses by maternal TSH in the range from 4 to 10 mIU/L. We a priori defined exposure based on our previous findings within the cohort and with the aim of identifying persistent hypothyroidism in early pregnant women. Considering assay differences, the cut-off investigated may not directly apply to other TSH methods. The rate of participation in the prenatal screening programme for chromosomal anomalies is high³⁹ and selection bias attributable to lack of participation is considered low. Women with known thyroid disease in pregnancy and outcomes of the pregnancy were identified from the Danish nationwide registers and the validity is considered high.^{17,18} It should be acknowledged that only clinically recognized pregnancy outcomes were studied and a woman was only included if a blood sample had been drawn in early pregnancy as part of the prenatal screening programme, thus, our study population did not include pregnancies with very early losses. The biochemical analyses were performed retrospectively and not related to any clinical practice related to the pregnancy. The samples were stored until biochemical analyses, and thyroid function parameters and thyroid autoantibodies are considered stable for long-term frozen storage.⁴⁰

5 | CONCLUSION

This large study focused on persistent maternal hypothyroidism and adverse outcomes of pregnancy. The frequency of spontaneous abortion and preterm birth was high when maternal hypothyroidism was overt and marked with TSH was above 10 mIU/L in an early pregnancy blood sample. In contrast, thyroid autoimmunity per se was not a risk factor for adverse outcomes of pregnancy. Results emphasize a clinical and scientific focus on the detection and treatment of marked overt hypothyroidism in pregnancy and substantiate that the severity of maternal hypothyroidism as reflected by the level of TSH in early pregnancy is important. The findings inform the debate on universal screening to detect marked maternal hypothyroidism in pregnancy.

ACKNOWLEDGEMENTS

This work was supported by grants from the Novo Nordisk Foundation (grant number: NNF18OC0033520 and NNF20OC0059465).

CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

Research data cannot be shared due to regulatory restrictions that apply to the availability of data generated and analysed during this study to preserve patient confidentiality and according to the GDPR regulations.

ORCID

Louise Knøsgaard  <http://orcid.org/0000-0002-6311-6727>

Stine Linding Andersen  <http://orcid.org/0000-0001-6336-1936>

REFERENCES

- Jølvig LR, Nielsen J, Kesmodel US, Nielsen RG, Beck-Nielsen SS, Nørgård BM. Prevalence of maternal chronic diseases during pregnancy—a nationwide population based study from 1989 to 2013. *Acta Obstet Gynecol Scand.* 2016;95:1295-1304.
- Morreale de Escobar G, Obregon M, Escobar del Rey F. Role of thyroid hormone during early brain development. *Eur J Endocrinol.* 2004;151:U25-U37.
- Andersen SL, Olsen J, Laurberg P. Foetal programming by maternal thyroid disease. *Clin Endocrinol.* 2015;83:751-758.
- Andersen SL, Carlé A, Karmisholt J, Pedersen IB, Andersen S. Mechanisms in endocrinology: neurodevelopmental disorders in children born to mothers with thyroid dysfunction: evidence of fetal programming? *Eur J Endocrinol.* 2017;177:R27-R36.
- Alexander EK, Pearce EN, Brent GA, et al. 2017 guidelines of the American thyroid association for the diagnosis and management of thyroid disease during pregnancy and the postpartum. *Thyroid.* 2017;27:315-389.
- Andersen SL, Andersen S. Turning to thyroid disease in pregnant women. *Eur Thyroid J.* 2020;9:225-233.
- Haddow JE, Palomaki GE, Allan WC, et al. Maternal thyroid deficiency during pregnancy and subsequent neuropsychological development of the child. *N Engl J Med.* 1999;341:549-555.
- Andersen SL, Andersen S, Liew Z, Vestergaard P, Olsen J. Maternal thyroid function in early pregnancy and neuropsychological performance of the child at 5 years of age. *J Clin Endocrinol Metabol.* 2018;103:660-670.
- Laurberg P, Andersen SL, Pedersen IB, Andersen S, Carlé A. Screening for overt thyroid disease in early pregnancy may be preferable to searching for small aberrations in thyroid function tests. *Clin Endocrinol.* 2013;79:297-304.
- Van Trotsenburg P, Stoupa A, Léger J, et al. Congenital hypothyroidism: A 2020-2021 consensus guidelines update—an ENDO-European reference network initiative endorsed by the European society for pediatric endocrinology and the European society for endocrinology. *Thyroid.* 2021;31:387-419.
- Wilson JMG, Jungner G, World Health Organization. Principles and practice of screening for disease/j. M. G. Wilson, G. Jungner. *World Heal Organ.* 1968;34:1-168.
- Knøsgaard L, Andersen S, Hansen AB, Vestergaard P, Andersen SL. Classification of maternal thyroid function in early pregnancy using repeated blood samples. *Eur Thyroid J.* 2022;11:e210055.
- Andersen SL, Andersen S, Carlé A, et al. Pregnancy Week-Specific reference ranges for thyrotropin and free thyroxine in the north Denmark region pregnancy cohort. *Thyroid.* 2019;29:430-438.
- Carlé A, Laurberg P, Pedersen I, et al. Epidemiology of subtypes of hypothyroidism in Denmark. *Eur J Endocrinol.* 2006;154:21-28.
- Stagnaro-Green A, Abalovich M, Alexander E, et al. Guidelines of the American thyroid association for the diagnosis and management of

- thyroid disease during pregnancy and postpartum. *Thyroid*. 2011;21:1081-1125.
16. Andersen SL, Bruun NH, Christensen PA, et al. Cut-offs for thyroid peroxidase and thyroglobulin antibodies in early pregnancy. *Eur Thyroid J*. 2022;11:e220142.
 17. Wallach Kildemoes H, Toft Sørensen H, Hallas J. The danish national prescription registry. *Scand J Public Health*. 2011;39:38-41.
 18. Schmidt M, Schmidt SAJ, Sandegaard JL, Ehrenstein V, Pedersen L, Sørensen HT. The danish national patient registry: a review of content, data quality, and research potential. *Clin Epidemiol*. 2015;7:449-490.
 19. Knøsgaard L, Andersen S, Hansen AB, Vestergaard P, Andersen SL. Thyroid function abnormalities and thyroid autoantibodies in Danish pregnant women. *Clin Endocrinol*. 2020;93:329-338.
 20. Bliddal M, Broe A, Pottgård A, Olsen J, Langhoff-Roos J. The danish medical birth register. *Eur J Epidemiol*. 2018;33:27-36.
 21. Danish Health Authority. Vejledning om kriterier for levende- og dødfødsel mv. August 31, 2005. Accessed August 19, 2022. <https://www.sst.dk/da/udgivelser/2005/~media/93C011AB599D483B976237969F082523.ashx>
 22. Brent GA. The debate over thyroid-function screening in pregnancy. *N Engl J Med*. 2012;366:562-563.
 23. Cooper DS, Pearce EN. Subclinical hypothyroidism and hypothyroxinemia in pregnancy—still no answers. *N Engl J Med*. 2017;376:876-877.
 24. Andersen SL, Christensen PA, Knøsgaard L, et al. Classification of thyroid dysfunction in pregnant women differs by analytical method and type of thyroid function test. *The Journal of Clinical Endocrinology & Metabolism*. 2020;105:e4012-e4022.
 25. Dong AC, Stagnaro-Green A. Differences in diagnostic criteria mask the true prevalence of thyroid disease in pregnancy: A systematic review and Meta-Analysis. *Thyroid*. 2019;29:278-289.
 26. Lee RH, Spencer CA, Mestman JH, et al. Free T4 immunoassays are flawed during pregnancy. *Am J Obstet Gynecol*. 2009;200:260.e1-260.e6.
 27. Bliddal S, Feldt-Rasmussen U, Boas M, et al. Gestational age-specific reference ranges from different laboratories misclassify pregnant women's thyroid status: comparison of two longitudinal prospective cohort studies. *Eur J Endocrinol*. 2014;170:329-339.
 28. Jonklaas J, Sathasivam A, Wang H, Gu J, Burman KD, Soldin SJ. Total and free thyroxine and triiodothyronine: measurement discrepancies, particularly in inpatients. *Clin Biochem*. 2014;47:1272-1278.
 29. Andersen S, Bruun NH, Pedersen KM, Laurberg P. Biologic variation is important for interpretation of thyroid function tests. *Thyroid*. 2003;13:1069-1078.
 30. Boas M, Forman JL, Juul A, et al. Narrow intra-individual variation of maternal thyroid function in pregnancy based on a longitudinal study on 132 women. *Eur J Endocrinol*. 2009;161:903-910.
 31. Jansen HI, van Herwaarden AE, Huijgen HJ, et al. Pregnancy disrupts the accuracy of automated FT4 immunoassays. *Eur Thyroid J*. 2022;11:e220145.
 32. Korevaar TIM, Derakhshan A, Taylor PN, et al. Association of thyroid function test abnormalities and thyroid autoimmunity with preterm birth: a systematic review and meta-analysis. *JAMA*. 2019;322:632-641.
 33. Toloza FJK, Derakhshan A, Männistö T, et al. Association between maternal thyroid function and risk of gestational hypertension and pre-eclampsia: a systematic review and individual-participant data meta-analysis. *Lancet Diab Endocrinol*. 2022;10:243-252.
 34. Derakhshan A, Peeters RP, Taylor PN, et al. Association of maternal thyroid function with birthweight: a systematic review and individual-participant data meta-analysis. *Lancet Diab Endocrinol*. 2020;8:501-510.
 35. Taylor PN, Minassian C, Rehman A, et al. TSH levels and risk of miscarriage in women on long-term levothyroxine: levothyroxine: a community-based study. *J Clin Endocrinol Metabol*. 2014;99:3895-3902.
 36. Allan WC, Haddow JE, Palomaki GE, et al. Maternal thyroid deficiency and pregnancy complications: implications for population screening. *J Med Screen*. 2000;7:127-130. <https://search.ebscohost.com/login.aspx?direct=true&db=c8h&AN=2001021380&site=ehost-live>
 37. Norstedt Wikner B, Skjöldebrand Sparre L, Stiller CO, Källén B, Asker C. Maternal use of thyroid hormones in pregnancy and neonatal outcome. *Acta Obstet Gynecol Scand*. 2008;87:617-627.
 38. Männistö T, Mendola P, Grewal J, Xie Y, Chen Z, Laughon SK. Thyroid diseases and adverse pregnancy outcomes in a contemporary US cohort. *J Clin Endocrinol Metabol*. 2013;98:2725-2733.
 39. Danish Health Authority 2022. Retningslinjer for fosterdiagnostik. January 2022. Accessed August 19, 2017. <https://www.sst.dk/-/media/Udgivelser/2020/Fosterdiagnostik/Retningslinjer-for-fosterdiagnostik.ashx>.
 40. Männistö T, Suvanto E, Surcel HM, Ruokonen A. Thyroid hormones are stable even during prolonged frozen storage. *Clin Chem Lab Med*. 2010;48:1662-1669.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Knøsgaard L, Andersen S, Hansen AB, Vestergaard P, Andersen SL. Maternal hypothyroidism and adverse outcomes of pregnancy. *Clin Endocrinol (Oxf)*. 2023;98:719-729. doi:10.1111/cen.14853