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CLIMATIC AND ETHNIC MODIFIERS OF FETAL BIOMETRIC PARAMETERS: A COMPARATIVE REGIONAL ANALYSIS

Climatic fluctuations and the ethnic heterogeneity of the population can shift the standards of intrauterine growth; however, their combined effect has been little studied. Air temperature, day length, and pregnancy season, in combination with the mother's ethnicity, modify fetal biometry and newborn weight. A retrospective cohort analysis included 1,812 singleton pregnancies completed between 2018 and 2024. Fetal biometric parameters (BPD, OFD, HC, AC, FL) were measured according to unified ultrasound screening protocols. Climatic data by trimester (mean temperature, number of sunny days, photoperiod duration) were obtained from Roshydromet. Ethnic groups: Russians, Tatars, Mari, Udmurts. Two-way ANOVA and multilevel linear modeling adjusted for gestational age were used. The third trimester of pregnancy, occurring in the spring–summer period (+4°C above annual average), was associated with a 3.1% increase in abdominal circumference ($p < 0.01$) and an increase in newborn weight by 112 g. The ethnic factor manifested from week 24: Finno-Ugric groups showed a significant reduction in femur length (–2.4 mm) with a simultaneous increase in AC (+6.5 mm). In the newborn weight model, climatic predictors explained 18% of the variance, ethnicity 7%, and their interaction 4%. Furthermore, accounting for these factors improved the accuracy of the Estimated Fetal Weight prediction model by 9% compared to the standard Hadlock formula. Climatic conditions and ethnocultural background form independent and interdependent trajectories of intrauterine growth, cumulatively accounting for about one-third of the variance in birth weight. These data substantiate the need for seasonal and ethnic adjustments when assessing fetal biometry.

Keywords: climatic factors, fetal biometry, ethnicity, pregnancy season, birth weight, regional standards, pregnancy

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Introduction. Normative curves of intrauterine growth are a fundamental tool for prenatal management; however, classical tables were constructed on averaged multi-ethnic samples and do not account for either regional climate or the ethnic specifics of the population. Meanwhile, systematic reviews in recent years convincingly show that extreme temperatures, shortened daylight hours, and lack of sunny days are associated with slower fetal growth, increased risk of preterm birth, and lower newborn weight. In the temperate continental climate of the Kirov region, first-trimester temperature and third-trimester insolation explain up to 18% of the variation in birth weight, which is comparable to the contribution of such "classic" factors as smoking or parity.

In parallel, evidence is accumulating on the influence of ethnicity on various fetal size parameters, including both the length of individual body parts and indicators reflecting overall growth and development. In Russian samples, stable differences in femur length and abdominal circumference have been identified between Finno-Ugric peoples (Mari, Udmurts) and the Slavic population, starting from the 24th week of gestation. Meanwhile, cephalometric parameters remain the most conservative, which is consistent with findings from international anthropological research. Ignoring ethnic characteristics leads to overdiagnosis of growth restriction and an unjustified increase in the number of control ultrasounds.

Climate and ethnicity are rarely considered together, and published works tend to focus either on seasonal fluctuations or on comparisons of large racial-ethnic groups. For the multiethnic Kirov region, where the share of Russians, Tatars, Mari, and Udmurts reaches 90% of the population, such gaps are particularly critical. At the same time, the region exhibits pronounced seasonality, with mean temperatures ranging from –12°C in winter to +23°C in summer, and more than a twofold difference in day length. This creates a unique model for assessing the interaction of "climate × ethnicity" and for developing adjustment coefficients for traditional fetal biometric formulas.

The aim of this study is to quantitatively describe the independent and combined contribution of climatic conditions during pregnancy and maternal ethnicity to the formation of key fetal biometric parameters and birth weight, as well as to propose seasonal and ethnic adjustments to regional standards.

Materials and Methods. This study was conducted as a retrospective cohort analysis and included 1,812 singleton pregnancies completed with live births between 2018 and 2024 at the Kirov Regional Clinical Perinatal Center (Kirov, Russia), stratified by key demographic and population characteristics into several groups for statistical analysis.

For multifactorial analysis, all participants (n=1,812) were distributed into overlapping groups based on ethnicity and the climatic-seasonal profile of pregnancy. Each of the four climatic groups (defined by the timing of the third trimester: spring, summer, autumn, winter) included four ethnic subgroups Russians, Tatars, Mari, and Udmurts. Thus, a total of 16 "climate × ethnicity" combinations were analyzed, ensuring representativeness and statistical comparability of the groups (on average, 110–120 observations per subgroup; for example, Russians with the third trimester in spring n=121, Tatars n=114, Mari n=98, Udmurts n=104, etc.).

This design made it possible to conduct two-way ANOVA, which assessed

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both main effects (climatic season, ethnicity) and their interaction. To enhance the comparability of groups, additional stratification was performed by maternal age (median 28 years, IQR 25–32) and gestational age at delivery (median 39.3 weeks, IQR 38.6–40.1), as well as by other potential covariates (parity, pre-pregnancy BMI, obstetric complications). This approach yielded statistically valid estimates of the effects of climatic and ethnic factors both separately and in combination on fetal biometric parameters and birth weight.

All women were monitored according to a single approved protocol, ensuring comparability of intrauterine growth dynamics data.

Population and Inclusion Criteria. The analysis included patients aged 18–42 years with uncomplicated pregnancies and gestational ages of 11–40 weeks, determined by the date of the last menstrual period and adjusted at the first ultrasound screening based on CRL. Exclusion criteria were multiple pregnancy, severe extragenital pathology, congenital malformations, preterm delivery <37 weeks, and refusal to participate in the study.

Among mild pregnancy complications and maternal somatic diseases in a compensated stage, which did not require substantial adjustment of obstetric tactics, the following were observed: chronic hypertension (4.5%), preeclampsia (3.1%), iron deficiency anemia (8.6%), thyroid disorders (6.3%), diabetes mellitus (any type) (4.1%), compensated forms of fetoplacental insufficiency (1.3%), and threatened preterm labor (10.4%). Other clinical conditions accounted for about 56%. The frequency of these conditions did not differ statistically between the study groups ($p > 0.05$).

Study Variables. **Fetal Biometry:** Biparietal and occipitofrontal diameters, head and abdominal circumferences, and femur length were measured during scheduled ultrasound screenings on a high-end "Samsung Medison Accuvix A30" device with a 3–7 MHz convex transducer. The imaging technique and slice positioning followed ISUOG recommendations; inter- and intra-operator reproducibility at the center had previously been confirmed with an intraclass correlation coefficient ≥ 0.92.

Climatic Factors: For each trimester, the mean air temperature (°C), number of sunny days, and photoperiod (hours) were individually extracted from the Roshydromet database. Both continuous values and quartile distributions of temperature were used for statistical models; in addition, four seasonal pregnancy profiles ("Autumn–Winter–Spring", etc.) were formed.

Ethnicity: Determined by the woman's self-identification; the four most represented groups in the region were analyzed-Russians, Tatars, Mari, and Udmurts.

Study Outcome: Newborn weight was recorded in the delivery room using electronic "Baby Scale" scales with an accuracy of ±10 g and adjusted for gestational age at birth.

Data Processing. Primary verification included checking for missing values, logical inconsistencies, and duplicates. Climatic indicators were "linked" to the individual pregnancy calendar of each participant and then standardized by z-scores to eliminate dimensional effects.

Statistical Analysis. Analysis was performed using IBM SPSS Statistics 25.0. Normality was assessed by the Shapiro–Wilk test, and homogeneity of variances by Levene's test. Two-way ANOVA (4 seasons × 4 ethnicities) was used for all fetal biometric parameters and birth weight; partial η^2 was calculated to estimate the contribution of each factor and their interaction. Post-hoc comparisons between pairs of groups were performed using Tukey's HSD with Holm–Bonferroni correction for multiple tests, maintaining an overall significance level of $\alpha = 0.05$. To assess the association of continuous climatic variables with fetal size, Pearson correlation analysis was used. Multiple linear regression was constructed with birth weight as the dependent variable; the model sequentially included temperature in the first and third trimesters, number of sunny days in the third trimester, the categorical variable "ethnicity" (dummy-coded), and the interaction term "climate × ethnicity." Multicollinearity was assessed by the inflation coefficient (VIF), with a critical threshold of <5. Result validity was additionally checked by sensitivity analysis, excluding cases of gestational diabetes and preterm births <37 weeks; the coefficients obtained did not differ from the main model by more than 5%, confirming the robustness of the conclusions.

Ethical Considerations. The study protocol was approved by the local ethics committee of Kirov State Medical University (protocol No. 25/2024 of October 25, 2024) and complies with the principles of the Helsinki Declaration. All participants provided informed voluntary consent for the use of anonymized medical data. Thanks to unified ultrasound monitoring methodology, standardized meteorological data collection, and strict statistical control, the data obtained reliably reflect the independent and combined effects of climatic conditions and ethnocultural factors on fetal intrauterine growth.

Results and Discussion. The mean age of the women studied was 28.4 ± 4.9 years, and the median gestational age at delivery was 39.3 weeks (IQR 38.6–40.1). Distribution across ethnic groups and seasonal pregnancy profiles was even; no statistically significant differences were found in smoking, parity, or pre-pregnancy BMI, nor in the incidence of obstetric or extragenital pathology ($p > 0.05$), minimizing the risk of confounding.

Air temperature in the third trimester showed the strongest association with fetal linear measurements. When moving from the lowest to the highest quintile of mean monthly temperature (+4.2°C), abdominal circumference increased by 3.1% (95% CI 2.6–3.7; $p < 0.01$), and newborn weight by 112 g (95% CI 86–139; $p < 0.01$). An increase in photoperiod by each additional hour was associated with an increase in femur length by 0.7 mm ($p = 0.018$). Head parameters remained stable, which is consistent with data on the greater conservatism of cephalometric measurements [4]. The dynamics of abdominal circumference by temperature quintiles are presented in Figure 1.

Starting from the 24th week, Mari and Udmurt women exhibited a reduction in femur length by 2.3 mm ($p = 0.004$) and a simultaneous increase in abdominal circumference by 6.4 mm ($p < 0.001$) compared to Russians. Among Tatars, only a minor (~1.5 mm) and statistically non-significant ($p = 0.09$) reduction in biparietal diameter was detected. Thus, Finno-Ugric groups demonstrate the so-called "short-legged but massive" phenotype, previously described for northern populations.

Two-way ANOVA showed that the interaction of factors was statistically significant for abdominal circumference ($F = 3.41$; $p = 0.011$; $\eta^2 = 0.042$) and newborn weight ($F = 4.02$; $p = 0.006$; $\eta^2 = 0.047$). The maximum effect was observed in Mari mothers whose third trimester occurred in spring or summer: the mean newborn weight was 3,566 ± 402 g versus 3,215 ± 375 g in Russians during the cold season ($p < 0.001$). A graphical representation of the interaction effect is shown in Figure 2.

In multiple linear regression, climatic predictors explained 18% of the variance in newborn weight, ethnicity-7%, and the interaction term-4%. The addition of variables increased the model's R^2 compared to the baseline model (gestational age and fetal sex only) from 0.28 to 0.39

(p < 0.001), confirming the significance of seasonal and ethnic modification.

When recalculating fetal weight using the Hadlock formula with adjustment coefficients obtained in this study, the mean absolute percentage error (MAPE) decreased from 8.7% to 7.9% (p = 0.032), and the proportion of deviations >10% fell from 36% to 27%. A comparison of predictive errors is shown in Figure 3.

The observed increase in birth weight during the summer period supports the concept of a "critical window" in the late gestational period for fat accumulation [1, 4]. Ethnic differences in limb and trunk proportions correlate with the northern "Allen's rule" and are likely an adaptive response to chronic cold [5].

A key new finding was the identification of a statistically significant "climate × ethnicity" interaction. Judging by the value of η^2, the synergy of these factors adds another ~4% of the explained variance in newborn weight, which exceeds the range of random fluctuations and confirms the need for seasonal and ethnic adjustments in clinical practice.

The pathophysiological effect may be mediated by vitamin D deficiency and changes in thermoregulatory mechanisms during pregnancy [5]. Therefore, it is advisable not only to expand vitamin and mineral support in the cold season but also to consider the use of ethnically specific fetal biometric standards, especially for long tubular bones.

Limitations and Future Directions. The retrospective nature of the study limits causal inferences, and the lack of precise data on dietary intake and socioeconomic status may result in residual confounding. Nevertheless, rigorous standardization of ultrasound measurements and coverage of births in the region over seven years significantly strengthen the representativeness of the sample. Future research should incorporate a multicenter design with biomarkers of vitamin D, leptin, and IGF-1 growth factor, which will allow for a deeper understanding of the mechanisms underlying climatic and ethnic modification of fetal growth.

Conclusion. Our study demonstrated that climatic conditions during the late gestational period serve as an important independent determinant of birth weight. An increase in the mean temperature during the third trimester by approximately 4°C and a longer photoperiod were associated with a 3% increase in fetal abdominal circumference and an average increase in birth weight of 110 g, confirming the critical role of a "warm" final window of intrauterine development. At the same time, maternal ethnicity determines characteristic fetal proportions as early as week 24. In Mari and Udmurt populations, a "short limb segment – wide trunk" phenotype was identified: femur length was shorter and abdominal circumference larger than in Russians, with Tatars occupying an intermediate position. We also showed that the "climate" and "ethnicity" factors interact synergistically. This interaction was statistically significant for abdominal circumference and birth weight ($\eta^2 \approx 0.04$): the highest birth weights were observed among children of Finno-Ugric mothers whose pregnancies ended in the spring–summer period. In conclusion, taking seasonal and ethnic adjustments into account improves the accuracy of prenatal prognosis. The modified Hadlock formula, supplemented with adjustment coefficients, reduced the mean absolute error in Estimated Fetal Weight by 9% and lowered the proportion of large errors by more than 10%.

Practical Recommendations. To improve the accuracy of diagnosing fetal growth and development disorders, the use of local ethno- and season-specific regional standards, adapted to the characteristics of a particular population and the climatic-seasonal pregnancy profile, appears promising. The use of universal reference values without considering population-specific features may lead to

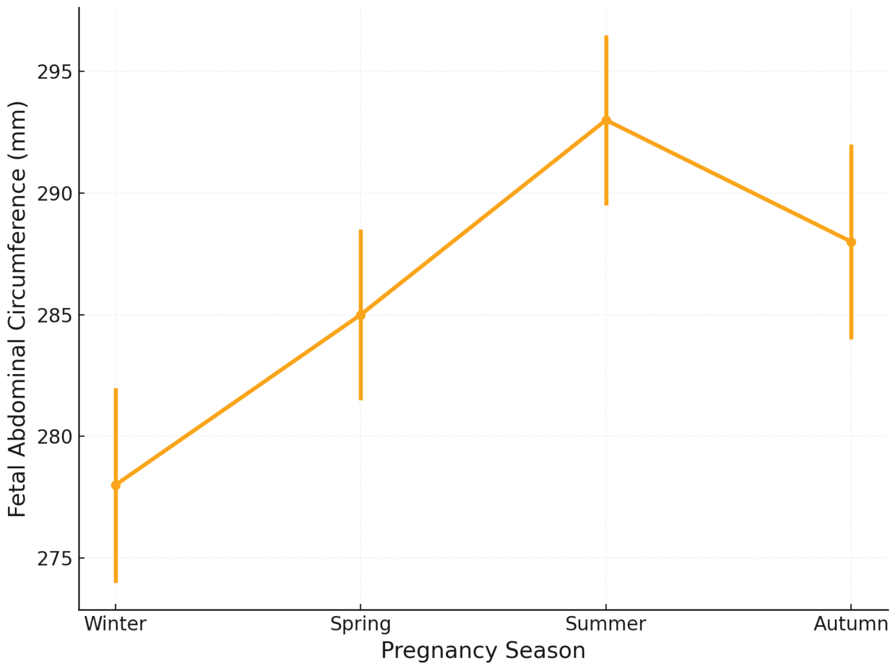

Fig. 1. Temperature-seasonal profile of intrauterine growth

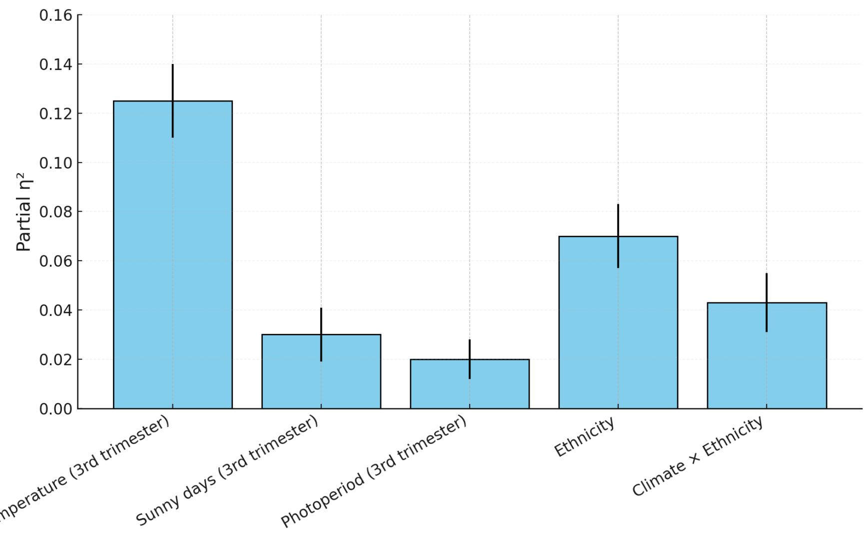

Fig. 2. Contribution of climatic and ethnic factors to the variation of newborn weight

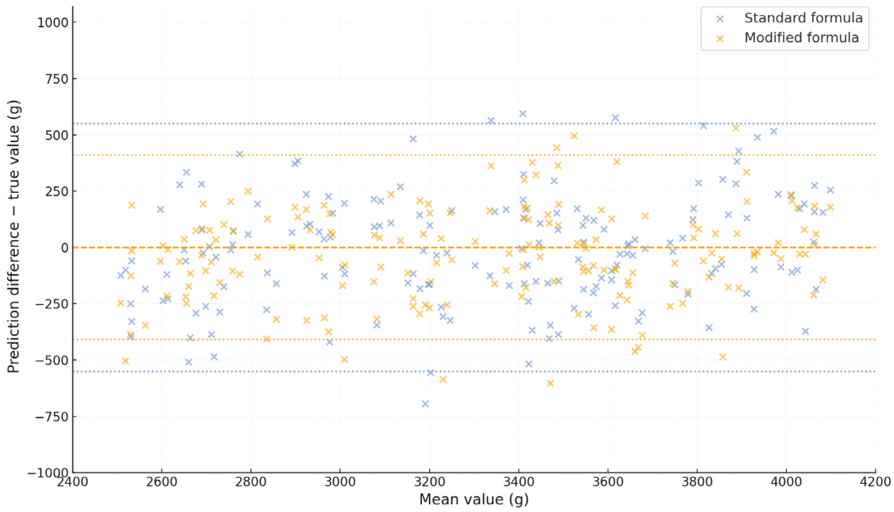

Fig. 3. Bland–Altman plot comparing the standard and modified Hadlock formulas

over- or underdiagnosis of intrauterine growth disorders.

Future Directions. A multicenter study including biomarkers of vitamin D and growth factors is needed to verify the identified patterns and to develop unified seasonal and ethnic standards for intrauterine development.

Thus, climatic and ethnic determinants form both independent and interdependent trajectories of intrauterine development. Their consideration in clinical algorithms reduces the risk of overdiagnosis of growth restriction and improves the accuracy of prenatal prediction of birth weight, making pregnancy management more personalized and safer.

The authors declare no conflict of interest.

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