# Artificial intelligence for automated Carnegie staging of the human embryo in three-dimensional ultrasound

## The Rotterdam periconception cohort

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overestimated in fetuses estimated as severe LGA (> 97th percentile; see figure 1). When stratified by maternal BMI-categories, fetal sex and fetal position, minor differences in MPE were found.

**Conclusions:** The systematic underestimation of actual birthweight was largest in extreme preterm estimated SGA-fetuses, while actual birthweight was generally overestimated in fetuses estimated as severe LGA. Knowledge about systematic errors in the fetal weight estimation formula used is of utmost importance in clinical decision making.

Supporting information can be found in the online version of this abstract

OP01.07
**Abstract withdrawn**

OP01.08
**Value of adding angiogenic factors to ultrasound Doppler criteria in the definition of fetal growth restriction**

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**Objectives:** To investigate the added value of maternal angiogenic factors to ultrasound and Doppler criteria currently used for the classification of small fetuses as low-risk small-for-gestational-age (SGA) or high-risk fetal growth restriction (FGR).

**Methods:** Singleton pregnancies (N = 602) with a diagnosis of fetal smallness (defined as estimated fetal weight (EFW) and birthweight < 10th centile) and a gestational age at delivery ≥34 weeks' gestation were prospectively recruited. Ultrasound assessment of EFW and Doppler [uterine arteries pulsatility index (UtA-PI) and cerebroplacental ratio (CPR)] was performed at diagnosis. Biochemical analysis of PlGF and sFlt-1 in peripheral maternal venous blood was measured by ELISA. The primary outcome was APO defined as a composite of perinatal death or metabolic acidosis (umbilical artery pH < 7) or emergency Caesarean section for fetal distress or neonatal unit admission. The predictive value of EFW < 3rd centile, Doppler parameters (UtA-PI >95th centile and CPR < 5th centile) and sFlt-1/PlGF ratio >95th centile, alone or in combination was assessed by logistic regression.

**Results:** All parameters were independently associated with APO: EFW < 3rd centile [adjusted odds ratio 2.58 (1.67 – 4)], UtA-PI [aOR 1.92 (1.25 – 2.94)], CPR [aOR 2.35 (1.46 – 3.78)] and sFlt-1/PlGF [aOR 1.71 (1.09 – 2.69)]. The presence of pre-eclampsia was a significant modifier of these associations. The detection rate (DR) for APO of a combined model including EFW, UtA-PI and CPR was 86.8% with 62% false positives (FP). For a model including only sFlt1/PlGF the DR and FP were 39.8%% and 16.9% respectively whereas in combination with EFW the DR and FP were 81.3%% and 52.3% respectively. A model including all the parameters yielded a DR of 88.5% for a 64.5% of FP.

**Conclusions:** Angiogenic factors as stand-alone criterion had a poor predictive value to identify high-risk FGR among late-onset small fetuses and it marginally improved the predictive value of currently used ultrasound-Doppler criteria.

OP01.09
**Ultrasound predictors of abnormal severe neonatal outcomes in late fetal growth restriction**

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**Objectives:** There is no published clinical trial demonstrating any benefit in timing delivery at term for late fetal growth restriction (FGR). The aim of this study was to determine the predicting performance of ultrasound parameters for severe abnormal neonatal outcomes in cases of late FGR.

**Methods:** This was a prospective study of women with a non-anomalous singleton pregnancy recruited from 32 weeks, at University College London Hospital, UK, between 2018 and 2022. Inclusion criteria comprised any of the following: estimated fetal weight (EFW) ≤ 10th centile (c.), abdominal circumference (AC) decrease ≥50th c. compared to a previous scan, umbilical artery (UmbA) Doppler pulsatility index (PI) >95th c. or cerebroplacental ratio (CPR) < 5th c. High-risk cases were delivered at 37-38 weeks if EFW < 10th c. plus any of the following: EFW < 3rd c. or AC >50 c. drop, or UmbA PI >95th c. or CPR < 5th c. Otherwise, late FGR was considered low-risk and managed conservatively until 40-41 weeks. Severe abnormal neonatal outcome was defined as a composite of any of the following: stillbirth, neonatal or infant death, advanced resuscitation, 5 min APGAR < 7, UmbA pH < 7, sepsis, cerebral, respiratory and circulatory morbidity.

**Results:** 1166 women were recruited and severe abnormal neonatal outcome rate was 12.9% (51/394) and 4.9% (38/772) in the high-risk and low-risk groups, respectively; OR 2.63 (95% CI 1.76, 3.93; p < 0.001). Univariate analysis demonstrated that EFW between 3rd and 10th c. plus CPR< 5th c. and UmbA PI >95th c. were associated with severe abnormal outcomes: OR 2.6 (95%CI 1.31, 5.17; p = 0.006) and OR 4.78 (95%CI 2.38, 9.60; p < 0.001) respectively. However, multivariate analysis showed only UmbA PI >95th c. remained significant, with adjusted OR 2.87 (95%CI 1.208, 6.8; p = 0.017).

**Conclusions:** Multivariate analysis identified UmbA PI >95th c. as the most predictive parameter for severe abnormal neonatal outcome in late FGR cases managed prospectively using a multiparameter strategy.

## OP02: MULTIPLE APPLICATIONS OF ARTIFICIAL INTELLIGENCE

OP02.01
**Artificial intelligence for automated Carnegie staging of the human embryo in three-dimensional ultrasound: the Rotterdam periconception cohort**

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**Objectives:** The Carnegie staging system facilitates the assessment of normal and abnormal development in terms of morphology during

the embryonic period. Using virtual reality (VR) it is possible to visually assess the Carnegie stage in-utero, which takes 1-2 minutes per ultrasound image. Adoption in clinical practice is hampered by the need for a VR set-up and required time for visual assessment. To overcome this, our aim is to automate in-utero Carnegie staging using Artificial Intelligence (AI).

**Methods:** 1357 first trimester three-dimensional (3D) ultrasound images of 797 ongoing pregnancies resulting in life birth from The Rotterdam Periconception Cohort were used. We used DenseNet, a state-of-the-art deep learning algorithm for image classification. The algorithm was trained to estimate the Carnegie stage < 16, 16-23, and 23> solely based on the ultrasound images. We used 1100 images of 642 pregnancies for training. For evaluation, we used a test set of 257 images of 155 pregnancies, not used during training.

**Results:** The AI algorithm achieved an overall accuracy of 61%, which is close to the results of an independent rater, who achieved an accuracy of 63% on 46 images selected for manual VR assessment training. The accuracy was for stage < 16: 55% (n = 9), for stages 16-19: 59% (n = 79), for stages 20-23:62% (n = 151), and for stage >23: 61% (n = 18). The performance differences can partly be explained by the limited size of the embryo early in the first trimester.

**Conclusions:** Since automatic Carnegie staging using AI is real-time and does not require a VR set-up adoption in clinical practice becomes feasible. In future work, we aim to enhance interpretability by analysing the specific morphological aspects in ultrasound scans utilised by the algorithm to assign the Carnegie stage. Understanding the morphological aspects linked to the Carnegie stage by the algorithm might lead to more in-depth insight into the patterns of normal and abnormal morphological development across pregnancies.

OP02.02

## Multimodal nomogram for the prenatal risk assessment of hypoplastic left heart syndrome using self-supervised learning

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**Objectives:** Early detection of HLHS is crucial for prenatal consultation and early clinical management. This retrospective study aims to develop and validate a multimodal nomogram for the prenatal risk assessment of hypoplastic left heart syndrome (HLHS) and to explore significant risk factors for HLHS.

**Methods:** This retrospective study enrolled 161 normal pregnancies and 52 pregnancies diagnosed with HLHS at the Maternal and Child Health Hospital of Hubei Province in China from September 2019 to September 2023. Experienced sonographers selected and delineated standard four-chamber cardiac views. A Resnet-like variational autoencoder was used to extract features from four-chamber views in a self-supervised learning strategy. These features were then converted into an image score. The proposed multimodal nomogram was developed using univariate and multivariate logistic regression analysis, incorporating demographics and morphological characteristics of the fetus heart. We constructed an expert model comprising three sonographers with varying years of clinical experience and a clinical regression model.

**Results:** The study identified several significant risk factors for assessing the risk of HLHS. A multimodal nomogram was constructed based on these factors, achieving an accuracy of 0.905 and an AUC of 0.991. The performance of the nomogram was better than that of the traditional logistic regression model and comparable to that of the expert model. Additionally, the multimodal nomogram outperforms sonographers with 3-year and 6-year experience, and performs only slightly worse than the sonographer with 10-year experience. When combined with the heat-map generated from RVAE, the nomogram can serve as an easy-to-use tool to help clinicians better understand the process of computer-aided diagnosis.

**Conclusions:** The proposed multimodal nomogram demonstrates its superiority, effectiveness and interpretability in prenatal risk assessment of HLHS. It could assist in better individual diagnosis and treatment during pregnancy.

OP02.03

## AI supported super-resolution image reconstruction in fetal MRI

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**Objectives:** Any technology improving image quality allows for a more accurate and reliable clinical integration of fetal MRI as a diagnostic tool in prenatal medicine. The clinical utility of novel k-space reconstruction techniques are currently under investigation in different fields of radiology, however have not yet been assessed in fetal MRI. This ongoing prospective study compares compressed sensing and deep learning/convolutional neural network-based reconstruction methods in fetal MRI.

**Methods:** Conventional T2-TSE sequences were acquired in a series of 30 clinically indicated fetal MR examinations at 3 Tesla, including cases with normal brain development and cerebral malformations. The same acquired data underwent three reconstruction methods: 1) compressed sensing reconstruction incorporating parallel imaging coil information (CS) [Meister 2022]; 2) sparsity constrained reconstruction [Pezzotti 2020] combining CS and deep learning (CSDL); 3) additional convolutional neural network - CNN (Precise-Image-Net) [Kim 2015] combining CSDL for removal of ringing artifacts and upscaling of image resolution (CSDL2). Different reconstruction methods were compared and rated according to detail/resolution, overall image quality and contrast.

**Results:** AI supported image reconstruction techniques were successful in several examinations. Initial experiences in 30 fetuses (study ongoing) indicate a higher detail and decreased noise after using CS and deep learning as well as CNN-based k-space reconstructions. Upscaling of image resolution lead to higher contrasts between arteries in the subarachnoid space and surrounding CSF as well as better delineation of the fetal vermis, optic nerves and olfactory bulbs.

**Conclusions:** Initial experiences indicate an improvement of diagnostic detail and image quality after using novel k-space derived image reconstructions.

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OP02.04

## Automated segmentation of fetal heart three-vessel view ultrasound video clips to facilitate prenatal assessment of congenital heart defects

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**Objectives:** To present an artificial intelligence (AI) method that characterises fetal heart anatomical structures and segments the fetal heart anatomy in the three-vessel view (3VV) on ultrasound videos.